THE STATE OF LAKE ERIE IN 2009

Great Lakes Fishery Commission

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THE STATE OF LAKE ERIE IN 2009

Special Editors

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TABLE OF CONTENTS

ABSTRACT[3]

The inaugural state-of-the-lake report for Lake Erie was published in 2004 covering information collected largely through 2003. This second state-of-the-lake report uses information collected in 2004-2008 to assess progress toward meeting fish community objectives (FCOs) established by the Lake Erie Committee (LEC) of the Great Lakes Fishery Commission. The LEC, comprised of representatives of fisheries-management agencies from the five jurisdictions bordering the lake—Michigan, New York, Ohio, Ontario, and Pennsylvania—established fish community goals and objectives in 2003 to help coordinate and guide agency efforts for collective fishery benefits. The goals call for having mesotrophic and oligotrophic conditions in Lake Erie with habitats that support balanced, well-functioning fish communities for the benefit of associated fisheries. The first goal is that mesotrophic waters in the western basin, central basin, and nearshore eastern basin should have a cool-water fish community with walleye (*Sander vitreus*) as a key predator. A second goal is that oligotrophic waters offshore in the eastern basin should have a cold-water fish community with lake trout (*Salvelinus namaycush*) and burbot (*Lota lota*) as key predators. Achievement of these goals is predicated on progress toward 13 objectives, aimed at having suitable environmental conditions and habitats to support key predators and their prey, interacting through a well-functioning food web to sustain valuable fisheries in all five jurisdictions. As of 2008, none of 13 FCOs were deemed fully attained. Seven FCOs that addressed

[3]Complete publication including map of place names, other chapters, scientific fish names, and references is available at http://www.glfc.org/pubs/SpecialPubs/Sp17_01.pdf.

ecosystem conditions, various habitats, contaminants, and genetic diversity of fish stocks were considered partially achieved. Six FCOs that addressed basin-specific sustainable harvests of fish stocks, food-web structure, productivity and fishery yield, and protection of rare fish species were mostly achieved. One rare fish species, lake sturgeon (*Acipenser fulvescens*), showed signs of improvement in Lake Erie during 2004-2008. The average annual fishery yield (14.4 million kg) from high-value species during 2004-2008 was above the lower end of the LEC's fish community objective (13.6-27.3 million kg).

Fish community goals for mesotrophic and oligotrophic areas were partially met in 2004-2008. The cool-water fish community persisted with walleye as the top predator lakewide and was generally stable (if not improving) in the mesotrophic nearshore of the eastern basin. However, in the eutrophic western basin, shifts in the forage-fish community and recruitment patterns for all piscivorous fishes portrayed an increasingly unstable food web. Improvements in environmental conditions through management of phosphorus loads into the western basin and continued habitat restoration are needed to fulfill the fish community goal. In the eastern basin, the cold-water fish community experienced generally suitable oligotrophic conditions. Lake trout abundance was low and well below rehabilitation targets but slowly improving, and natural recruitment was not detected. Burbot abundance was high but declining due to failing recruitment. Lake trout and burbot suffered high mortality from sea lamprey (*Petromyzon marinus*). Cold-water predators were dependent on abundant rainbow smelt (*Osmerus mordax*), emerald shiner (*Notropis atherinoides*), and round goby (*Neogobius melanostomus*) in the absence of *Diporeia* spp., and cisco (*Coregonus artedi*). Restoration of a naturally reproducing and abundant lake trout population and improved recruitment of burbot are needed to fulfill the cold-water fish community goal. Cisco restoration also would improve food-web functionality but may require low abundance of rainbow smelt.

Management efforts to address recommendations from the first state-of-the-lake report include several key accomplishments during 2004-2008. Environmental objectives in support of the fish community goals and objectives were drafted by the LEC in 2005 and provide priorities for habitat protection and improvement that would benefit fish communities and fisheries. A new walleye fishery-management plan was developed by the LEC to improve management responses to population changes. Efforts continued to improve percid stock assessment models and research was initiated to determine new methods for identifying discrete percid stocks. Lastly, the LEC created a new position statement related to changing water levels and began work on a position statement for offshore wind power, an emerging issue.

The LEC remains committed to achieving fish community stability through management—promoting healthy stocks of top predators, minimizing impacts from invasive species, and protecting and/or restoring important coastal nearshore and tributary habitats. Emerging issues of concern include hypoxia, fish health and diseases, wind-power development, and increases in dissolved reactive phosphorus that have precipitated harmful algal blooms. Priorities for the next five years are to: (1) work with partners to reduce phosphorus loads; (2) understand the risk from potential wind-power initiatives to shared fisheries; (3) address habitat priorities in the lake basin; (4) support research on percid stock discrimination, movements, recruitment, and mechanisms affecting food webs and fish community structure in each basin; (5) support aggressive sea lamprey control to attain targets for adult lamprey abundance and lake trout marking rates; (6) develop a rehabilitation plan for cisco; (7) develop sustainable harvest policies on walleye and yellow perch stocks that meet fish community goals and objectives and stakeholder needs; and (8) explore opportunities to improve fish habitats in connecting corridors (St. Clair-Detroit River system and upper Niagara River).

INTRODUCTION TO STATE OF LAKE ERIE 2009[4]

James L. Markham[5] and Roger L. Knight

This report is an assessment of the state of Lake Erie from 2004 through 2008, updating a previous assessment through 2003 (Tyson et al. 2009). We begin with a brief review of important physical and biological attributes of the lake that support its diverse fish communities. These attributes underlie management of fisheries on fish stocks shared among Lake Erie's five jurisdictions (four states and one province; Fig. 1) and serve as the basis for the fish community goals and objectives (Ryan et al. 2003) of the Lake Erie Committee (LEC) of the Great Lakes Fishery Commission. We follow with a description of status and trends of parameters relevant to the LEC's objectives and a synthesis of progress toward the goals of the LEC ending by identifying emerging issues and priorities for the next assessment period (2009-2013).

Lake Erie is the shallowest and southernmost Laurentian Great Lake, with three distinct basins (western, central, and eastern) that differ in shape, depth, hydrology, and biological productivity (see Fig. 1 for location of all place names). Although Lake Erie overall is considered mesotrophic (moderate biological productivity), some areas in the shallow western basin are "eutrophic" (high productivity), and much of the deep eastern basin is "oligotrophic" (low productivity). Productivity of central-basin waters generally follows a gradient between the western and eastern basins

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[4]Complete publication including other chapters and references is available at http://www.glfc.org/pubs/SpecialPubs/Sp17_01.pdf.

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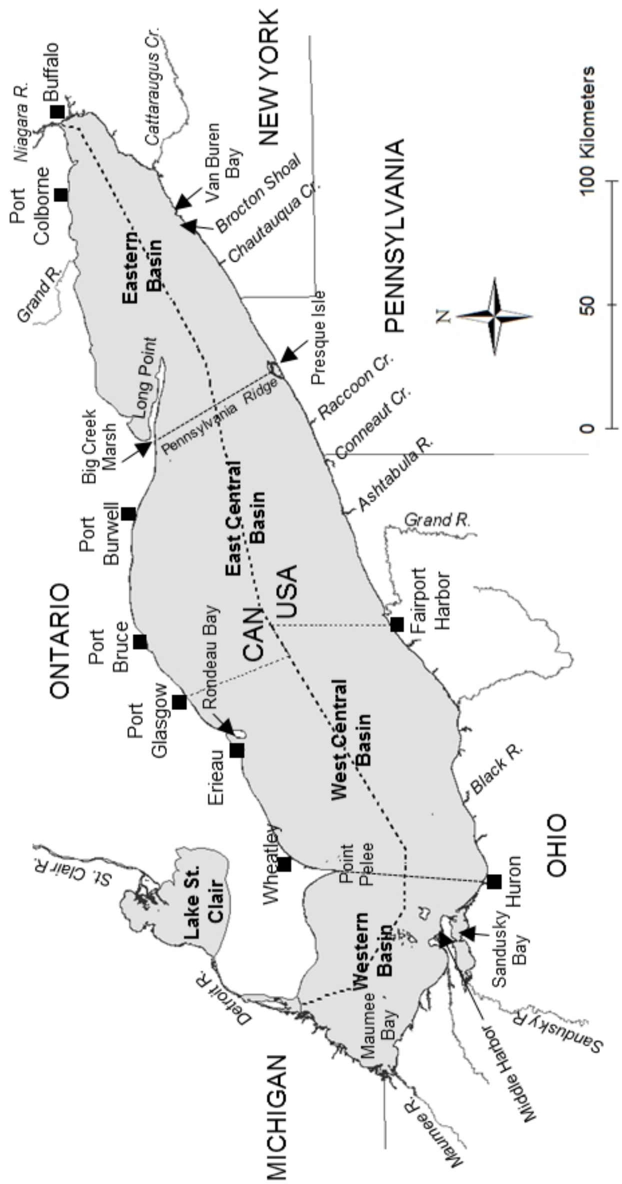
declining from west to east. Productivity also decreases from shallow inshore areas to deep offshore areas in all basins.

Variation in physical features and biological productivity within and among the basins of Lake Erie affects fish ecology and community diversity, stock structure, behavior (movements), and ultimately how fisheries are managed (Ryan et al. 2003; Tyson et al. 2009). Generally, mesotrophic areas of Lake Erie support cool-water fish communities of walleye, yellow perch, smallmouth bass, northern pike, and muskellunge, with a soft-rayed shiner forage base (see Table 1 for common and scientific names of fishes). *Hexagenia* mayfly populations are sentinels of mesotrophic conditions in Lake Erie (Edwards and Ryder 1990). Eutrophic-area fish communities are characterized by black basses, white perch, white bass, channel catfish, freshwater drum, and a prey base dominated by gizzard shad and age-0 spiny-rayed fishes (yellow perch, white perch, white bass, and freshwater drum). Oligotrophic areas sustain cold-water salmonids (lake trout, lake whitefish, steelhead, cisco) and burbot with a forage-fish community dominated by naturalized rainbow smelt, soft-rayed shiners, and, historically, cisco. Deep-water amphipods *Diporeia* spp., an indicator of healthy oligotrophic food webs, are no longer found in Lake Erie (Barbiero et al. 2011). Lake sturgeon occupy nearshore areas across the lake but remain rare. Nearshore fish communities tend to organize around dynamic coastal habitats, such as wetlands, bays, rivers, and estuaries, whereas offshore fish communities are strongly influenced by thermal stratification, dissolved oxygen levels, bottom structure (reefs), and circulation patterns (gyres). Repeatability and persistence of key spawning and nursery habitats over time have supported stock formation for several high-value species (walleye, yellow perch, and lake whitefish) whose movements within and among basins provide fisheries benefits to multiple jurisdictions through coordinated management.

Fig. 1. Map of Lake Erie showing the eastern and western basins, two sub-basins of the central basin, international boundary line, various municipalities and landmarks, and selected tributaries (italics), as referenced in the text.



NEW YORK
PENNSYLVANIA
OHIO
MICHIGAN
ONTARIO
CAN
USA
Buffalo
Niagara R.
Port Colborne
Grand R.
Cattaraugus Cr.
Van Buren Bay
Brocton Shoal
Chautauqua Cr.
Eastern Basin
Long Point
Presque Isle
Raccoon Cr.
Conneaut Cr.
Ashtabula R.
Pennsylvania Ridge
Big Creek Marsh
Port Burwell
East Central Basin
Grand R.
Fairport Harbor
Port Bruce
Rondeau Bay
Port Glasgow
Erieau
West Central Basin
Black R.
Wheatley
Point Pelee
Huron
Lake St. Clair
St. Clair R.
Detroit R.
Western Basin
Maumee Bay
Maumee R.
Sandusky Bay
Sandusky R.
Middle Harbor
0
50
100 Kilometers
N

Table 1. A list of common and scientific names of indigenous and introduced fishes and invasive species used in this report. Also shown is each species' role in the Lake Erie food web as adults and its current use by fisheries (commercial, recreational, both, or protected). Indigenous fishes that have been extirpated are so noted.

Common Name	Scientific Name	Role in Food Web	Fishery Use
	Indigenous Fishes		
Black basses	*Micropterus* spp.	Nearshore omnivores	Recreational
Blue pike	*Sander vitreus glaucus*	Piscivore	Extirpated
Burbot	*Lota lota*	Benthic piscivore	Both
Channel catfish	*Ictalurus punctatus*	Nearshore omnivore	Both
Cisco	*Coregonus artedi*	Pelagic planktivore	Protected
Emerald shiner	*Notropis athernoides*	Pelagic planktivore	Commercial
Freshwater drum	*Aplodinotus grunniens*	Benthic omnivore	Both
Gizzard shad	*Dorosoma cepedianum*	Pelagic planktivore	Commercial
Lake sturgeon	*Acipenser fulvescens*	Benthic omnivore	Protected
Lake trout	*Salvelinus namaycush*	Offshore piscivore	Recreational
Lake whitefish	*Coregonus clupeaformis*	Benthic omnivore	Commercial
Muskellunge	*Esox masquinongy*	Nearshore piscivore	Recreational
Northern pike	*Esox lucius*	Nearshore piscivore	Recreational
Sauger	*Sander canadense*	Nearshore piscivore	Extirpated
Shiners	*Notropis* spp.	Planktivore	Commercial
Smallmouth bass	*Micropterus dolomieu*	Benthic omnivore	Recreational
Trout-perch	*Percopsis omiscomaycus*	Benthic planktivore	None

Table 1, continued

Common Name	Scientific Name	Role in Food Web	Fishery Use
Walleye	*Sander vitreus*	Piscivore	Both
White bass	*Morone chrysops*	Pelagic piscivore	Both
Yellow perch	*Perca flavescens*	Benthic omnivore	Both
	Introduced Fishes		
Common carp	*Cyprinus carpio*	Benthic omnivore	Commercial
Rainbow smelt	*Osmerus mordax*	Benthic planktivore	Commercial
Steelhead	*Oncorhynchus mykiss*	Pelagic omnivore	Recreational
	Invasive Species		
Alewife	*Alosa pseudoharengus*	Pelagic planktivore	none
Quagga and zebra mussels	*Dreissena* spp.	Benthic planktivore	N/A
Round goby	*Neogobius melanostomus*	Benthic omnivore	None
Tubenose goby	*Proterorhinus semilunaris*	Benthic omnivore	None
Sea lamprey	*Petromyzon marinus*	Pelagic piscivore	None
Spiny water flea	*Bythotrephes longimanus*	Pelagic planktivore	N/A
White perch	*Morone americana*	Pelagic omnivore	Both

Other factors that have affected the capacity of the Lake Erie ecosystem to support desired fisheries include degradation of habitats and overfishing, both of which contributed to the loss of native fish stocks (Ryan et al. 2003; Tyson et al. 2009). Spawning and nursery habitats in rivers, estuaries, wetlands, and nearshore coastal areas are most affected by human activities.

Lost stocks of lake trout, walleye, cisco, lake whitefish, blue pike, sauger, and lake sturgeon are attributed in large part to declining recruitment due to degradation of critical habitats for reproduction. Fisheries responded to declining catches by increasing effort and switching to other more-abundant species, which also contributed to stock collapses. Several populations of indigenous species (blue pike, sauger, and lake trout) never recovered from these stressors or persist only as remnant populations (cisco and lake sturgeon) that remain unavailable to current fisheries. Habitat and fish community responses to anthropogenic stresses are useful indicators of ecosystem condition.

During 2004-2008, just as in the past 40 years, Lake Erie commercial and recreational fisheries targeted primarily walleye and yellow perch, and secondarily, various other native species (e.g., white bass, freshwater drum, lake whitefish, and channel catfish) and non-native species (e.g., rainbow smelt, common carp, and white perch). Quota management of inter-jurisdictional fisheries continued for a large walleye stock that spawns in the western basin but moves throughout the lake. Coordinated (non-quota) management continued between Ontario and New York on an eastern-basin walleye population that is smaller and less migratory than the western stock (Kutkuhn et al. 1976; LEC 2004; Tyson et al. 2009). A new plan was implemented by the LEC in 2005 to guide quota management primarily on the western-basin walleye stock (Locke et al. 2005). The LEC also continued quota management for four recognized stocks of yellow perch (western basin, west central basin, east central basin, and eastern basin). Annual yield of primary and secondary species from Lake Erie fisheries averaged 16.1 million kg during 2004-2008 with percids comprising 43-73% of yearly totals.

The LEC, comprised of representatives of fisheries-management agencies from Michigan, New York, Ohio, Ontario, and Pennsylvania, has two broad goals: (1) “to secure a balanced, predominantly cool-water fish community with walleye as a key predator in the western basin, central basin, and the nearshore waters of the eastern basin, characterized by self-sustaining indigenous and naturalized species that occupy diverse habitats, provide valuable fisheries, and reflect a healthy ecosystem,” and (2) “to secure a predominantly cold-water fish community in the deep, offshore waters of the eastern basin with lake trout and burbot as key predators" (Ryan et al. 2003). Achievement of these goals depends on progress toward 13 objectives (Table 2) aimed at having suitable environmental conditions and habitats to support key predator and prey species interacting through a well-functioning food web to sustain valuable fisheries in all jurisdictions on the lake.

Table 2. Fish community objectives of the Lake Erie Committee (Ryan et al. 2003) and an assessment of their achievement during the 2004-2008 reporting period.

Component	Fish Community Objective	Assessment
Ecosystem conditions	Maintain mesotrophic conditions (10-20 $\mu g \bullet L^{-1}$ phosphorus) that favor a dominance of cool-water organisms in the western, central, and nearshore waters of the eastern basins; summer water transparencies should range from 3-5 m (9.75-16.25 ft) in mesotrophic areas.	Partially achieved
Nearshore habitat	Maintain nearshore habitats that can support high-quality fisheries for smallmouth bass, northern pike, muskellunge, yellow perch, and walleye.	Partially achieved
Riverine and estuarine habitat	Protect and restore self-sustaining, stream-spawning stocks of walleye, white bass, lake sturgeon, and rainbow trout.	Partially achieved
Fish habitat	Protect, enhance, and restore fish habitat throughout the watershed to prevent degradation and foster restoration of the fish community.	Partially achieved
Contaminants	Reduce contaminants in all fish species to levels that require no advisory for human consumption and that cause no detrimental effects on fish-eating wildlife, fish behavior, fish productivity, and fish reproduction.	Partially achieved

Table 2, continued

Component	Fish Community Objective	Assessment
Western basin	Provide sustainable harvests of walleye, yellow perch, smallmouth bass, and other desired fishes.	Mostly achieved
Central basin	Provide sustainable harvests of walleye, yellow perch, smallmouth bass, rainbow smelt, rainbow trout, and other desired fishes.	Mostly achieved
Eastern basin	Provide sustainable harvests of walleye, smallmouth bass, yellow perch, whitefish, rainbow smelt, lake trout, rainbow trout, and other salmonids; restore a self-sustaining population of lake trout to historical levels of abundance.	Partially achieved
Genetic diversity	Maintain and promote genetic diversity by identifying, rehabilitating, conserving, and/or protecting locally adapted stocks.	Partially achieved
Rare, threatened, and endangered species	Prevent extinction by protecting rare, threatened, and endangered fish species (for example, lake sturgeon and cisco) and their habitats.	Mostly achieved
Forage fish	Maintain a diversity of forage fishes to support terminal predators and to sustain human use.	Mostly achieved
Food-web structure	Manage the food-web structure of Lake Erie to optimize production of highly valued fish species; recognize the importance of *Diporeia* and *Hexagenia* as key species in the food web and as important indicators of habitat suitability.	Mostly achieved
Productivity and yield	Secure a potential annual sustainable harvest of 13.6-27.3 million kgs (30-60 million lbs) of highly valued fish.	Mostly achieved

In the chapters that follow, we examine recent changes in environmental conditions that affect habitats and food webs in the various basins of Lake Erie and cause detectable responses in fish communities and fisheries as a means of evaluating the LEC's fish community goals and objectives during 2004-2008. We also identify emerging issues of concern to the LEC and their priorities for attention over the next reporting cycle (2009-2013).

ENVIRONMENTAL CONDITIONS[6]

James L. Markham[7], Jeffrey T. Tyson, Elizabeth Trometer, and Timothy B. Johnson

Background

Changes to the trophic status of Lake Erie since pre-settlement times have been well documented. Excessive nutrient enrichment from a variety of sources during the 1950s and 1960s (Burns and Ross 1972) moved the western basin from mesotrophic to hyper-eutrophic, the central basin from mesotrophic to eutrophic, and the eastern basin from oligotrophic to mesotrophic (Ryan et al. 2003). By 1970, the over-enrichment of phosphorus stimulated excessive production of nuisance algae, which caused basinwide anoxia (Beeton 1969) that affected drinking-water supplies, recreation, and fish communities. In 1972, the Canada-U.S. Great Lakes Water Quality Agreement established phosphorus load management in Lake Erie to control algal abundance and anoxic conditions in the central basin. Annual goals for total phosphorus (TP) loads were set at 11,000 metric tons•year^{-1} with spring

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[6]Complete publication including map of place names, other chapters, scientific fish names, and references is available at http://www.glfc.org/pubs/SpecialPubs/Sp17_01.pdf.

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concentrations of 15 μg•L^{-1} in the western basin and 10 μg•L^{-1} for the central and eastern basins (Dermott et al. 1999; Ryan et al. 2003). Improved wastewater treatment and modified land-use practices reduced TP loadings 55% by the mid-1980s, and spring TP concentrations in the central basin averaged <10 μg•L^{-1} during 1988-1992 (Neilson et al. 1995). The Lake Erie fish community, especially walleye and yellow perch populations, responded positively to these changes beginning in the late 1970s and continuing through the late 1980s, although the mechanisms for the positive responses were not clear (Knight 1997).

The arrival of *Dreissena* spp. (quagga and zebra mussels) in 1987 and their subsequent expansion throughout the lake brought further changes to the Lake Erie ecosystem, including increases in water clarity, declines in chlorophyll *a*, and the alteration of rocky-bottom areas used by fish for spawning (Leach 1993; Nicholls and Hopkins 1993). Phytoplankton biomass declined 68-86% (Makarewicz 1993; Johannsson and Millard 1998), primary production declined 22-55% (Millard et al. 1999), and energy flow shifted from the pelagic to the benthic food web (Ryan et al. 2003). By the late 1980s, the combined effects of TP load management and *Dreissena* spp. proliferation caused the western basin to return to a mesotrophic state while the central basin became oligotrophic (Bertram 1993), which was unfavorable for percids (Ryan et al. 2003). The eastern basin became ultra-oligotrophic periodically in the 1990s, adversely affecting yellow perch (Charlton 1994; MacDougall et al. 2001) but benefiting lake whitefish and burbot. *Dreissena* spp. biomass generally stabilized in most areas of Lake Erie by 2002 (Patterson et al. 2005) perhaps because of predation by native fishes (freshwater drum and yellow perch) and invasive round goby.

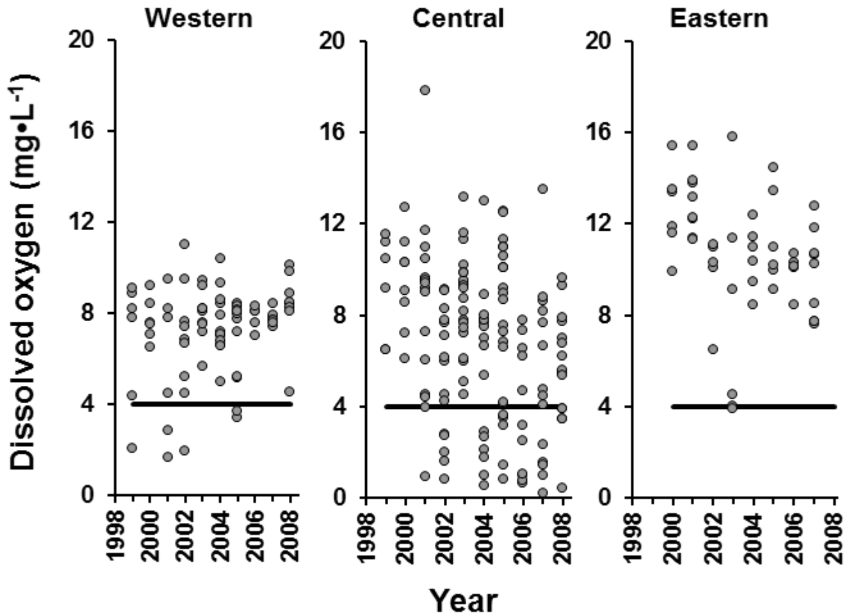
In 1999, the Lake Erie Forage Task Group of the Lake Erie Committee (LEC) initiated a lower trophic-level assessment to aid scientists and fisheries managers in evaluating changes in the ecosystem. As recommended by Tyson et al. (2009), the assessment has continued through 2008 and is likely to continue for the foreseeable future. The assessment consists of biweekly sampling from May through September at three offshore and three inshore stations per basin to collect water temperature, dissolved oxygen (DO), light level, water transparency, total phosphorus, chlorophyll *a*, phytoplankton, zooplankton, and benthos. Following, we present data summaries for several of these lower trophic parameters and relate them to targets established by the LEC under their Ecosystem Conditions Objective (Ryan et al. 2003).

Hypolimnetic Dissolved Oxygen

The concentration of DO in the hypolimnion (bottom layer of water below the thermocline) is an important component of fish habitat and an indicator of ecosystem health. Low (<4 mg•L^{-1}) DO is stressful to fish and other aquatic organisms, and hypoxic (1-2 mg•L^{-1}) or anoxic (<1 mg•L^{-1}) conditions can be lethal. Given the bathymetry of the lake, low DO is common only in the central basin where thermal stratification occurs within a couple meters of the lake bottom leaving a thin hypolimnion with limited oxygen storage capacity due to its low water volume (Burns and Ross 1972). In the shallow western basin, mixing of the water column by wind generally prevents thermal stratification, and DO remains >4 mg•L^{-1}. In the deep eastern basin, DO is rarely limiting owing to a thick (>20 m) hypolimnion with ample oxygen storage capacity.

Levels of hypolimnetic DO generally exceeded 4 mg•L^{-1} in Lake Erie during June-August of 2004-2008, but hypoxic conditions were detected annually in the central basin (Fig. 2). Compared to 1999-2003, low DO was less evident in the western and eastern basins during 2004-2008 but more prevalent in the central basin, particularly in 2004-2007.

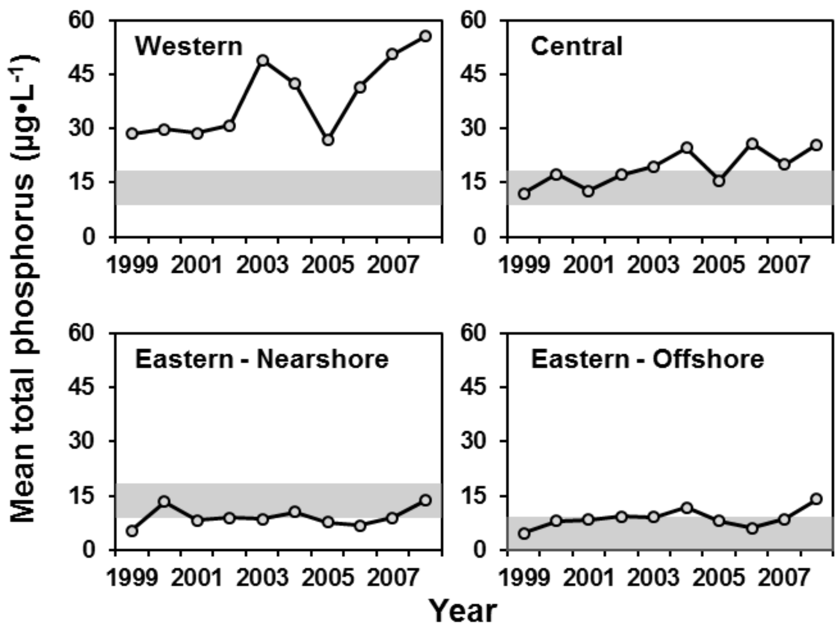
Fig. 2. Dissolved oxygen (DO) concentrations (mg•L^{-1}) near bottom at offshore sites in the western, central, and eastern basins of Lake Erie during June-August, 1999-2008. The horizontal line at 4 mg•L^{-1} marks the concentration below which DO limits the distribution of many temperate freshwater fishes (Lake Erie Forage Task Group data).



Phosphorus

Concentrations of TP in the open waters of Lake Erie generally reflect the availability of nutrients to phytoplankton and overall biological productivity. Phosphorus should range from 10-20 μg•L^{-1} in mesotrophic areas and 5-10 μg•L^{-1} in oligotrophic areas to support desired fish communities in Lake Erie (Leach et al. 1977; Ryan et al. 2003). Average annual TP concentrations exceeded 25 μg•L^{-1} in the western basin during 1999-2008 jumping sharply after 2002 from about 30 μg•L^{-1} to about 40 μg•L^{-1} during much of 2003-2008 (Fig. 3) placing the western basin within the eutrophic range (20-48 μg•L^{-1}). Sampling stations in the Maumee and Sandusky River plumes in the open lake produced hyper-eutrophic levels of TP (>48 μg•L^{-1}). Despite stable loading of TP to the western basin during 2004-2008, a higher proportion of phosphorus was in a dissolved reactive phosphorus (DRP) form, which is more readily available for algal uptake than particulate-bound forms (see Progress, Emerging Issues, and Priorities chapter in the full report). The higher proportion of DRP caused harmful algal blooms throughout the western basin in 2004, 2005, and 2006 with particularly extensive blooms in 2007 and 2008 (Lake Erie Nutrient Science Task Group 2009; Joosse and Baker 2011). Reasons for increased DRP loads include increased runoff from spring storms, changes in agricultural practices, high winds that re-suspend nutrients from lake sediments, and recycling of nutrients by *Dreissena* spp. (Reutter et al. 2011).

Fig. 3. Mean total phosphorus (TP) concentrations ($\mu g \cdot L^{-1}$) weighted by month in Lake Erie at offshore sites in the western, central, and eastern basins and at inshore sites in the eastern basin during June-August, 1999-2008. Shaded areas show the range of TP concentrations in the targeted trophic class for each basin according to Leach et al. (1977) (Lake Erie Forage Task Group data).



Although the marked increase in TP that occurred in the western basin was not as evident in the central and eastern basins, mean concentrations of TP more than doubled between 1999 and 2008 in both of these basins (Fig. 3). Central-basin TP levels increased during 1999-2003 but remained within 10-20 $\mu g \cdot L^{-1}$ and then hovered around 15-25 $\mu g \cdot L^{-1}$ from 2004 to 2008. Unusually large phosphorus loads from a 500-year flood event on the Grand River in Ohio elevated TP concentrations in 2006. Nearshore, in the eastern basin, TP ranged from 5 to 15 $\mu g \cdot L^{-1}$ and was ~10 $\mu g \cdot L^{-1}$ in most years from 1999 to 2008, with the highest value occurring in 2008. In the eastern-basin's offshore waters, average TP concentrations ranged from 5 to 10 $\mu g \cdot L^{-1}$, with the exception of 2008 when TP approached 15 $\mu g \cdot L^{-1}$.

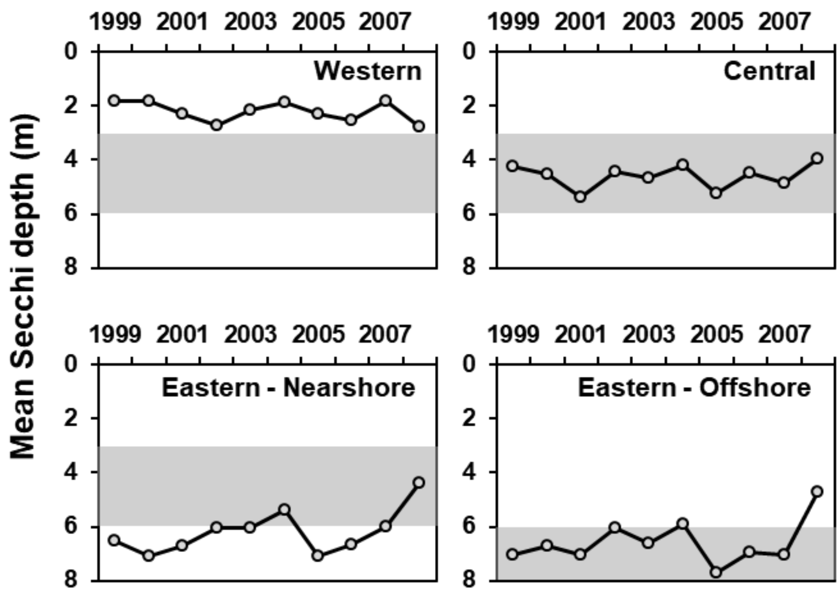
The west to east phasing of the rise in TP concentrations suggests a time-lagged gradient of response to major tributary inputs. Marked increases in TP from 2002 to 2003 in the western basin were expressed one year later in the central basin and offshore eastern basin and about five years later in the inshore eastern basin.

Transparency

Water transparency measured with a Secchi disk (hereafter, Secchi depth) should range from 3 to 6 m in mesotrophic areas and >6 m in oligotrophic areas to support desired fish communities and production in Lake Erie (Leach et al. 1977; Ryan et al. 2003). Secchi depth is limited by suspended sediment and algal turbidity; the relative composition of each affects the fish community differently. Doubling the Secchi depth value provides an approximation of the photic zone where pelagic algal production occurs.

Trends in the mean Secchi depth from summer 1999-2008 varied among the basins (Fig. 4). In offshore western-basin waters, mean Secchi depth fluctuated around 2 m with no trend and was less than the mesotrophic target range over the entire decade. Mean Secchi depth in offshore central-basin areas was 4-5 m with no trend during 1999-2008. In nearshore eastern basin, mean Secchi depth oscillated between mesotrophic and oligotrophic conditions during most of 1999-2008 with only two years (2004, 2008) clearly falling within the mesotrophic range. Mean Secchi depth in offshore eastern-basin waters ranged between 6 and 7 m during 1999-2004 and between 5 and 8 m during 2005-2008 but was near or deeper than the oligotrophic threshold (>6 m) for all years except 2004 and 2008.

Fig. 4. Mean Secchi depth (m) weighted by month in Lake Erie at offshore sites in the western, central, and eastern basins and at inshore sites in the eastern basin during June-August 1999-2008. Shaded areas show the range of Secchi depth in the targeted trophic class for each basin according to Leach et al. (1977) and Ryan et al. (2003) (Lake Erie Forage Task Group data).



Trends in Secchi depth coarsely tracked changes in phosphorus levels that affected algal production throughout the lake during 1999-2008. Secchi depth was consistently lowest in the western basin where annual summer TP concentrations far exceeded the mesotrophic threshold over the entire decade, and was highest in the eastern basin where TP targets were more often met. However, mean Secchi depth remained stable and within the mesotrophic range over the decade in the central basin despite TP levels that exceeded mesotrophic status in most years after 2003. Whereas algal production was driven by TP loadings that varied among the basins, Secchi depth was also affected by wind patterns, sediment turbidity, and the removal of suspended particles by filter-feeding of *Dreissena* spp., which may account for discordance of trends between Secchi depth and TP levels over the decade in any basin.

Progress: Ecosystem Conditions Objective

Lower trophic-level assessments indicate changing ecosystem conditions in Lake Erie between 1999-2003 and 2004-2008. Phosphorus concentrations increased in all basins between the two periods, exceeding the mesotrophic target (10-20 $\mu g \bullet L^{-1}$) in offshore western and central-basin waters, and oligotrophic status (5-10 $\mu g \bullet L^{-1}$) in offshore eastern-basin waters. Phosphorus concentrations increased into the mesotrophic range during 2004-2008 in the nearshore eastern basin. Recurring cyanobacteria blooms occurred during 2004-2008 in the western basin where TP concentrations were the highest of any basin. Summer water transparency (mean Secchi depth) was consistently shallower than the mesotrophic range (3-5 m) in the western basin during 1999-2008 but within the mesotrophic range in offshore central and eastern-basin areas for all years except 2008. Mean Secchi depth in nearshore eastern-basin waters changed from oligotrophic to mesotrophic status during 2004-2008. Low DO was more prevalent in the central basin during 2004-2008 than during 1999-2003 but was less evident in the other basins.

The Ecosystem Conditions Objective (Ryan et al. 2003) calls for mesotrophic conditions throughout most of Lake Erie with specified ranges for TP and Secchi depth. By 2008, mean TP concentrations were about two to three times higher than levels of 1999 in all basins and exceeded the mesotrophic range in two of three basins. In contrast, mean Secchi depths were within mesotrophic range in two of three basins in 2008. Further changes in ecosystem conditions are expected if DRP loadings to the western basin persist at high levels (or increase) with lagged responses in the central and eastern basin.

Recommendations

1. The current lower trophic-level recommendations for TP and Secchi depth indicators of mesotrophic conditions in the western, central, and nearshore eastern basins remain valid to promote harmonic percid populations.

2. Other data on lower trophic levels that have been collected should be analyzed, particularly for benthos, which could be important sentinels of hypoxia impacts on the ecosystem.

3. DRP loads in the western basin must be managed to prevent excessive production of nuisance algae that can reduce water transparency and increase the frequency of low DO events. Combined with stresses from invasive species, climate change, and the current eutrophic state of the western basin, objectives for percid production and fisheries harvest may be compromised if mesotrophic conditions are not restored.

4. Although mesotrophic conditions persist in parts of the central basin, recent trends of increasing TP and lower transparency should be abated through management of DRP loads to the western basin. Phosphorus levels and water transparencies should be monitored in the near future along with yellow perch production to determine if mesotrophic conditions are being maintained.

5. Research in the western basin should focus on the impacts of cyanobacteria blooms on lower trophic-level organisms relative to food-web disruption and on the contribution of cyanobacteria blooms to hypoxia in the central basin.

6. In the deep offshore waters of the eastern basin, the recommendation to maintain oligotrophic conditions in lower trophic levels remains valid to promote the rehabilitation of a balanced cold-water fish community with self-sustaining stocks of lake trout and ecologically important populations of burbot and coregonines.

7. Research is needed to determine how *Dreissena* spp., after two decades of establishment, have affected fish recruitment, growth, diets, and behavior, particularly in the nearshore areas of the eastern basin.

ENVIRONMENTAL OBJECTIVES AND HABITAT[8]

Ann M. Gorman[9] and Tom MacDougall

Background

In addition to an ecosystem conditions objective (Ryan et al. 2003), the Lake Erie Committee (LEC) established three fish community objectives (FCOs) that address habitat—nearshore habitat, riverine and estuarine habitat, and fish habitat—and an objective to address contaminants (Ryan et al. 2003). Through 2004, the LEC addressed Habitat and Contaminant Objectives through position statements; support and participation in initiatives, such as the Lake Erie Lakewide Management Plan (LaMP); and habitat work by individual member agencies (Tyson 2009).

In 2005, the LEC formalized 10 environmental objectives (Table 3; LEC 2005) to systematically guide actions through a framework that incorporates identifiable habitat units, key fish stocks, and relevant spatial scales. The spatial scales include local-scale instream habitat/stream flows, meso-scale nearshore zones, broad-scale offshore water masses (gyres), open-lake hydrodynamics, and large-scale inflows.

The environmental objectives describe general actions and expected outcomes that link directly to over half of the LEC's fish community

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[8]Complete publication including map of place names, other chapters, scientific fish names, and references is available at http://www.glfc.org/pubs/SpecialPubs/Sp17_01.pdf.

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objectives, including Nearshore Habitat, Riverine and Estuarine Habitat, Fish Habitat, Contaminants, Ecosystem Conditions, Forage Fish, and Food-Web Structure (Ryan et al. 2003). Several of the environmental objectives identify Priority Management Areas (PMAs) that recognize the importance of specific locations to the recovery of locally adapted fish stocks that are depressed or extirpated.

Achievement of the environmental objectives will directly affect progress toward the related FCOs. Efforts to implement the environmental objectives in 2005-2008 included: (1) actions that directly addressed specific objectives, (2) standardization and collation of disparate data sets, and (3) communication of the objectives to managers and scientists working in the Lake Erie basin.

Table 3. Ten environmental objectives of the Lake Erie Committee (LEC 2005) with linkages to directly related fish community objectives (in parentheses) (Ryan et al. 2003) for a description of each fish community objective).

1.	Coastal and shoreline processes—restore natural coastal systems and nearshore hydrological processes (nearshore habitat, fish habitat).
2.	Rivers and estuaries—restore natural hydrological functions in Lake Erie rivers and estuaries (riverine and estuarine habitat).
3.	Water levels and climate change—recognize and anticipate natural changes in water level and long-term effects of global climate change and incorporate these into management decisions (nearshore habitat, fish habitat).
4.	Wetlands and submerged macrophytes—restore submerged aquatic macrophyte communities in estuaries, embayments, and protected nearshore areas (nearshore habitat, fish habitat).
5.	Fish-habitat protection—halt cumulative incremental loss and degradation of fish habitat and reverse, where possible, loss and degradation of fish habitat (fish habitat).
6.	Fish access—improve access to spawning and nursery habitat in rivers and coastal wetlands for native and naturalized fish species (fish habitat).

Table 3, continued

7.	Open-water transparency—re-establish open-water transparency consistent with mesotrophic conditions that are favorable to walleye in the central basin and areas of the eastern basin (ecosystem conditions).
8.	Dissolved oxygen (DO)—maintain DO conditions necessary to complete all life-history stages of fishes and aquatic invertebrates (ecosystem conditions).
9.	Contaminants—minimize the presence of contaminants in the aquatic environment such that the uptake of contaminants by fishes is significantly reduced (contaminants).
10.	Habitat impacts of invasive species—prevent the unauthorized introduction and establishment of additional non-native biota into the Lake Erie basin that have the capability to modify habitats in Lake Erie (forage fish, food-web structure).

Actions toward Environmental Objectives, 2004-2008

Coastal and Shoreline Processes (Objective #1, Table 3)

Understanding and inventorying coastal hydro-modification and the resulting impacts on coastal processes are the focus of this environmental objective. During 2004-2008, state programs for coastal management assisted in the regulation of shoreline construction and manipulation and generated maps of coastal wetlands, coastal erosion areas, and priority conservation areas for potential development of offshore wind farms (see Progress, Emerging Issues, and Priorities chapter in the full report). Other groups initiated projects to restore natural hydrology in PMAs in Ontario at Long Point, Big Creek Marsh, and Rondeau Bay and in Ohio at Middle Harbor. Goals for these projects include restoration of connectivity so as to promote water exchange and the extent of submerged aquatic vegetation, both of which can improve fish habitat. Because these areas consist of wetland habitats, the four projects also address fish access (see Environmental Objective #6, Table 3).

Fish-Habitat Protection (Objective #5, Table 3)

Protection and restoration of fish habitat occurred at specific sites in various locations across the basin. Below are summaries of major projects undertaken in the past five years. Many other small-scale projects were underway in the basin, and most are documented annually (HTG 2009; see http://www.glfc.org/pubs/lake_committees/erie/spatial_inventory/inventory_index.html).

Fish Access (Objective #6, Table 3)

The Sandusky River (Ohio) and Grand River (Ontario) are recognized as PMAs because of issues associated with access to spawning habitat for locally adapted stocks (extant or extirpated). In the Sandusky River, efforts continued toward removal of the large Ballville Dam, which will restore hydraulic connectivity, improve water quality, and open 39 km of river previously inaccessible to fish (specifically walleye) moving upstream from Lake Erie. Investigations into the hydrology, sediment, and biotic communities of the Sandusky River were underway. The Dunnville Dam in the Grand River also blocks a Lake Erie walleye stock from over 90% of its historical spawning habitat and contributed to the extirpation of a lake sturgeon stock that spawned in the river. Efforts to allow walleye to access upstream habitat have included the creation of a fishway, a hatchery stocking program, and manual lifting of fish past the barrier. However, evaluation of these efforts through 2008 indicates that large-scale manipulations of the system, including dam removal, need to be considered for full habitat restoration. The transfer of information and experience from arranging for the Ballville Dam removal via members of the LEC's Habitat Task Group has helped to inform the habitat-rehabilitation discussion in the Grand River. The LEC's environmental and LaMP (see below) objectives also have factored into the decision processes for both dam removal projects. Other examples of progress involve fish-passage projects. The Great Lakes Fishery and Ecosystem Restoration Program funded a project at Chautauqua Creek (New York) to improve access to over 16 km of spawning and rearing habitats for steelhead and other stream fishes. Likewise, the Pennsylvania Fish and Boat Commission investigated the feasibility, costs, and benefits associated with fish passage at a pair of dams on the East Branch Conneaut Creek.

In general, fish access continues to be a major habitat issue for Lake Erie, and dam removals proceed as opportunities allow. Although dam and barrier removal is acknowledged as important by all agencies, the ongoing problem of sea lamprey control (see Progress, Emerging Issues, and Priorities chapter in the full report) and recent government commitments to renewable energy sources (e.g., hydro-electric power) may pose challenges to restoring fish access via dam removal.

Contaminants (Objective #9, Table 3)

Changes in Lake Erie contaminant levels can be tracked by advisories to the public on consumption of fish that reflect broad-scale contamination, whole-fish-based contaminant concentrations that reflect local-scale contamination, and the presence of sentinel species like *Hexagenia* mayflies.

Each of the five jurisdictions publishes annual consumption advisories for local sport fishes based on levels of contaminants (e.g., organochlorines and toxic metals) in fish tissue. The number and type of contaminants sampled, advisory reporting method (i.e., number of ounces per meal and number of meals per month, week, or year), length ranges of fish, and risk assessment are not standardized among state agencies (Scherer et al. 2008) and Ontario, thereby making inter-jurisdictional consumption advisories difficult to compare. Moreover, trends in advisories sometimes differ among jurisdictions. For example, Ohio reported improvement between 2004 and 2008 in advisories for walleye (reduced from one meal per month to one meal per week), yellow perch (from one meal per week to two meals per week), and channel catfish ("do not consume" to one meal bimonthly) (http://www.epa.state.oh.us/dsw/fishadvisory/index.aspx). In Ontario waters during 2004-2008, however, mid-sized walleye (~55 cm) were restricted from eight to four meals per month, whereas larger walleye (~75 cm) either remained the same at four meals (central basin) or were restricted from four to two meals per month (eastern basin) (Ontario Ministry of the Environment 2011). Lack of a standard for reporting fish-consumption advisories compromises discernment of lakewide trends in fish-tissue contaminants.

Studies on contaminants from whole-fish samples showed variability in trends depending on contaminant, methodology, and species. For example, although organochlorine (total DDT, chlordane, dieldrin, hexachlorobenzene, heptachlor epoxide, and lindane) declined in whole-fish tissues of lake trout from Ontario waters (M. Keir, Environment Canada, personal communication, 2010), mercury levels in walleye increased (Bhavsar et al. 2010). On local scales, studies from select areas reported ongoing sources of fish contamination, such as in eastern Lake Erie, the upper Niagara River (Karst-Riddoch et al. 2008), and the Black River (Ohio), but the general trend for contaminant concentrations in Lake Erie fishes was downward through 2008.

In 1985, the Water Quality Board of the International Joint Commission designated 12 locations in the Lake Erie basin as Areas of Concern (AOC). Comprehensive Remedial Action Plans (RAPs) were developed to restore beneficial uses to these areas, most of which have impaired uses due to contaminants. By 2008, the Wheatley Harbour AOC (Ontario) had satisfied criteria and a delisting process was begun, and the Presque Isle Bay AOC (Pennsylvania) became the first AOC to be listed as in a “recovery” phase. Only one other AOC of the 38 AOCs in the Great Lakes basin had achieved that status. On the Black River (Ohio), the fish tumor indicator for beneficial use was changed from impaired to “in recovery,” and benthos degradation was delisted in its East Branch tributary. Also signifying progress toward reducing Lake Erie contaminants were the dredging of the Ashtabula and Maumee Rivers (Ohio) and the remediation of contaminated sediments at the Black Lagoon in the Detroit River (Michigan)

Hexagenia mayflies represent not only a desirable component of the food web (Ryan et al. 2003) but also a possible pathway for introducing sediment contamination to higher trophic levels. Although *Hexagenia* populations were not restored lakewide by 2008, results of annual monitoring were promising but variable (Bowen and Schloesser 2009). Their population status is addressed in the Lake Erie’s Western Basin chapter in the full report. Monitoring of *Hexagenia* should continue because the mayflies move contaminants (particularly heavy metals, such as cadmium and zinc; Opfer 2008) from lake sediment into the food chain.

Understanding Fish-Habitat Interactions

Broad-scale habitat issues that encompass basin or lakewide watershed scales are difficult to encapsulate and prioritize in a manner that facilitates effective management, especially by single jurisdictions that often lack the necessary authority to address them. Some habitat data sets are unsuitable because they are incomplete or contain pooled data that cannot be fully integrated due to disparities in scale, classification scheme, or temporal relevance (for dynamic parameters). Improved assessment and understanding of habitat requirements and use by Lake Erie fishes are needed to develop tools and databases that can guide decision making to protect and improve important habitats. The sections that follow describe efforts during 2004-2008 to compile data and gain knowledge for select species (lake trout) and habitats (nearshore) and to apply fish-habitat linkages to walleye.

Habitat Data Compilations

Progress was made in cataloguing, categorizing, standardizing, and collating habitat data on broad scales. Habitat data were collected to establish fish-habitat associations where data were scarce (e.g., nearshore habitat) or where historical information was missing or outdated (e.g., lake trout spawning habitat). Current, contiguous, integrated habitat data sets are a critical need of managers weighing potential modifications in the lake basin, such as in siting wind farms (see Progress, Emerging Issues, and Priorities chapter in the full report).

Several initiatives were underway to provide decision tools for managers during 2004-2008. The Lake Erie Geographic Information System project (LEGIS), described previously as a fish-habitat priority (Tyson 2009), collated habitat and fisheries data sets from across the basin and combined them into lakewide sets, where possible. Although recently expanded with additional data sets and distributed across agencies during 2004-2008, LEGIS has yet to realize its full potential as a fisheries tool for incorporating habitat into management decisions. The Lake Erie binational map project developed for the Lake Erie LaMP, tracked changes in habitat quantity and quality that resulted from preservation, conservation, and restoration efforts, and helped managers guard against further loss or degradation from land-use alterations. This tool will be useful for establishing land-use fisheries connections outside of typical fisheries agency mandates. The Lower Trophic Level Assessment database (FTG 2009), maintained by the Forage Task Group since 1999, remained a key tool for assessing fish community and environmental objectives associated with nutrient status and related habitat indicators (see Environmental Conditions chapter in the full report). The Lake Erie Limnological Synthesis Project (2007-2008) focused on abiotic limnological data (temperature, Secchi depth, DO) collected throughout the lake by numerous agencies from the 1960s to 2009. This tool sought to improve knowledge about the dynamics of these abiotic components of fish habitat, such as the applicability of LEC nutrient objectives in the presence of *Dreissena* spp. (quagga and zebra mussels) and the nearshore phosphorus shunt (Hecky et al. 2004; see Progress, Emerging Issues, and Priorities chapter in the full report).

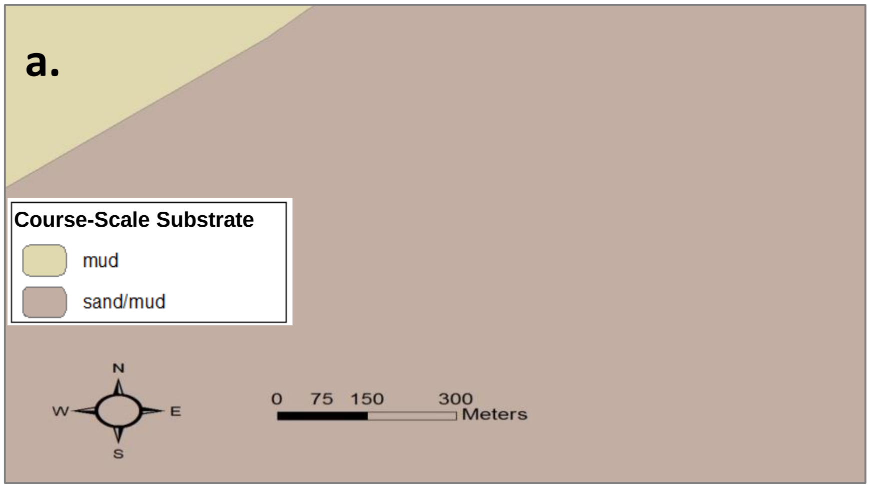
Lake Trout Habitat

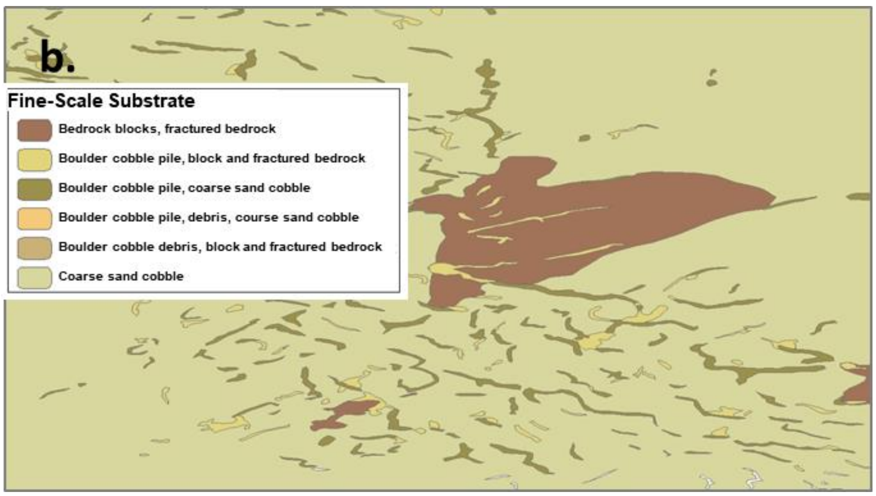
Research toward lake trout rehabilitation in Lake Erie (HTG 2009; CWTG 2009) provides an example of efforts to overcome data gaps and poor resolution of habitat data as well as to identify new issues. In 2005, the LEC called for a collaborative effort of the Coldwater Task Group and Habitat Task Group to assess the quality, quantity, and location of potential lake trout spawning habitat in Lake Erie. The objective, derived from the Lake Erie lake trout management plan (Markham et al. 2008), was to determine if habitat is limiting lake trout production and to better direct stocking efforts over suitable habitat. The research, funded through the Great Lakes Fish and Wildlife Restoration Act and the Canada Ontario Agreement, included the development of a predictive geographic information system (GIS) model, based on published habitat preferences, to be assessed with remote sensing techniques (side-scan sonar and RoxAnn® acoustic seabed classification) and validated with underwater video.

Several key findings emerged from the assessment of lake trout spawning habitat. Firstly, the accuracy of the GIS model to assess habitat at a biologically relevant scale was severely limited by the coarse resolution and inaccuracies of the available base layers (i.e., National Oceanic and Atmospheric Administration bathymetry and substrate maps from the

LEGIS). New data of finer resolution revealed areas of suitable (cobble) habitat on localized scales (Fig. 5). Secondly, underwater video assessments of substrate at several areas initially deemed suitable from side-scan sonar showed that the substrate was buried under *Dreissena* spp. and algae (*Cladophora* spp.) with occluded interstitial spaces that possibly retained sediment. Therefore, remote sensing of substrates alone is not always an accurate assessment of their biological suitability for lake trout spawning. Thirdly, the unexpected discovery of unsuitable conditions at Brocton Shoal (New York), a reference site known historically to have supported reproduction of indigenous lake trout, has important management and research implications. Habitat features (substrate composition) considered to be stable were susceptible to alteration by invasive or nuisance species. Stocking of lake trout at areas like Brocton Shoal to re-establish a naturally reproducing stock may be unrealistic given the present-day condition of the substrate. Lastly, unexpected collections of sexually mature lake trout over non-cobble areas during spawning periods suggest that the fish are adapting to alterations of previously preferred habitat by seeking other, possibly unsuitable, areas for spawning.

Fig. 5. The distribution of bottom substrates on Brocton Shoal (New York) in Lake Erie as depicted in (a) National Oceanic and Atmospheric Administration maps and the Lake Erie Geographic Information System and (b) a fine-scale sonar map made during 2007.


a.
Course-Scale Substrate
mud
sand/mud
N
W
E
S
0 75 150 300
Meters


b.
Fine-Scale Substrate
Bedrock blocks, fractured bedrock
Boulder cobble pile, block and fractured bedrock
Boulder cobble pile, coarse sand cobble
Boulder cobble pile, debris, course sand cobble
Boulder cobble debris, block and fractured bedrock
Coarse sand cobble

Nearshore Habitat

Nearshore (<5 m bottom depth) environments provide critical spawning and nursery habitats, support higher biodiversity and more rare species than offshore habitats, and are subjected to higher levels of nutrient loading due to riverine and coastal inputs. However, comparatively little is known about nearshore fish habitats because assessments of fish communities and habitats have largely focused on offshore areas where most fishing occurs. Nearshore community assessments were initiated during 2004-2008 in the upper Niagara River by the State University of New York, College of Environmental Science and Forestry, along the south shore of the western basin by the Ohio Department of Natural Resources (DNR), in the St. Clair-Detroit River System (SCDRS) by the U.S. Geological Survey and the U.S. Fish and Wildlife Service and along the north shore of Lake Erie by the Ontario Ministry of Natural Resources and Forestry (OMNRF). These surveys employed a variety of sampling gears, including beach seines (OMNRF), bottom trawls (Ohio DNR), and electrofishing (OMNRF and Ohio DNR) with objectives to document species diversity and rare species and to examine habitat characteristics. Although considerable knowledge was gained about these previously unsampled areas, a comprehensive, standardized approach for assessing nearshore habitats is needed to establish fish-habitat linkages on a basinwide scale.

Communication of Fishery and Environmental Objectives

Achievement of fishery and environmental objectives that involve coastal processes, water levels, climate change, watershed loadings of nutrients and suspended solids, as well as critical habitats in tributaries, estuaries, and nearshore areas, require coordinated efforts from resource managers. In 2004-2008, the LEC continued to coordinate efforts in several ways: agency member participation in LaMP groups, participation in other state and federal initiatives, and the issuing of position statements.

The LaMP management committee approved ecosystem management objectives in 2004 and in 2005 began work on environmental indicators; both were informed by the LEC's fishery and environmental objectives through the active participation of agency members. For example, total phosphorus targets of the LaMP match those from the LEC's Ecosystem Conditions Objective. The LaMP 2008 update (https://www.epa.gov/sites/production/files/2015-10/documents/lake-erie-lamp-2008.pdf) reveals considerable overlap between the LEC-defined PMAs and the priority watersheds and focal areas of the LaMP, which is helpful in aligning priorities of federal, state, provincial, and local agencies for implementation of the Great Lakes Water Quality Agreement. In Ontario, watershed management is led predominantly by provincial conservation authorities that actively participate in the LaMP process and that recognize LaMP objectives. In U.S. jurisdictions, RAPs for individual watersheds are in accordance with the LaMP.

During 2004-2008, LEC agency members also participated in other state and federal initiatives that could affect fish habitat, specifically the Michigan-Great Lakes Plan, Ohio's Balanced Growth Initiative, and the federally led Great Lakes Basin Fish Habitat Partnership of the National Fish Habitat Action Plan. All of these initiatives benefitted from communication of the LEC's fish community and environmental objectives as plans and priorities were established.

The LEC continues to issue position statements to highlight issues of collective importance to agency fishery managers (http://glfc.org/pubs/lake_committees/erie/LEC_docs/position_statements/changing_water_level_effects.pdf). A 2005 position statement ("Changing water level effects on Lake Erie and the Lake St. Clair Ecosystem") recognized that fluctuating water levels and subsequent shifts of the littoral zone are important to the structure, function, and productivity of aquatic systems. It referenced impacts under four environmental objectives (coastal and shoreline processes, water levels and climate change, wetlands and submerged macrophytes, and fish-habitat protection). By 2008, the LEC had begun developing a position statement on offshore wind power (see Progress, Emerging Issues, and Priorities chapter in the full report).

Progress: Habitat-Related Fish Community Objectives

Action has been taken on a number of recommendations by Tyson et al. (2009). Environmental objectives were formalized to better define habitat-related FCOs (LEC 2005). Several data sets on geospatial habitat were collected between 2004 and 2008 (e.g., updated substrate information from lake trout habitat work) and put in the LEGIS. A series of workshops in 2007 increased knowledge and use of LEGIS. Recommendations to assess nearshore habitats were realized in a number of jurisdictions to the extent resources allowed. Plans to incorporate environmental variables into management decisions on fish populations throughout the lake (e.g., "traffic light" approach) were discussed but hampered by a lack of understanding about interactions between environmental variables and fish populations on a lakewide scale. Progress was slow on recommendations seeking to continue incorporating data into the LEGIS.

Progress toward four habitat-related FCOs (Ryan et al. 2003) is summarized below. Actions have modestly improved fish habitat in Lake Erie, but considerable work is needed to achieve these FCOs. Further details can be found in the Actions toward Environmental Objectives, 2004-2008 section (see above).

Fish Habitat

Coastal processes continue to be addressed through efforts of state Coastal Management Programs and the completion of projects in PMAs in Ontario at Long Point, Big Creek Marsh, and Rondeau Bay, and in Ohio's Middle Harbor. Fish access will be improved following completion of dam removal or fish-passage projects in New York (Chautauqua Creek) and Ohio (Conneaut Creek, Grand River, and Sandusky River). Numerous small-scale projects were initiated or completed across the basin. Environmental objectives (Table 3), involving processes, environmental conditions, and habitat degradation, were established in 2005, and they are relevant to fulfilling the Fish Habitat Objective. Expansion and distribution of the LEGIS database will facilitate its use in determining fish-habitat targets and planning assessments. Further achievement of the Fish Habitat Objective should occur through improvements to fish access, restoration of coastal and shoreline processes, restoration of wetlands and submerged aquatic macrophyte communities, incorporation of water-level changes and climate change into management decisions, and general protective actions that halt or reverse cumulative incremental loss and degradation of habitat (Table 3).

Nearshore Habitat

Projects that benefit coastal processes (described under Fish Habitat above) also signify progress toward protecting or improving nearshore habitats. Monitoring programs in nearshore areas were initiated in the SCDRS, Upper Niagara River, the western basin, and along the Ontario shoreline to assess habitat types and fish-species diversity and fish-habitat use. In conjunction with LEGIS, new nearshore monitoring projects will help the LEC determine how much habitat is needed to support desired fish communities and identify habitat-type targets to guide restoration projects (Tyson 2009). Further achievement of the Nearshore Habitat Objective should result from restoration of coastal and shoreline processes, restoration of aquatic macrophytes, and incorporation of water-level changes and climate change into management decisions.

Riverine and Estuarine Habitat

Projects that benefit fish access (described under Fish Habitat above) also signify progress in increasing the amount of river and estuarine habitats. Projects to restore habitats in the SCDRS and upper Niagara River connecting channels represent important progress for the Riverine and Estuarine Habitat Objective. Further achievement of this objective should result from restoration of natural hydrology through barrier removal and from improvements to management of watershed drainage, riparian zones, and river-mouth areas.

Contaminants

The general trend suggests declining impacts from contaminants on the Lake Erie ecosystem based on signals from consumption advisories (mixed), whole-fish tissue samples (improvements at 6 of 12 AOCs), and abundance of *Hexagenia* mayflies (increased). Further achievement of the Contaminants Objective should result from actions that minimize the addition of contaminants to Lake Erie and the availability of extant contaminants for uptake by aquatic organisms.

Recommendations

Further progress to achieve habitat-related FCOs should focus on:

1. Improving knowledge about interactions between environmental variables and fish populations on a lakewide and a relevant time scale by:
    a. Standardizing assessment methodology and database formats;
    b. Challenging conventional knowledge about fish-habitat relationships that, in reality, may be dynamic, adaptive responses to stressors;
    c. Cautiously applying results from broad-based species-habitat models;
    d. Considering potential impacts of newly established invasive species, even in habitats that are believed to be well understood; and
    e. Supporting ongoing maintenance, development, promotion, and distribution of LEGIS, including incorporation of regularly updated biological data sets.
2. Developing additional protocols or guidelines for application of the environmental objectives to identify priority actions needed to achieve the LEC's habitat-related FCOs.
3. Standardizing quantification of fish-tissue contaminants across the Great Lakes to provide a more continuous and regional perspective than exists currently.

LAKE ERIE'S WESTERN BASIN[10]

Richard Drouin[11] and Karen Soper

Background

The western-basin's morphology, hydrology, and biota are distinctive within Lake Erie. The western basin is separated from the rest of the lake by a series of islands and shoals running from west of Huron, Ohio, to Point Pelee, Ontario. It is the shallowest of Lake Erie's three basins with an average depth of 7.4 m and a maximum depth of 18.9 m and constitutes 13% of the lake's surface area and 5% of its volume (Bolsenga and Herdendorf 1993). Over 90% of the lake's annual water input enters from tributaries to this basin. Southern areas of the western basin are strongly influenced by nutrient-rich waters from the Maumee River and the Sandusky River, whereas the northern portion is largely influenced by nutrient-poor waters from Lake Huron and Lake St. Clair via the Detroit River (Zhu et al. 2008). The divergent inflows create gradients in productivity and transparency that affect biological production and diversity in the basin. The western basin warms faster and reaches higher summer temperatures than the other basins and is the first to ice over in winter. Basin substrates vary from soft sediments that support an array of benthic invertebrates to limestone reefs and islands that attract structure-seeking fauna, including many fishes. Wetlands that formerly dominated the watershed and shorelines of a pristine western basin are greatly diminished in quantity (area) and functionality (disconnected from Lake Erie via dikes). Despite environmental

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[10]Complete publication including map of place names, other chapters, scientific fish names, and references is available at http://www.glfc.org/pubs/SpecialPubs/Sp17_01.pdf.

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degradation, the western basin still provides important spawning, nursery, and foraging habitats for the highest diversity of fishes in the lake, including key stocks of walleye, yellow perch, and lake whitefish, which have persisted as others were extirpated (Edwards and Ryder 1990; Ryan et al. 2003).

Of Lake Erie's three basins, environmental conditions and habitats in the western basin respond most rapidly to changes in weather and watershed land uses that affect tributary dynamics (e.g., discharge rates, sediment and nutrient loads, tributary water plumes in the open lake, extent of mixing zones in estuaries). Biota respond relatively quickly to changing conditions in the western basin, initially through production of lower-trophic-level organisms followed by lagged responses in food webs, fish recruitment, fish behavior, and fisheries performance. Over longer time periods, persistent spawning groups become stocks that lend a stabilizing influence to the fish community and food web given their adaptations to the dynamic environmental conditions (Zhu et al. 2008).

Following, we explore changes in the western-basin food web relative to Tyson et al. (2009) and assess progress toward the Lake Erie Committee's (LEC) fish community objectives (FCOs) (Ryan et al. 2003).

Food-Web Structure

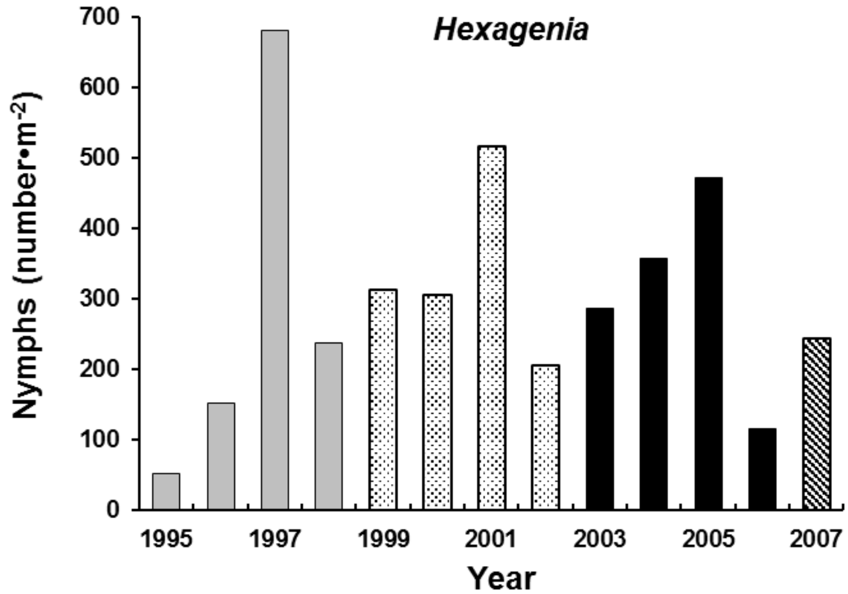
Summer phosphorus concentrations in the western basin exceeded 20 $\mu g \cdot L^{-1}$ (eutrophic status) during 1999-2003 and 40 $\mu g \cdot L^{-1}$ during most years of 2004-2008 (Fig. 3) and produced cyanobacteria blooms annually after 2003 (See Environmental Conditions chapter in the full report). Next we examine responses by *Hexagenia* mayfly nymphs, the forage-fish community, and top predators to eutrophic conditions that have persisted for a decade in the western basin.

Hexagenia

Burrowing mayflies (*Hexagenia limbata*, and *H. rigida*) are indicator organisms for mesotrophic environments (Edwards and Ryder 1990; Krieger et al. 2007). As nymphs, they were widely distributed and abundant throughout the western basin until the 1950s when bouts of anoxia essentially eliminated them (Britt 1955a). The recovery of oxygenated conditions through the 1980s, following actions implemented through the Great Lakes Water Quality Agreement, led to recolonization of the western basin by mayflies (Makarewicz and Bertram 1991; Gerlofsma 1999). Studies of recolonizing adult mayflies in the western basin indicate that abundance is likely a function of temperature and wind conditions (Corkum 2010; Corkum et al. 2006). Although *H. rigida* was the early colonizer, *H. limbata* now represents over 90% of the adult population. Edwards et al. (2009) concluded that restoration of western-basin *Hexagenia* populations could occur if stable densities of nymphs are maintained.

Trends in *Hexagenia* density over several studies from 1995 through 2007 (Bowen and Schloesser 2009) indicate cyclic patterns of increasing density over four-year periods, which may reflect compensatory mechanisms in the mayfly populations (Fig. 6). Britt (1955b) reported average densities of 283-510 nymphs•m^{-2} from samples collected in 1929-1930 and 1942-1943. Average nymph densities ranged from 286 to 681•m^{-2} in over half of the years during 1995-2007 but were lower during 2004-2007 (116-472 nymphs•m^{-2}) than in 1999-2003 (206-516•m^{-2}). Thus far, these data indicate no compelling evidence of anoxia-induced mortality of nymphs in a eutrophic western basin.

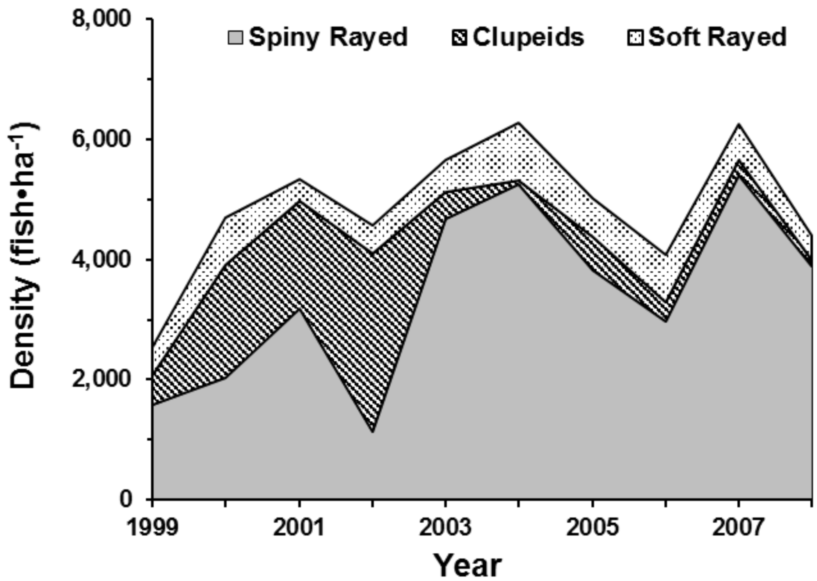
Fig. 6. Mean density (number•m^{-2}) of *Hexagenia* nymphs in the western basin of Lake Erie during four separate studies (differently shaded bars) conducted in 1995-2007 (Bowen and Schloesser 2009).



Forage Fishes

Density of forage fish in the western basin was less variable in 2004-2008 than in 1999-2003, but shifts in prey types were evident (Fig. 7; FTG 2009). Interagency surveys with bottom trawls produced annual estimates of 4,000-6,000 forage fish•ha^{-1} in 2004-2008, compared to 2,600-5,500 forage fish•ha^{-1} in 1999-2003. Forage-fish composition shifted toward more spiny-rayed species (mostly age-0 white perch) and fewer clupeids during 2004-2008. Mean density (fish•ha^{-1}) of spiny-rayed forage fishes rose from 2,519 in 1999-2003 to 4,271 in 2004-2008 while that of clupeids fell from 1,512 to 255. In contrast, density of soft-rayed forage fishes in 2004-2008 (680) was generally similar to that in 1999-2003 (532). Density of soft-rayed fishes (especially emerald shiners and round gobies) during 2004-2006 was above the long-term mean but declined during 2006-2007. Clupeid (age-0 gizzard shad) density remained low from 2004 through 2008, following a recent peak in 2002. Alewife has been absent or rare in the western basin since 2002 (O'Gorman et al. 2012).

Fig. 7. Density (fish•ha^{-1}) of three types of forage fish in Lake Erie's western basin, as determined by area swept with bottom trawls towed in Michigan, Ohio, and Ontario waters during August, 1999-2008 (FTG 2009). The forage types "clupeids" and "spiny rayed" include only fish of age 0, whereas the forage type "soft rayed" includes fish of all ages.



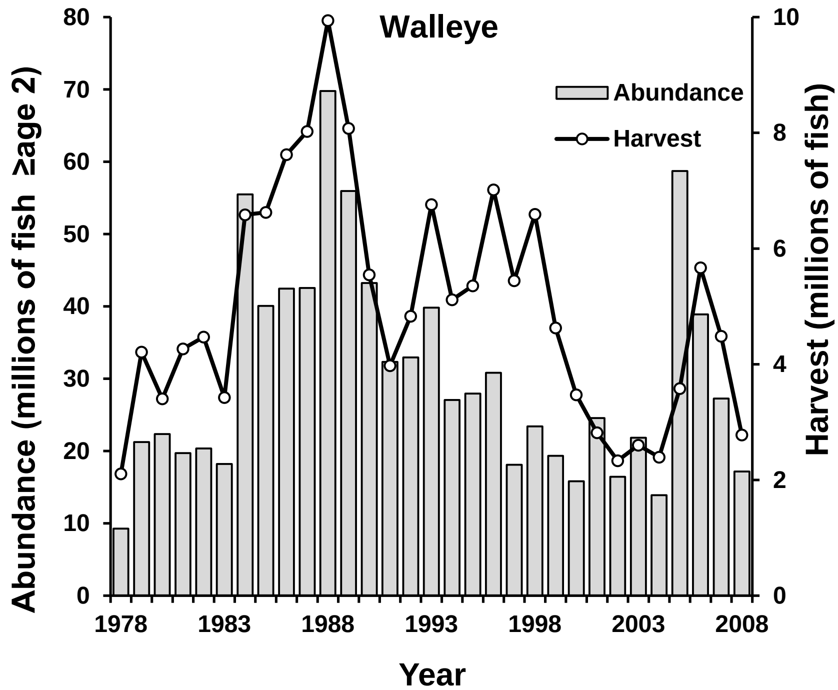
Walleye

Walleye are abundant predators in the western basin that can elicit responses in the forage-fish community and lower trophic levels through intensive and/or selective predation (Knight and Vondracek 1993). In the western basin, walleye become obligate piscivores early in life and select soft-rayed *Notropis* and clupeids over spiny-rayed fishes (Knight et al. 1984). During 2004-2008, walleye diet remained dominated by gizzard shad and *Notropis* despite high abundance of spiny-rayed forage fish and low abundance of clupeids. Walleye growth was not impaired by the reduced density of clupeids (Vandergoot et al. 2010).

The western basin of Lake Erie is the major spawning and nursery area for walleye in Lake Erie. Discrete stocks of walleye spawn in the Maumee and Sandusky Rivers and on reef complexes in Ohio and Ontario waters (Goodyear et al. 1982). Results from tagging and genetic studies show strong fidelity to spawning areas with low straying behavior (Wang et al. 2007; Stepien and Faber 1998). After spawning, the stocks mix and move throughout Lake Erie. Some fish range as far north as northern Lake Huron (Wang et al. 2007). Key research efforts are underway or needed to understand the genetic composition of stocks, to develop stock-specific identification markers (genetic, otolith microchemistry), to determine potential and realized production from western-basin habitats, and to explore options to manage exploitation on a stock-specific basis.

Walleye abundance in the western basin peaked in the 1980s and then declined throughout the 1990s and into the early 2000s (Fig.8; Vandergoot et al. 2010). During 2004-2008, the number of adult (≥age 2) walleye increased from an estimated 14 million fish in 2004 to 59 million fish in 2005, due to an exceptional 2003 year-class, before falling to 17 million fish in 2008 (WTG 2009). The number of adult walleye averaged 31.2 million fish during 2004-2008, as compared to 19.6 million fish during 1999-2003. Annual survival rates of adult walleye during 2004-2008 (58-64%) were similar to survival rates during 1999-2003 (53-62%). Annual exploitation rates in 2004-2008 (10-17%) were also similar to exploitation rates during 1999-2003 (13-23%) (WTG 2009). Variation in adult numbers was driven by annual variability in age-0 recruitment, and walleye numbers during 2004-2008 were sustained by moderate recruitment from 1999 and 2001 as well as strong recruitment from 2003. During 2004-2008, recruitment was weak in 2004, 2005, 2006, and 2008 and moderate in 2007, which will likely lead to a reduction in adult walleye numbers during 2009-2013 relative to 2004-2008.

Fig. 8. Walleye abundance (millions of fish ≥age 2) and harvest (millions of fish) in the western basin of Lake Erie, 1978-2008 (WTG 2009).



Interagency quota management of mixed-stock walleye fisheries continued during 2004-2008. Following implementation of a three-year harvest strategy to halt population declines and promote stock recovery (LEC 2004), a new Walleye Management Plan was developed by the LEC in 2004-2005 primarily to manage stocks spawning in the western basin (Locke et al. 2005). The plan implemented a new policy with a variable fishing rate that tracks changes in population abundance as opposed to the constant fishing-rate policies formerly used. Quotas and resulting exploitation rates in the current year fluctuated with changes in recruitment that were measured two years earlier. Total harvest for the western basin averaged 985,000 fish annually during 2004-2008 (range: 438,000-1,607,000 fish; Fig. 8). Annual yield averaged 2.6 million kg during both 2004-2008 and 1999-2003.

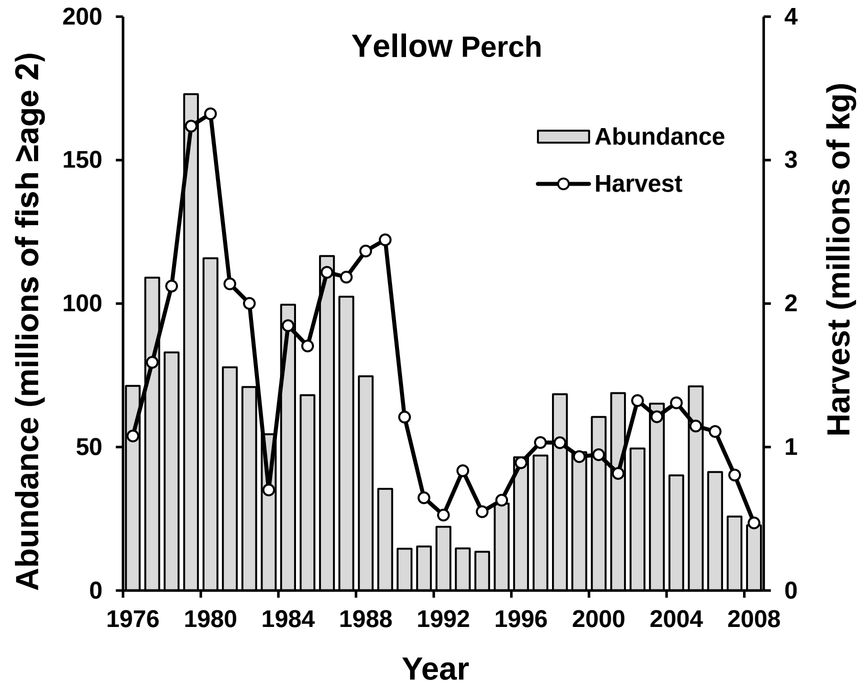
Yellow Perch

Yellow perch are opportunistic omnivores in western Lake Erie. Adults eat mostly benthic invertebrates (including *Dreissena* spp. (quagga and zebra mussels) and *Hexagenia*) and forage fishes, but they will switch to zooplankton if necessary (Knight et al. 1984). Like walleye, large yellow perch prefer *Notropis* and gizzard shad. Unlike walleye, yellow perch will switch to spiny-rayed fishes in the absence of preferred soft-rayed fishes (Knight et al. 1984). Tyson and Knight (2001) found that changes in *Hexagenia* abundance elicited a diet and growth response by yellow perch in western Lake Erie during the 1990s. Yellow perch diets were not examined during 2004-2008, but mean total lengths of adult (ages 2-4) perch from agency fall trawl and gillnet collections in the western basin was relatively stable between 1999-2003 and 2004-2008 with the highest values of the decade occurring in 2007-2008 (YPTG 2009). However, mean condition (Fulton’s K) of adult yellow perch from fall surveys in the western basin remained among the lowest of the three basins in most years during 1999-2008 (YPTG 2009). Hayward and Margraf (1987) determined that growth of yellow perch in the western basin was slower than in the central basin because of higher summer water temperatures and the lower abundance of macroinvertebrates.

Lake Erie's yellow perch stocks came from similar glacial refugia (Todd and Hatcher 1993), and 80% of their haplotypes are common among basin populations (Ford and Stepien 2004). However, biological differences exist between the western-basin stock and other stocks in the lake, and the LEC recognizes a discrete western-basin stock for quota management. Spawning occurs in nearshore areas and bays of western Lake Erie (Goodyear et al. 1982) on the bottom mostly over vegetation. Little is known about their fidelity to spawning areas, post-spawning movements, or other behavior, but yellow perch are believed to be far less migratory than fishes like walleye, white bass, and lake whitefish, given distinct differences in biological characteristics among perch stocks. Ryan et al. (2003) cite the loss of nearshore vegetation as a factor in the decline of yellow perch populations in Lake Erie.

Abundance of adult yellow perch declined in the western basin during 2004-2008 because an exceptionally strong 2003 year-class passed through the population. There were about 35 million yellow perch ≥age 2 in the basin in 2008, approaching the low levels of the late 1980s (Fig. 9), owing to weak year-classes produced in 2004, 2005, 2006, and 2008. Crane (2007) found that warm winters and low copepod production during May were important factors leading to small yellow perch year-classes in the western basin. Ludsin (2000) established that yellow perch recruitment in the western basin was influenced by spring water temperatures during 1969-1983 but that, during 1984-1998 following mandated reductions in point-source phosphorus loadings, recruitment was influenced more by nutrient loading from rivers than by temperature. Carreon-Martinez et al. (2014) determined that predation of larval yellow perch by walleye, white bass, and white perch within plumes of the Maumee and Detroit Rivers was substantial and could affect age-0 recruitment in the basin.

Fig. 9. Yellow perch abundance (millions of fish ≥age 2) and total harvest (millions of kg) in the western basin of Lake Erie, 1976-2008 (YPTG 2009).



Western-basin fisheries harvested about 1.0 million kg of yellow perch annually during 2004-2008, but harvests declined steadily from 1.4 million kg (2004) to 0.5 million kg in 2008, which was the lowest in the time series dating back to 1976 (Fig. 9). The exceptionally strong 2003 year-class was a major contributor to the fishery, representing the largest fraction of yellow perch caught between 2006 and 2008 in the western basin. In Ontario, commercial gillnet effort for yellow perch in 2004-2008 was the lowest since 1975. High harvests of the late 1970s and early 1980s (pre-nutrient controls) could not be sustained through the early 1990s given low recruitment and relatively low adult survival rates (YPTG 2005).

Smallmouth Bass

Diet studies show a feeding behavior that is opportunistic with a high use of invasive round goby since its establishment in the western basin, resulting in increases in the growth rate of smallmouth bass (Steinhart et al. 2004b). Smallmouth bass populations thrive under less-productive conditions than percids and are less tolerant of high turbidity, which has been linked to reductions in population size (Edwards et al. 1983). They eat mostly fish and crayfish (Decapoda) in western waters. Round goby, a soft-rayed fish, is abundant on rocky substrates, and its density remained high in 2004-2008 in the western basin (FTG 2009). Growth and condition of smallmouth bass in western Lake Erie are high compared to bass in other lakes located at a similar latitude.

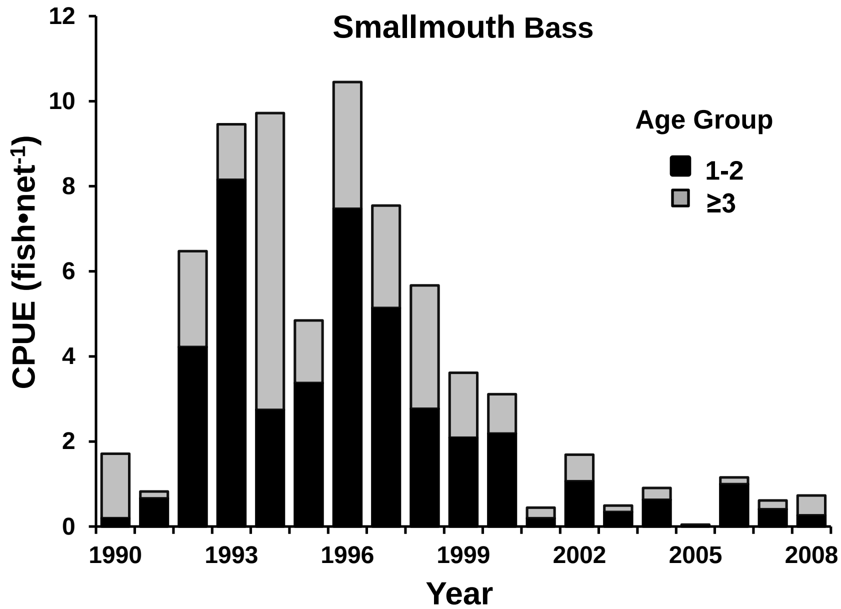
Smallmouth bass spawn in nearshore areas of western Lake Erie (Goodyear et al. 1982) where nests are fanned out of bottom substrates by the males who guard eggs and fry against predators. Limited tagging studies indicate that smallmouth bass have highly localized home ranges, and captured fish return quickly to nesting areas (Steinhart et al. 2004a). Round gobies are known predators of fish eggs and fry and can quickly decimate a nest in the absence of the guarding male bass (Steinhart et al. 2004a). Other predators on smallmouth bass nests include yellow perch and white perch. Nesting success declined between 2005 and 2008 around the western-basin islands owing to the frequency and severity of storm events more so than from round goby predation on eggs and fry (Steinhart et al. 2005).

Trends in smallmouth bass abundance during 2004-2008 were determined for Ontario waters of the western basin with Ontario Ministry of Natural Resources and Forestry (OMNRF) index gillnets set at specific locations, based on the habitat preference and site fidelity of bass. Following major increases from 1990 to 1996, catch rates (number of fish per gang of nets) declined through 2001 and remained low through 2008, averaging about one tenth of the peak values in 1996 (Fig. 10). Ohio initiated standardized gillnetting for smallmouth bass at key locations in 2005 and will report results in the next state-of-the-lake report.

During 2004-2008, smallmouth bass were less abundant than in previous years in western-basin surveys conducted with bottom trawls towed in suboptimal habitats for bass (OMNRF, Lake Erie Management Unit, Wheatley, Ontario, unpublished data). In addition to nest raiding by round goby and storm events, increased dissolved reactive phosphorus since the late 1990s may be related to declining abundance of smallmouth bass (Nicholls et al. 2001; Dolan and McGunagle 2005). Another potential factor in declining smallmouth bass abundance is increased mortality from double-crested cormorants (*Phalacrocorax auritus*) (Tyson et al. 2009). Although Bur et al. (1999) found low incidence of smallmouth basin in avian predator diets, reduction of Lake Erie double-crested cormorant colonies is underway in various jurisdictions (albeit for different purposes) and may be lessening effects of cormorant predation on the smallmouth bass population in the western basin.

Performance of smallmouth bass fisheries generally declined during 2004-2008 relative to earlier periods. Smallmouth bass are not commercially harvested and are targeted by a relatively minor segment of recreational fisheries in the western basin. In Ohio waters, smallmouth bass fisheries experienced major declines in effort, harvest, and harvest rates from 1999-2003 to 2004-2008 following a new (2004) regulation that prohibited the harvest of smallmouth bass from May 1 to June 26 (ODNR 2005). Michigan fisheries harvested an average of 226 fish annually during 2004-2008, which was 79% less than the average in the previous five-year period (MDNR 2009). In Ontario waters, the average annual catch (5,021 fish) of smallmouth bass in 2005 and 2008 (the only years assessed during 2004-2008) was 35% lower than the average from five previous yearly surveys (1985, 1990-1992, and 1998), although average catch per angling hour increased to 0.56 in 2005-2008 from 0.46 in earlier surveys (Belore et al. 2008).

Fig. 10. Relative abundance of two age groups of smallmouth bass in Ontario waters of Lake Erie's western basin based on catch-per-unit effort (CPUE; fish•net^{-1}) in index gillnets, 1990-2008.



Fisheries exploitation is not believed to be the predominant factor affecting abundance of smallmouth bass during 1999-2008. A majority of smallmouth bass were released upon capture in all recreational fisheries in the western basin and bycatch mortality from commercial fisheries should have been relatively low given major reductions in the number of gillnets set on the bottom for yellow perch in 2004-2008 (YPTG 2009).

Lake Sturgeon

Lake sturgeon have been largely absent from the Lake Erie fish community for over a century. In the St. Clair-Detroit River System (SCDRS), the lake sturgeon is relatively abundant and feeds extensively on invertebrates, including *Dreissena* spp., as well as on round gobies and other small benthic fishes (Boase 2005). Little is known about the current diet of lake sturgeon in western Lake Erie.

Lake sturgeon spawn in gravel areas of large rivers (Goodyear et al. 1982), such as those in the SCDRS. Spawning runs persisted through 2008 in the St. Clair River, and efforts are underway to improve spawning habitats there and in the Detroit River where minimal reproduction is occurring. The western basin of Lake Erie is a suspected nursery area for juveniles and a foraging area for adults of the SCDRS stock. The addition of artificial reefs in the Detroit River during 2004-2008 attracted spawning fish of several species, including lake sturgeon, but recruitment of sturgeon from these reefs remains to be proven. A spawning run may have once been present in the Maumee River, but surveys during 2004-2008 failed to capture any lake sturgeon (FWS, Alpena Fish and Wildlife Conservation Office, unpublished data).

Historical commercial harvests indicate that the western basin of Lake Erie had one of the largest lake sturgeon populations in the Great Lakes (OMNR 2009a). By the turn of the 20th century, however, the western-basin population collapsed from intense exploitation, pollution, and loss of riverine and estuarine habitat (Zollweg et al. 2001; OMNR 2009a). Over the ensuing decades, efforts were made to remediate stressors that led to the collapse, and they have recently produced positive results, as evidenced by an increase in the number of lake sturgeon reported to Lake Erie fisheries agencies by commercial and recreational fishers. In 2004-2008, commercial fishers reported 29 lake sturgeon, and anglers reported 31 in western Lake Erie. Moreover, biologists collected 38 lake sturgeon during assessments with gillnets and bottom trawls in the western basin. Lengths of the lake sturgeon ranged from 304-1,829 mm, suggesting that reproduction is occurring in the western basin or in the SCDRS. In comparison, lake sturgeon collections from 1992 through 2003 totaled 182 fish, 17 from fall sampling with gillnets in Ontario, and 165 tagged in 1996-1998 and 2001 by the U.S. Fish and Wildlife Service in Ontario waters, with total lengths ranging from 320-970 mm (Zollweg et al. 2001).

Currently, lake sturgeon are designated as threatened in Ontario and endangered in Michigan and Ohio (MDNR 2009; ODNR 2009; OMNR 2009a). Commercial harvest of lake sturgeon has been prohibited from U.S. waters of the Great Lakes since 1977 and from Ontario waters since 2009. Recreational fisheries in Michigan, Ohio, and Ontario (as of 2008) are restricted to catch and immediate release with no possession. In 2009, the OMNRF prohibited targeting of lake sturgeon by recreational fisheries.

Other Species

Monitoring of channel catfish, freshwater drum, white bass, and white perch is not conducted in the western basin, but these species are caught in western-basin fisheries (Table 4). Because most commercial and sport fisheries typically do not target these species in the western basin, their fishery yields are "bycatch," and thus provide only coarse indicators of abundance. Average annual fishery yields (Table 4) increased between 1999-2003 and 2004-2008 for white perch (147%), freshwater drum (11%), channel catfish (11%), and white bass (4%). Collectively, these four species accounted for 28% of the total annual yield of nine major fishes in the western basin during 1999-2003 and 33% during 2004-2008.

Table 4. Annual yield (thousands of kg) of various fish species from commercial and sport fisheries in the Michigan, Ohio, and Ontario waters of Lake Erie's western basin during 2004-2008. Also shown are the average annual yields for 1999-2003 and 2004-2008.

Species	Year 2004	2005	2006	2007	2008	Averages 2004-2008	1999-2003
Burbot	-	-	< 1	-	-	< 1	< 1
Channel catfish	181	142	204	259	236	204	171
Freshwater drum	147	206	214	181	256	201	164
Lake whitefish	137	33	100	183	250	141	209
Rainbow smelt	< 1	-	-	< 1	-	< 1	< 1
Walleye	1,546	2,244	3,586	3,426	2,280	2,616	2,629
White bass	736	743	717	841	909	789	742
White perch	466	359	522	516	481	469	186
Yellow perch	1,317	1,147	1,109	801	467	968	1,082
Total	**4,530**	**4,874**	**6,454**	**6,209**	**4,880**	**5,388**	**5,183**

Progress: Western-Basin Fish Community Objectives

Several recommendations from Tyson et al. (2009) for achieving FCOs apply to the western basin, including: (1) improve an understanding of how habitats affect fish production, particularly for walleye, yellow perch, white bass, lake sturgeon, muskellunge, and northern pike; (2) ensure that population models and exploitation strategies are maintained or improved to sustain fisheries on percid stocks while accommodating changing ecosystem conditions and stakeholder support; and (3) consider how percid fisheries management affects other species, such as smallmouth bass and lake whitefish. Two key actions occurred during 2004-2008 relative to these recommendations. First, research was initiated to further understand walleye stock discreteness, movements, and contributions to fisheries. When coupled with guidance from the new environmental objectives, this research will help the LEC determine priorities for increasing fish production from habitats essential to key stocks. Second, the quota management plan for walleye was completed (Locke et al. 2005), an important step in revising the stock assessment model to account for ecosystem changes in a transparent fashion to better inform stakeholders. Other items relative to the recommendations of Tyson et al. (2009) are included in an assessment of progress toward the FCOs (below).

Food-Web Structure and Forage-Fish Dynamics

The western basin was eutrophic and unstable during 2004-2008 (see Environmental Conditions chapter in the full report), and responses were expressed in both benthic and pelagic food webs. Prey-fish abundance was relatively stable, but the community shifted from dominance by predator-preferred clupeids to less-preferred spiny-rayed fishes. Age-0 white perch accounted for most of the increase in spiny-rayed forage fishes. Increases in round goby abundance may have increased mortality on early life stages of native fishes through predation but benefitted the growth of juvenile-and-older life stages by providing a readily available and abundant food item. *Hexagenia* continues to be important in the western basin as they are eaten by many fishes, but their existence may be threatened by anoxia stemming from increased algal production. Historically, *Hexagenia* populations collapsed almost immediately upon exposure to short-term anoxia in the 1950s, and their recovery lagged a decade behind the re-aeration of sediments in the early 1980s. Continued adjustments to food-web structure should be expected if eutrophic conditions persist in the western basin into the foreseeable future. The shifts could include major declines in *Hexagenia*, declines in forage-fish growth rates, and declines in clupeid and *Notropis* abundance, unless predatory demand (piscivore biomass) drops sharply.

Habitat Objectives

Actions to improve fish habitat or access to habitats by key fish stocks are summarized above (see Environmental Objectives and Habitats chapter in the full report). Although these actions are important, nutrient management to move the western basin back to a mesotrophic condition remains the highest priority to obtain optimal production from all desired fishes recognized in the FCOs. Wetland restoration projects are needed in the western basin to benefit species like northern pike.

Fish Stocks and Genetic Diversity

Persisting and increasing eutrophic conditions in the western basin during 1999-2008 are cause for concern about the future status of locally adapted fish stocks. Percid stocks that are dependent on nearshore, riverine, and estuarine habitats for spawning and nurturing of young, particularly those dependent on the Maumee and Sandusky Rivers and Ohio reef systems, may be especially responsive to changes in nutrient loadings that are driving eutrophication of western-basin waters. Percid recruitment was variable and weak during 2004-2008. Further responses are expected, including reduced growth and continued weak recruitment of percids, declines in recruitment from stocks of lake whitefish that spawn in the western basin, and increases in fish species tolerant of eutrophic conditions (e.g., freshwater drum, channel catfish, white bass, and white perch). Declines in local smallmouth bass stocks may also be related to eutrophication, the negative effects of storms and round goby on nesting success, and mortality from double-crested cormorant predation.

Assessment and research remained critically important to LEC management of the western basin during 2004-2008. Interagency bottom trawling and monitoring of lower trophic levels are instrumental in detecting and understanding system responses to major environmental changes in the basin that affect fish recruitment and fishery yields. Research to determine stock-specific recruitment contributions to western-basin fish populations and associated fisheries is underway and is needed to guide prioritization of habitat protections and improvements. Sampling programs are still needed for species that are not currently being rigorously assessed and have shown signs of continued stress in the western basin for just under a decade, such as smallmouth bass and lake whitefish. Smallmouth bass may be a useful sentinel species for detecting nearshore habitat changes related to climate and shoreline alterations in the western basin. Efforts to address fish production and to maintain relatively conservative fishery exploitation represent partial achievement of the Genetic Diversity FCO.

Rare, Threatened, and Endangered Species

Results of current inter-jurisdictional collaborative efforts aimed at restoring lake sturgeon have been relatively encouraging. Although there are still many unknowns with respect to the population status of lake sturgeon in the western basin, recently there has been a more-optimistic outlook for the recovery of the species as both adult and juvenile fish were reported with increasing frequency. In addition, LEC agencies have continued to restrict harvest of rare, threatened, and endangered species, such as lake sturgeon. Eutrophic conditions are not optimal for lake sturgeon. Persistence of eutrophic conditions in the western basin will likely delay, if not preclude, recovery of a Lake Erie spawning stock. However, future nutrient management in the Maumee River watershed could provide opportunities to restore historically important spawning habitat for lake sturgeon in the western basin.

Productivity and Yield from Western-Basin Fisheries

Western-basin fishery yields of all major species averaged 5.4 million kg during 2004-2008 as compared to 5.2 million kg in 1999-2003 (Table 4). Most (85-90%) of the annual yields were from high-value species (e.g., walleye, yellow perch, white bass, and lake whitefish) in both five-year periods. Percids accounted for 67% of the average annual yield from all major species and 80% of the yield from high-value species in 2004-2008, which was similar to their contributions during 1999-2003. On average, western-basin fisheries accounted for 31% (4.5 of 14.4 million kg) of the lakewide yield of high-value species during 2004-2008 compared to 34% (4.7 of 13.8 million kg) in 1999-2003.

Recommendations

1. Work with water-quality managers to restore phosphorus, transparency, and dissolved oxygen levels to within target ranges.

2. Continue research on mechanisms affecting recruitment and mortality of walleye and yellow perch stocks in the western basin and their associated implications for habitat management, food-web structure, and fishery yields.

3. Continue to work collaboratively with federal agencies and universities to better understand the distribution and population status of aquatic species at risk, particularly lake sturgeon, within the western basin.

4. Encourage continued monitoring by environmental science and water-quality agencies to track *Hexagenia* status and trends.

5. Develop and implement agency-specific assessment programs for smallmouth bass in the western basin, standardizing sampling gears and protocols as much as practicable.

LAKE ERIE'S CENTRAL BASIN[12]

Kevin A. Kayle[13] and Charles Murray

Background

The central basin of Lake Erie is delineated by the Lake Erie Committee (LEC) as that part of the lake east of a north-south line between Point Pelee, Ontario, and Huron, Ohio, and west of a north-south line bounded by the Pennsylvania Ridge at Presque Isle, Pennsylvania, and the landward end of Long Point, Ontario (Fig. 1). It has an average depth of 18.5 m, a maximum depth of 25.6 m, and makes up 63% of the lake's surface area and volume (Bolsenga and Herdendorf 1993). For fishery-management purposes (stock assessments and quota allocations), the central basin is split north-south, almost equally into west central and east central sub-basins along a jagged dividing line from Fairport Harbor, Ohio, to the U.S.-Canada boundary, then west to a line from the international boundary to Port Glasgow, Ontario (YPTG 2009).

Although the central basin is mostly mesotrophic, it became increasingly eutrophic during 2004-2008 (Fig. 3). Nutrients enter the nearshore areas from large harbors in and rivers discharging to the central basin and from Ohio rivers discharging to the western basin. Another source of total phosphorus (TP) to the central basin is release from sediments under anoxic

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[12]Complete publication including map of place names, other chapters, scientific fish names, and references is available at http://www.glfc.org/pubs/SpecialPubs/Sp17_01.pdf.

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conditions, which occurred during 2004-2008 (see Environmental Conditions chapter in the full report).

Environmental conditions and habitats in the central basin often reflect a gradient between the shallow western basin and deep eastern basin for many abiotic and biotic features, although they also reflect features that are unique to the central basin. For example, water depths, temperatures, and lower trophic-level indicators in the central basin tend to be intermediate to those of the other basins, yet hypoxia occurs naturally only in the central basin (Fig. 2). Additionally, the western and eastern basins have water masses that rotate within the boundaries of each country, whereas the central basin has two dominant gyres (one per sub-basin) that span the waters of both countries, with counter-clockwise rotation in the west central and clockwise rotation in the east central sub-basins (Saylor and Miller 1987). How these gyres affect food-web structure of the central basin is not well understood, but they are known to affect algal distributions (LEC 2005) and may have additional implications for pelagic food webs and fish behavior. At present, and historically, migratory fish stocks have traversed the central basin during spring or fall en route to feeding or spawning grounds. Resident stocks of many fishes were extirpated in the central basin by the 1960s, likely due to degradation of nearshore spawning and foraging habitats.

Food-Web Structure

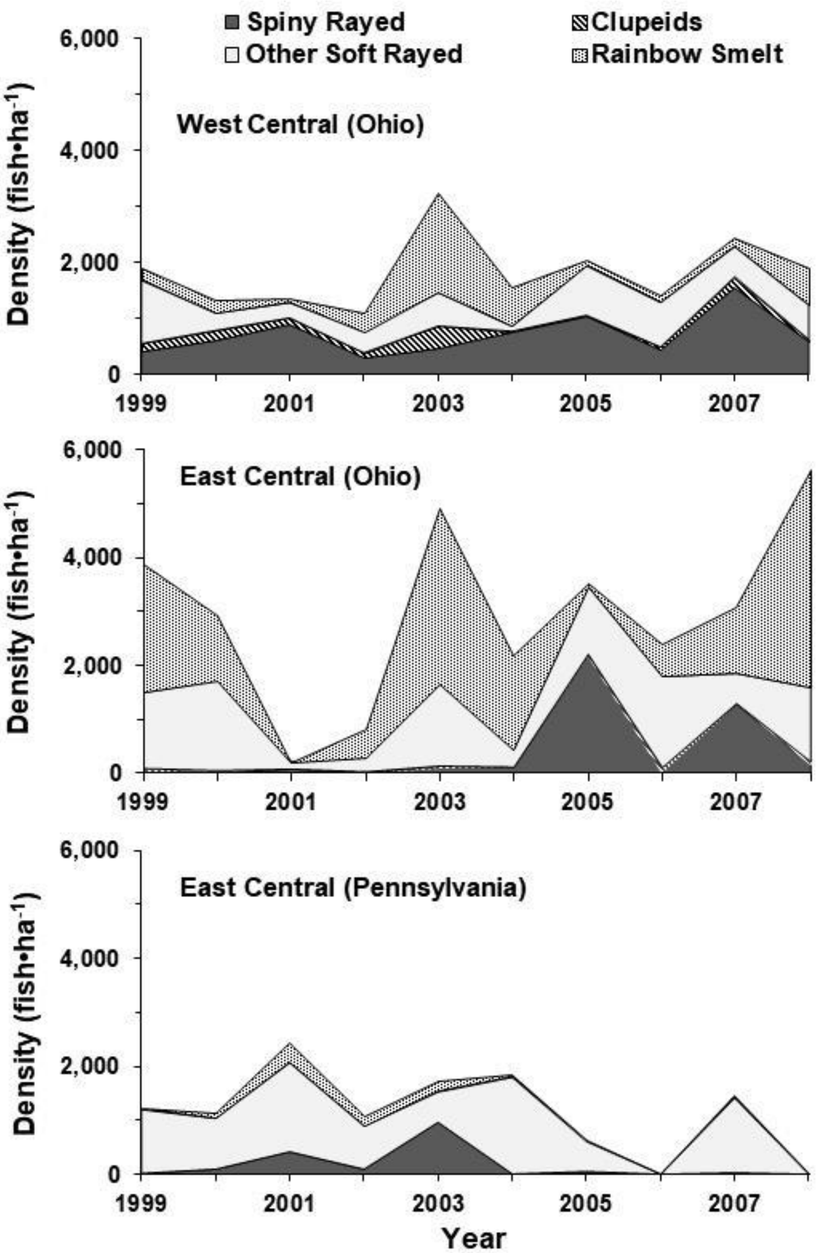
Forage Fishes

In the central basin, density of forage fish in agency surveys conducted with bottom trawls in fall varied among sub-basins and years during 1999-2008. In Ohio waters, average density (fish•ha^{-1}) was similar between 1999-2003 (1,774) and 2004-2008 (1,851) in the west central sub-basin but 31% higher between 1999-2003 (2,564) and 2004-2008 (3,371) in the east central sub-basin (Fig. 11). In 2008, forage-fish density in Ohio was among the highest values recorded in 1999-2008. In Pennsylvania waters of the east central sub-basin, average density of forage fish decreased 14% between 1999-2003 and 2004-2008 from 1,509 to 1,304 fish•ha^{-1}, but trawling was not conducted in two years (2006, 2008) of the latter period. Bottom trawling was not conducted in Ontario during 1999-2008.

Walleye

Composition of the central-basin's forage-fish community shifted noticeably between 1999-2003 and 2004-2008 (Fig. 11). In the west central sub-basin, average clupeid (age-0 gizzard shad and alewife) abundance in 2004-2008 declined 69% from that in 1999-2003 with clupeids contributing only 3% to total forage-fish abundance in 2004-2008. Abundance of rainbow smelt declined 36% between the five-year periods, and smelt made up about 18% of the total forage in 2004-2008. Abundance of other soft-rayed fishes (*Notropis*, trout-perch, and round goby) was similar between time periods and made up about 30% of the forage base throughout 1999-2008. Spiny-rayed species (age-0 yellow perch and white perch) increased substantially (65% on average) between 1999-2003 and 2004-2008, comprising 47% of total forage-fish abundance in 2004-2008. In the east central sub-basin, spiny-rayed species (especially age-0 white perch) in Ohio waters increased from 51 to 757 fish•ha^{-1} (2-22% of total forage-fish density) from 1999-2003 to 2004-2008. A different pattern was evident in the abbreviated data from Pennsylvania waters, where density of spiny-rayed fishes (primarily age-0 yellow perch) declined between 1999-2003 and 2004-2008. Rainbow smelt and other soft-rayed fishes were the dominant forage fishes in the east central basin during 1999-2008. Clupeids were never abundant in Ohio or Pennsylvania in either time period. Throughout the central basin, alewife hatches were poor during 1999-2008; age-0 fish were caught in trawl surveys only in 2006. No tubenose gobies were captured in any of the trawl surveys conducted in the central basin.

Fig. 11. Density (fish•ha^{-1}) of rainbow smelt and three types of other forage fish in three areas of Lake Erie's central basin—Ohio waters of the western sub-basin and Ohio and Pennsylvania waters of the eastern sub-basin—as determined by area swept with bottom trawls during October 1999-2008 (FTG 2009). No trawling was done in Pennsylvania waters in 2006 or 2008. The forage types "clupeids" and "spiny rayed" include only fish of age 0, whereas the forage type "other soft rayed" and rainbow smelt include fish of all ages.



Spiny Rayed
Clupeids
Other Soft Rayed
Rainbow Smelt
West Central (Ohio)
Density (fish•ha-1)
6,000
4,000
2,000
0
1999
2001
2003
2005
2007
East Central (Ohio)
East Central (Pennsylvania)
Year

Mean sizes of forage fishes or composition of predator diets did not differ between 1999-2003 and 2004-2008 (FTG 2009). Diets of various predator species were predominantly emerald shiner, rainbow smelt, round goby, and gizzard shad in both five-year periods.

Walleye is the most-abundant top predator in the central basin during summer and fall, and its feeding preferences in the central basin are the same as in the western basin (see Lake Erie's Western Basin chapter in the full report). During 2004-2008, walleye diets in the central basin were dominated by gizzard shad, rainbow smelt, and *Notropis* (FTG 2009), just as in preceding years.

Walleye populations in the central basin of Lake Erie are mostly dependent on production of young fish from stocks that spawn in the western basin even though there are tributary and reef spawning aggregations of walleye in the central basin. A Grand River (Ohio) spawning stock annually produces age-0 walleye but with minimal contribution to the central-basin walleye population. Similarly, production of age-0 walleye from nearshore reefs in Ohio and Ontario waters of the central basin is believed to be minimal.

Older walleye, particularly age 3 and older females, migrate seasonally from the western basin into and through the central basin. Annual abundance of age 3 and older fish (males and females) in the western walleye stock averaged 11.3 million fish (range 8.5 to 12.8 million) in 1999-2003 and 19.8 million fish (range 8.5 to 37.4 million) in 2004-2008 (WTG 2009). The increase in walleye abundance was driven entirely by the large 2003 year-class (see Lake Erie's Western Basin chapter in the full report), members of which became migratory during the latter years of 2004-2008.

The average annual yield of walleyes from central-basin fisheries increased from 1.4 to 1.8 million kg between 1999-2003 and 2004-2008. Annual yields ranged from 1.1 to 2.3 million kg between 2004 and 2008, with a peak in 2006 that reflected full recruitment of the 2003 year-class. In the east central sub-basin, fishery performance (yield, catch-per-unit effort, and mean age harvested) in 2006-2008 was the highest since the late 1980s (WTG 2009). Lower yields are expected during 2009-2013, given a new variable fishing-rate policy (Locke et al. 2005) and low to moderate annual recruitment of walleye from the 2004-2008 year-classes.

Yellow Perch

Diets of adult yellow perch in the central basin were dominated by the zooplankter *Bythotrephes longimanus* (spiny water flea) and emerald shiner during 2004-2008. Other plankton and Chironomidae were seasonally important to earlier life stages. No changes in adult growth rates were evident between 1999-2003 and 2004-2008.

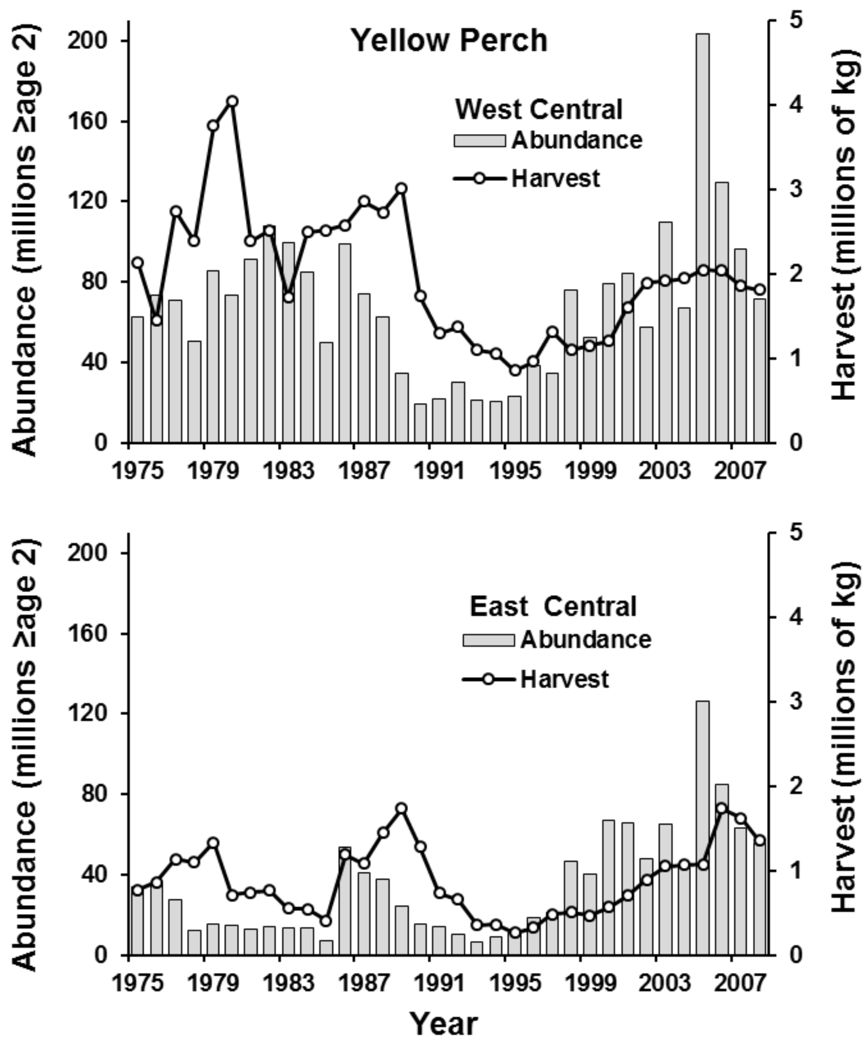
Spawning stocks of yellow perch remain well distributed throughout the central basin. Many of the major spawning areas are located near tributary inputs of nutrients and warm turbid water. These conditions foster growth of plankton and provide refuge for larval and juvenile fish from predators. Bottom trawling indicates inshore movements for spawning by some fish while others remain in deep (10-15 m) waters (Ohio DNR, Fairport Harbor Fisheries Research Station, unpublished data). After spawning, yellow perch move farther offshore and are affected by hypoxia and upwellings, but impacts on feeding, growth, survival, and future recruitment are uncertain (see Progress, Emerging Issues, and Priorities chapter in the full report).

An emerging issue for yellow perch (and other species) during 2004-2008 was the outbreak of a new, unique strain of viral hemorrhagic septicemia virus (VHSV) in Lake Erie (see Progress, Emerging Issues, and Priorities chapter in the full report). Moribund yellow perch tested positive for VHSV in 2006 as did gizzard shad in 2007-2008. No other percid die-offs were observed after this initial event, but further testing and research are being completed to determine the extent of the virus's mobility and to examine the status of fish health in the central basin, other portions of Lake Erie, other Great Lakes, and neighboring inland waters in the United States and provinces of Canada.

Adult yellow perch were abundant in the central basin during 2004-2008 relative to 1975-2003 owing to a strong 2003 year-class and moderately strong 1999, 2001, 2005, and 2006 year-classes (YPTG 2009). Between 1999-2003 and 2004-2008, average abundance increased from 76.5 to 113.3 million fish in the west central sub-basin, and from 57.2 to 74.7 million fish in the east central sub-basin. Adult abundance in 2005-2006 was the highest of any year during 1975-2008 in both sub-basins of the central basin (Fig. 12).

The average annual yield of yellow perch from central-basin fisheries increased from 2.3 to 3.3 million kg between 1999-2003 and 2004-2008 (YPTG 2009). During 2004-2008, annual yields ranged from 1.8 to 2.0 million kg (mean: 1.9 million kg) in the west central sub-basin and from 1.1 to 1.7 million kg (mean: 1.4 million kg) in the east central sub-basin. Current LEC harvest policy for yellow perch invokes a risk-based assessment of a constant fishing rate for each central-basin stock. Development of a new Yellow Perch Management Plan will guide future interagency management of fishery exploitation.

Fig. 12. Yellow perch abundance (millions of fish ≥age 2) and harvest (millions of kg) in the western and eastern sub-basins of Lake Erie's central basin, 1975-2008 (YPTG 2009).


Yellow Perch
West Central
Abundance
Harvest
Abundance (millions ≥age 2)
Harvest (millions of kg)
0
40
80
120
160
200
0
1
2
3
4
5
1975
1979
1983
1987
1991
1995
1999
2003
2007
East Central
Abundance
Harvest
Abundance (millions ≥age 2)
Harvest (millions of kg)
0
40
80
120
160
200
0
1
2
3
4
5
1975
1979
1983
1987
1991
1995
1999
2003
2007
Year

Smallmouth Bass

Round goby is the primary prey of adult smallmouth bass in the central basin of Lake Erie with new evidence of increasing consumption by juvenile smallmouth bass during 2004-2008 relative to previous years. Growth of age-0 and age-1 smallmouth bass, as judged from the size of individuals caught with bottom trawls in 2004-2008, has increased compared to that in the decades prior to round goby establishment.

Rare catches of smallmouth bass in offshore gillnet assessments indicate that stocks along the north shore of the central basin are small and localized, supporting minor sport fisheries near the ports of Erieau, Burwell, and Bruce (OMNR 2009b; MacDougall et al. 2004). Most spawning occurred on reefs and shoals in water <10 m deep. Adults are scattered in waters as deep as 15 m after nest protection is completed in midsummer.

Gillnet surveys targeting smallmouth bass were initiated in the Ohio waters of the central basin in 2006 to monitor age composition of adults. Survey results from 2006-2008 indicate minor increases in recruitment and the presence of fish up to age 17 (ODNR 2009). Annual nearshore monitoring is being initiated to determine the status of juvenile smallmouth bass (ODNR 2009).

Smallmouth bass fisheries in the central basin are small compared to those in the western and eastern basins, and they are diminishing. During 2004-2008, fishery effort for smallmouth bass in Ohio waters averaged 68,000-142,000 angler hours annually as compared to 138,000-203,000 angler hours in 1999-2003. Catch rates were high in both five-year periods with many anglers practicing catch and release while harvesting <4,000 smallmouth bass per year (ODNR 2009). The implementation in 2004 of a "no-harvest" season in May-June reduced angler effort in Ohio waters of the central basin, although to a lesser degree than in the western basin (see Lake Erie's Western Basin chapter in the full report). In Pennsylvania waters, fishing effort for smallmouth bass ranged from 2,000 to 10,000 angler hours during 2004-2008, as compared to 6,000 to 20,000 angler hours annually during 1999-2003. Release rates were high as evidenced by an average annual harvest of only 189 fish from an average annual catch of 5,700 smallmouth bass (PFBC 2009).

Steelhead

Steelhead diets varied between sub-basins and among months, and the presence of pelagic and benthic prey reflected feeding throughout the water column. At least seven species of fish and ten species of invertebrates (aquatic and terrestrial) were eaten, but fish were the predominate prey (>99% dry weight biomass). Shiners composed 71% of diet (dry weight biomass) in the west central sub-basin and 36% of the diet in the east central sub-basin. Rainbow smelt were also important prey (20% dry weight in the west central and 42% in the east central sub-basins). Round goby was eaten only in the east central sub-basin (<1% dry weight).

Steelhead, an introduced species, spawn in various tributaries that are largely unsuitable for recruitment at levels sufficient to sustain stocks in the central basin. Fisheries are maintained through stocking of hatchery-reared fish by state and provincial agencies. As in 1999-2003, about 1.3-1.4 million yearling steelhead were stocked annually in the central-basin drainage during 2004-2008, the vast majority in Ohio and Pennsylvania tributaries (CWTG 2009). Steelhead stocked in the central-basin drainage made up about 70-80% of the 1.7-2.0 million steelhead stocked annually in the Lake Erie watershed since 1990.

Steelhead survival is likely influenced by predation from sea lamprey. Sea lamprey monitoring and control continue in the Grand River (Ohio), Conneaut Creek (Ohio and Pennsylvania), and Raccoon Creek (Pennsylvania). Lampricide treatments in two consecutive years (2008 and 2009) are being implemented in the Grand River and Conneaut Creek (as well as in other major sea lamprey producing tributaries to Lake Erie) to stem the upturn in sea lamprey numbers and marking rates on target species (see Lake Erie's Eastern Basin chapter in the full report).

Steelhead sport fisheries in the central basin occur mostly in tributaries during spawning runs. An evaluation of Pennsylvania's steelhead fishery was completed in 2004 (Murray and Shields 2004). Monitoring of steelhead fisheries in Ohio tributaries began in fall 2008 and extended through spring 2010. Annual harvest of steelhead by the sport fishery in the open waters of the central basin during 2004-2008 ranged from 5,000 to 32,000 fish (CWTG 2009), which was lower than in 1999-2003 (23,000-123,000 fish).

Variation in annual harvests between the five-year periods was driven by sub-par catch rates of walleye in the offshore sport fishery in 2004-2008, a fishery in which steelhead are bycatch. Sub-par catch rates of walleye led to reduced effort and thus a lower harvest of steelhead. A paucity of creel data from all agencies on the open-lake fishery may be creating an appearance of highly variable harvests. Targeted catch rates for steelhead anglers in the open waters of the central basin averaged 0.14 fish•hr^{-1} (range 0.06 to 0.25 fish•hr^{-1}) during 2004-2008 (CWTG 2009), which is at least as high as averages (~0.1 fish•hr^{-1}) reported for other Great Lakes (Hanson 2006).

Other Species

Population trends for burbot, lake whitefish, and rainbow smelt are covered in the Lake Erie's Eastern Basin chapter in the full report. Adults of these species are largely limited to oligotrophic areas that are mostly in eastern Lake Erie but also include limited offshore regions in the central basin. In the central basin, the average of annual fishery yields declined between 1999-2003 and 2004-2008 for burbot (82%), lake whitefish (56%), and rainbow smelt (2%) (Table 5). Rainbow smelt provided the highest yield of any species in 2004 and the second highest annually during 2005, 2007, and 2008. In aggregate, burbot, lake whitefish, and rainbow smelt accounted for about 26% of the annual yield of major species in the central basin in 2004-2008, as opposed to 34% in 1999-2003. In comparison, percids made up 44-45%, respectively, of the average annual yields in the central basin in 1999-2003 and 2004-2008.

Targeted monitoring of secondary fish populations (e.g., channel catfish, freshwater drum, white bass, and white perch) is not conducted by any LEC agency in the central basin; these species are harvested mostly as bycatch in central-basin fisheries (Table 5). Trends in fishery yields provide only coarse indicators of the four secondary species' abundance. The average of annual fishery yields (Table 5) declined between 1999-2003 and 2004-2008 for white bass (16%) and freshwater drum (3%) but increased substantially for white perch (196%) and channel catfish (91%). Collectively, the four species accounted for about 20% of the total annual yield of major fishes in both five-year periods.

Table 5. Annual yield (thousands of kg) of various fish species from commercial and sport fisheries in Ohio, Ontario, and Pennsylvania waters of Lake Erie's central basin during 2004-2008. Also shown are the average annual yields for 1999-2003 and 2004-2008.

	Year					Averages	
Species	**2004**	**2005**	**2006**	**2007**	**2008**	**2004-2008**	**1999-2003**
Burbot	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Channel catfish	16	26	45	10	25	25	13
Freshwater drum	37	63	46	30	40	43	44
Lake whitefish	140	106	55	120	107	105	240
Rainbow smelt	4,138	2,192	50	2,446	2,416	2,248	2,303
Walleye	1,079	1,550	2,298	2,204	1,872	1,801	1,359
White bass	974	639	549	857	1,300	864	1,032
White perch	512	816	783	949	804	773	261
Yellow perch	3,017	3,095	3,678	3,413	3,138	3,268	2,287
Total	**9,915**	**8,492**	**7,507**	**10,031**	**9,704**	**9,128**	**7,544**

Progress: Central-Basin Fish Community Objectives

As eutrophic conditions (increasing TP and hypoxia) developed in the central basin during 2004-2008 (see Environmental Conditions chapter in the full report), several recommendations from Tyson et al. (2009) remain especially relevant for achieving fish community objectives (FCOs), including: (1) the LEC should improve their understanding of how habitats affect fish production for offshore-spawning species, such as yellow perch; (2) ensure that population models and exploitation strategies are maintained or improved to sustain fisheries on percid stocks while accommodating changing ecosystem conditions and stakeholder support; and (3) consider how percid fisheries management affects other species, such as smallmouth bass. Actions toward these recommendations during 2004-2008 largely focused on assessment of changing ecosystem conditions and associated responses in fish community dynamics, as well as on communication with stakeholders. Details on specific FCOs are provided below.

Food-Web Structure and Forage-Fish Dynamics

Trends of increasing TP concentrations and low DO events between 1999-2003 and 2004-2008 indicate that the central basin transitioned from mesotrophic to eutrophic, which likely drove shifts in the forage-fish community and food-web structure. As the central basin became increasingly productive during 2004-2008, the numbers of spiny-rayed fishes (especially age-0 white perch) in Ohio waters rose, a trend that was also apparent in the increasingly eutrophic western basin over the same five years. The increased numbers of age-0 white perch during 2004-2008 were particularly noticeable in the east central sub-basin where previously they had been inconspicuous. Gizzard shad declined in abundance between 1999-2003 and 2004-2008 in the western basin and the west central sub-basin but not in the east central sub-basin where they maintained similar (albeit low) levels of abundance between periods. These results suggest that shifts in the structure of the forage-fish community in the central basin during 1999-2008 reflect a general west-to-east trophic response to increasing TP similar to trends observed in the western basin. Piscivorous fishes did not shift their diets to less-preferred spiny-rayed fishes in the presence of abundant rainbow smelt and *Notropis*, and growth rates of high-value fishes remained high. Therefore, the FCOs related to food-web structure and forage-fish dynamics are judged to have been largely met during 2004-2008 but are in jeopardy for future years if eutrophication accelerates or persists. Shifts that could jeopardize meeting the FCOs include major declines in benthic invertebrates and changes in feeding behavior, movement, growth, and reproduction of forage and piscivorous fishes in response to increasing anoxia.

Habitat Objectives

Actions to improve fish habitat in Lake Erie were summarized previously (see Environmental Objectives and Habitat chapter in the full report). Shoreline modification, dredging, and erosion continued to affect fish habitat in the central basin during 2004-2008. Much work is needed to improve habitats for fish that spawn in rivers and/or in nearshore waters. Nutrient management aimed at restoring mesotrophic conditions in the central basin remains the highest priority to obtain optimal production from all desired fishes recognized in the objectives. A potential threat to fish habitat emerged during 2004-2008 when a developer of offshore wind-power projects explored opportunities in Ohio waters of the central basin raising concerns related to siting, design, funding, and potential effects on aquatic biota and habitat. Ohio Department of Natural Resources personnel were engaged in assessment requirements for site leasing and development, prescribing a regimen of activities that developers needed to complete before, during, and after installation of wind-power turbines.

Fish Stocks and Genetic Diversity

The intent of the Genetic Diversity FCO is to protect or improve locally adapted indigenous fish stocks through management of habitat and fishery exploitation. Given the variety of nearshore habitats in the central basin, including numerous tributaries, extensive shoreline bluffs, embayments, harbors, and nearshore reefs, as well as a large offshore area that periodically becomes hypoxic, the existence of fine-scale discrete fish stocks is presumed but largely unproven. Some local stocks, such as blue pike, were permanently lost as nearshore habitats of the central basin became degraded in the 1960s. The LEC recognizes and broadly assesses two large stocks of yellow perch (west central and east central sub-basins) for quota management purposes, but fine-scale stock structure is unknown. Smallmouth bass may have spatially discrete stocks among and within Ohio, Ontario, and Pennsylvania waters. Little was learned about biological, genetic, and behavioral differences among local stocks of any fish species between 1999-2003 and 2004-2008. Increasingly eutrophic conditions in the central basin may affect local stocks differently, depending on the distribution and duration of anoxic zones that could influence foraging behavior, growth, and survival. Research on stock identification that is underway for walleye will help elucidate stock structure for that species and, if successful, similar techniques may also be applicable to yellow perch, smallmouth bass, and lake whitefish in the central basin. Efforts to address fish production from different habitats and to maintain relatively conservative fishery exploitation represent partial achievement of the Genetic Diversity FCO.

Productivity and Yield from Central-Basin Fisheries

Fishery yields of major species from the central basin averaged 9.1 million kg during 2004-2008, as compared to 7.5 million kg in 1999-2003 (Table 5). Most (90%) of the increase in average yield was due to higher yields of percids. Average annual yield of all high-value species (walleye, yellow perch, lake whitefish, white bass, and rainbow smelt) increased from 7.2 to 8.3 million kg between 1999-2003 and 2004-2008, with percids accounting for 50% and 61% of those totals, respectively. Central-basin fisheries accounted for 52% of the average lakewide yield of high-value species in 1999-2003 and 50-62% of the average lakewide yield annually from 2004 through 2008.

Recommendations

1. Strive to maintain mesotrophic conditions in the central basin by supporting efforts to reduce TP concentrations in the western basin and by working with water-quality managers and researchers to better understand and control major nutrient inputs from streams and combined sewer overflows.

2. Support monitoring and research on lower trophic levels and environmental conditions in the central basin with a specific focus on understanding the effects of hypoxia on fish distribution, fisheries, and fish assessments.

3. Identify specific coastal, riverine and estuarine, and nearshore fish habitats in the central basin that require protection and improvement.

4. Continue efforts to understand mechanisms affecting recruitment and mortality of yellow perch in the central basin.

5. Continue efforts to understand fish production in, and migration through, the central basin in response to changing lake conditions, nutrients, and hypoxia.

6. Continue efforts to control sea lamprey in lamprey producing tributaries to the central basin. Monitor other tributaries where sea lamprey may contribute to the central-basin stock.

LAKE ERIE'S EASTERN BASIN[14]

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Background

The eastern basin of Lake Erie is separated from the adjacent central basin by the submerged Pennsylvania Ridge, which crosses the lake from Long Point, Ontario, to Presque Isle, Pennsylvania (Burns 1985; Ryan et al. 1999), and extends east to the head of the Niagara River at Buffalo, New York. The eastern basin has an average depth of 18.9 m, a maximum depth of 64.0 m, and makes up 24% of the lake's surface area and 32% of its volume (Bolsenga and Herdendorf 1993). The eastern basin receives most of its

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[14]Complete publication including map of place names, other chapters, scientific fish names, and references is available at http://www.glfc.org/pubs/SpecialPubs/Sp17_01.pdf.

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water from the upstream central basin but also has major river inflows on the north shore from the Grand River (Ontario) and on the south shore from Cattaraugus Creek (New York) (Sly 1976). Extensive areas of marsh and wetlands are found in Long Point Bay and in the lower reaches of the Grand River (Ryan et al. 1999). Bottom substrates vary with exposed bedrock and deposits of sand and gravel along the south shore, whereas the north shore is dominated by clay and sand. Mud bottoms predominate in the deeper waters (Burns 1985).

The seasonal thermal cycle of the eastern basin closely resembles that of the other Great Lakes (Hartman 1972). During the winter, the basin is nearly isothermal at 0.1°C (Burns 1985). In spring, after ice breakup in the central and western basins, ice flows move east and cover the eastern basin, causing the warming of near-surface water there to lag behind the western basin by 18 days and the central basin by 11 days (Hartman 1972). Slight warming and complete ice-out occurs during April and early May. Then the upper waters warm more rapidly, and a relatively stable and thick metalimnion forms that narrows and sinks as the summer progresses. The epilimnion is well mixed, reaching around 24°C by early August before it starts to cool. Hypolimnetic water warms slowly, reaching 7-9°C before fall turnover in late October, and winter conditions are reached by late December (Hartman 1972). The eastern basin can be classified as deep dimictic; it stratifies thermally and has a thicker hypolimnetic layer of cold water than exists in the central basin (Ryan et al. 1999). At full thermal stratification (typically early September), the metalimnion usually forms at depths near 20 m but can be deeper or shallower depending on summer heat intensity or upwelling events associated with sustained strong winds.

A diversity of habitats, fish species, and stock behavior makes the eastern basin unique among the three basins of Lake Erie. Environmental conditions and habitats are most stable in the eastern basin as compared to the western and central basins, but, when conditions change, responses in food webs and in the cool-water fish community occur initially in mesotrophic areas nearshore. Oligotrophic offshore areas provide the vast majority of thermal habitat necessary to sustain a cold-water fish community in Lake Erie but also provide a thermal barrier that affects movements of some cool-water species and fosters the formation of localized stocks. Together, nearshore and offshore habitats support (or once supported) resident and migratory stocks of several key fish species, including walleye, yellow perch, smallmouth bass, lake trout, cisco, burbot, lake whitefish, and rainbow smelt. Spawning and nursery habitat for most of these stocks are in the nearshore waters of the eastern basin. However, adults of some cold-water fish stocks (lake whitefish and rainbow smelt presently; cisco and lake trout historically) reproduce in the western basin and migrate to the eastern basin as waters warm. Cool-water species (walleye) also spawn in the western basin and use eastern-basin habitats during warm months. The combination of having cool- and cold-water habitats and resident as well as migratory fish stocks has important implications for food-web structure, fish production, and ultimately, fisheries yield.

Food-Web Structure

Diporeia *spp.*

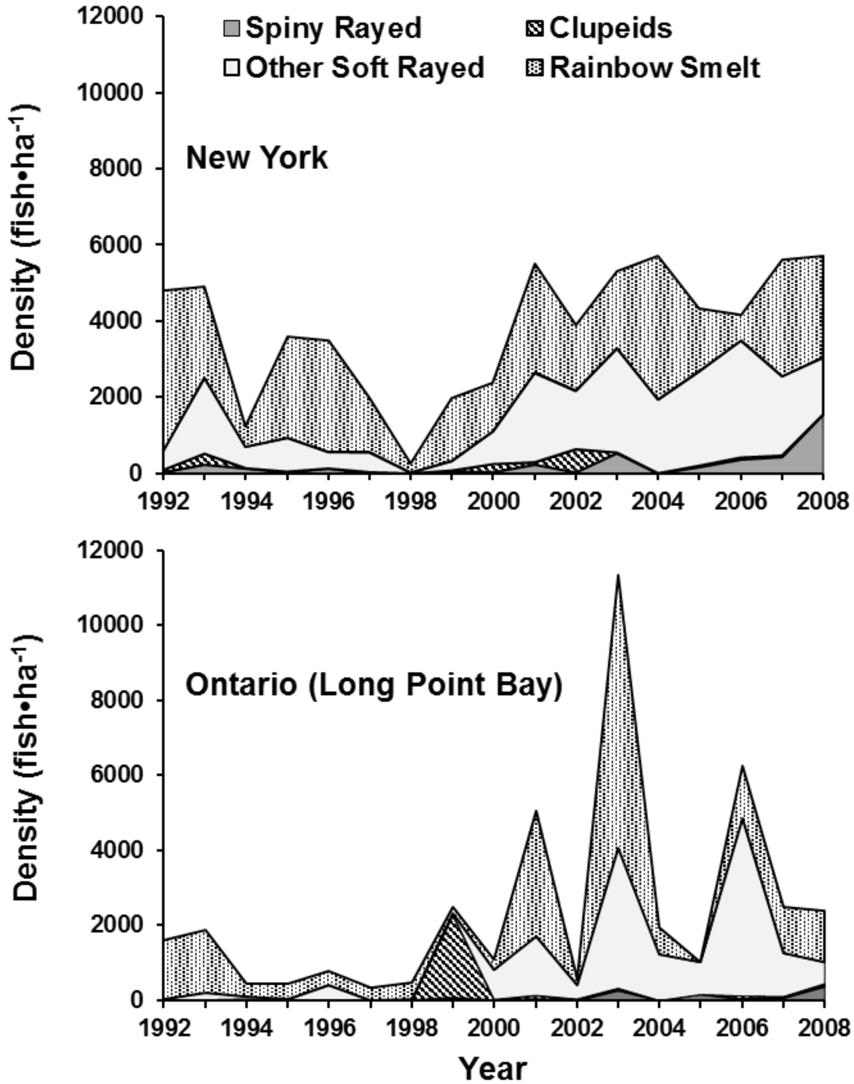
Diporeia spp. are deep-water amphipods that were once the dominant benthic macroinvertebrates in all five of the Great Lakes (Cook and Johnson 1974). They were important to the diets of a number of forage fishes, including cisco, lake whitefish, and rainbow smelt, and thus provided an important conduit of energy from phytoplankton to higher trophic levels (Barbiero et al. 2011 and references within). Declines in *Diporeia* spp. populations became evident across the Great Lakes in the early 1990s, including deep areas of Lake Erie's eastern basin (Dermott and Kerec 1997). Sampling at 12 sites across Lake Erie between 1997 and 2009 produced no *Diporeia* spp. (Barbiero et al. 2011). Although the cause for the disappearance of *Diporeia* spp. remains unknown, suspicion has centered upon interactions with *Dreissena* spp., (quagga and zebra mussels); however, the mechanism(s) remain unclear (Barbiero et al. 2011 and references within).

Forage Fishes

A diverse and abundant base of forage fishes is vital to the sustainability of eastern-basin cold- and cool-water fish communities. A century ago, cisco, a soft-rayed fish, was the major forage fish in eastern Lake Erie. Rainbow smelt, emerald shiners, gizzard shad, all pelagic species, and the benthic round goby have replaced extirpated cisco. Rainbow smelt and round goby are major prey of lake trout and burbot, two top cold-water predators. Rainbow smelt are also major prey of walleye, whereas round goby provide abundant prey for yellow perch and smallmouth bass. Assessments of forage-fish abundance in the eastern basin are accomplished through independent surveys conducted with standardized bottom trawls by the Ontario Ministry of Natural Resources and Forestry (OMNRF) and the New York State Department of Environmental Conservation (DEC) (OMNR 2009b; Einhouse et al. 2009).

Density and diversity of forage fishes in the eastern basin were high during 2004-2008 as compared to 1999-2003. Overall densities in 2004-2008 ranged from 4,168 to 5,714 fish•ha^{-1} in New York waters and 1,019 to 6,259 fish•ha^{-1} in Ontario waters as compared with densities in 1999-2003 of 1,978 to 5,514 fish•ha^{-1} (New York) and 572 to 11,346 fish•ha^{-1} (Ontario) (Fig. 13). Similar shifts in forage species between 1999-2003 and 2004-2008 were detected by the OMNRF and DEC with increases in mean densities of round goby, other soft-rayed fishes (emerald shiners and trout-perch), and spiny-rayed fishes (age-0 yellow perch, white perch, and white bass), and decreases in clupeids (Fig. 13). Increased density of spiny-rayed fish was largely due to above-average recruitment of yellow perch. Clupeids (gizzard shad and alewife) did not have major year-classes after 1999 (Ontario) or 2002 (New York). Rainbow smelt increased in New York waters and decreased in Ontario waters during 2004-2008 relative to previous years, but they were abundant throughout the eastern basin during 1999-2008. In general, the forage-fish community in the eastern basin provided abundant soft-rayed prey for both cool- and cold-water piscivores.

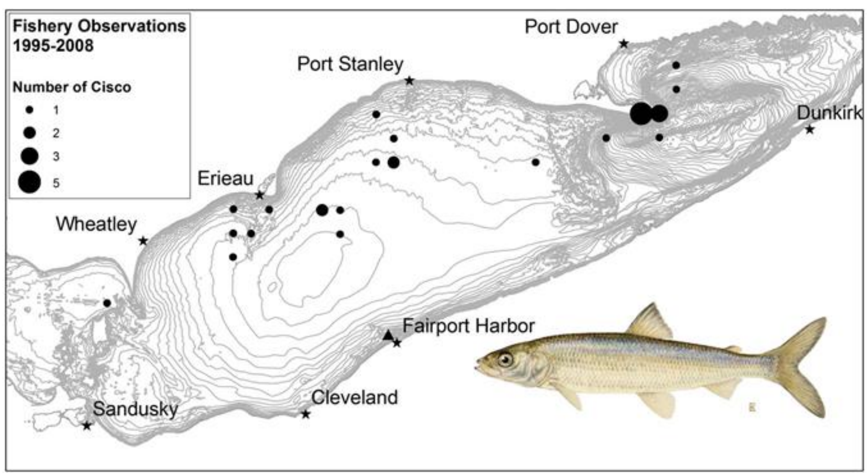
Fig. 13. Density (fish•ha^{-1}) of rainbow smelt and three types of other forage fish in two areas of Lake Erie's eastern basin—Long Point Bay in Ontario and waters of the open lake in New York—as determined from the area swept with bottom trawls during October 1992-2008 (FTG 2009). The forage types "clupeids" and "spiny rayed" include only fish of age 0, whereas the forage type "other soft rayed" and rainbow smelt include fish of all ages.


Spiny Rayed
Clupeids
Other Soft Rayed
Rainbow Smelt
New York
Density (fish•ha-1)
Ontario (Long Point Bay)
Year

Cisco

Cisco is indigenous to the Great Lakes and historically supported one of the most-productive fisheries in Lake Erie (Scott and Crossman 1973; Trautman 1981). It was also the dominant planktivore in the eastern basin and the most-important food for lake trout. Cisco is considered extirpated in Lake Erie, although commercial fisherman have recorded >20 individuals since 1996 (Fig. 14). The population's demise is attributed to a variety of factors, including overfishing, habitat loss and degradation, eutrophication, and interactions with non-indigenous species, such as rainbow smelt and alewife (Christie 1974; Ebener 1997; Madenjian et al. 2008; Baldwin et al. 2009).

Fig. 14. Lake Erie showing the number of cisco caught at various locations in 1995-2008. All ciscoes were caught in the Ontario commercial gillnet and trawl fisheries (circles) with the exception of one fish (triangle) that was caught in index gillnetting by the Ohio Department of Natural Resources near Fairport Harbor, Ohio. Total number of cisco caught in 1995-2008 is slightly higher than that shown because catches without location information have been excluded.



A remnant cisco stock may still exist in Lake Erie. A total of 11 cisco were collected by commercial fishers during 2004-2008 bringing the total number of cisco collected since 1994 to 31 (Fig. 14). An examination of DNA from nine of the cisco caught between 1995 and 2003 found that they were most-similar genetically to Lake Erie cisco from the 1950s and 1960s based on microsatellite markers (U.S. Geological Survey, Northern Appalachian Research Laboratory, unpublished data). Of cisco from extant Great Lakes populations, those from Lake Huron were most similar to the recently collected cisco from Lake Erie. Workshops were conducted in 2003 to review the current status of cisco and impediments to stock recovery in the Great Lakes and in 2006 to discuss a model of cisco management developed for Lake Superior with implications for cisco restoration in the Lower Great Lakes (CWTG 2009).

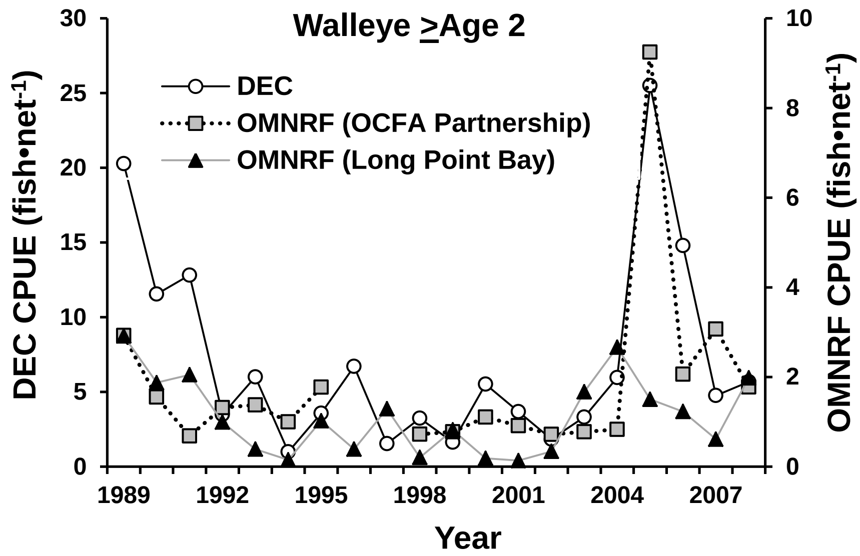
Walleye

During 2004-2008, walleye diets remained dominated by rainbow smelt with minor contributions from numerous other species, including emerald shiners, round goby, *Morone* spp., and clupeids (FTG 2009). Discrete stocks of walleye spawn in Ontario's Grand River, nearshore areas in eastern Ontario and New York waters, and in New York's Cattaraugus Creek and Van Buren Bay. Historically, resident stocks in the eastern basin were considered spatially and genetically distinct from western- and central-basin stocks (Wolfert and Van Meter 1978; Nepszy et al. 1991). However, a synthesis of tagging studies (Wang et al. 2007), genetic investigations (Stepien and Faber 1998; McParland et al. 1999; Gatt et al. 2003), and analysis of harvest patterns (WTG 2010) indicates that considerable mixing occurs seasonally in the eastern basin between walleye that are resident there and those that migrate from the western basin. The degree of mixing, and thus the relative contribution of western-basin walleye to individual eastern-basin fisheries, varies geospatially, seasonally, and annually as a function of the magnitude of the western-basin walleye population and environmental and biotic factors. For example, the proportion of western-basin walleye in the eastern-basin sport fishery was 73% in 1995-96 (Gatt et al. 2003) and 21-35% in 1999-2000, but their proportional contributions to the commercial fishery remained similar between these two time periods (Einhouse and MacDougall 2010). A lack of suitable habitat is limiting production of walleye for at least the Grand River stock (see Environmental Objectives and Habitat chapter in the full report) where a dam blocks access to >90% of available spawning substrate (MacDougall et al. 2007).

Abundance of walleye ≥age 2 in the eastern basin (combined resident and migrant fish) was higher in 2004-2008 than in most years between 1992 and 2003 based on two of three agency surveys with gillnets (Fig. 15). Peak abundance occurred in 2005 due to recruitment of fish from a dominant 2003 year-class. Elevated abundance was less pronounced but also evident in the survey conducted in Ontario's Long Point Bay. Although much of the rise in walleye abundance in recent years was due to the persistence of the strong 2003 year-class, moderate year-classes were also produced in the eastern basin in 2005-2006, and they also contributed to higher walleye abundance in the eastern basin in 2007-2008.

The average annual yield of walleye to eastern-basin commercial and sport fisheries decreased from 118.6 to 88.7 thousand kg between 1999-2003 and 2004-2008. Annual yields ranged from 32.1 to 151.1 thousand kg between 2004 and 2008 with a peak in 2006 that reflected full recruitment of the 2003 year-class to the fisheries. Performance of the walleye sport fishery in the eastern basin (harvest, catch-per-unit effort, and mean age harvested) in 2004-2008 was the highest since the late 1980s when the strong 1984 year-class recruited to the fishery (Einhouse et al. 2009).

Fig. 15. Relative abundance of walleye ≥age 2 in three areas of Lake Erie's eastern basin—Long Point Bay in Ontario and waters of the open lake in Ontario and in New York—based on catch-per-unit effort (CPUE; fish•net^{-1}) in index gillnets, 1989-2008. The Ontario Ministry of Natural Resources and Forestry (OMNRF) conducted netting in Long Point Bay and, in partnership with the Ontario Commercial Fisheries' Association (OCFA), in the open Ontario waters of the basin. The New York State Department of Environmental Conservation (DEC) conducted netting in the open New York waters of the basin. Note that scales of the vertical axes differ.



Yellow Perch

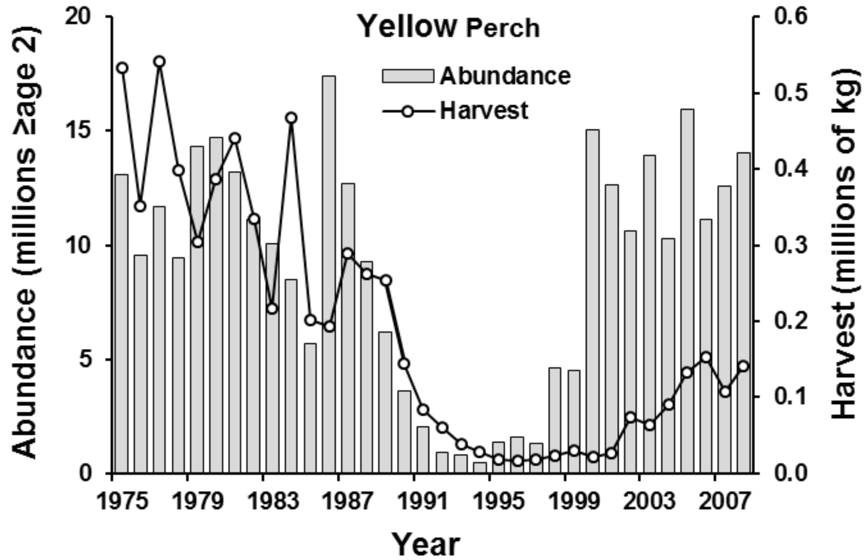
Yellow perch is an abundant, adaptable benthic omnivore in the eastern basin able to use a wide variety of water temperatures and habitats (Scott and Crossman 1973). The diet of yellow perch changes with size and season but is largely comprised of fish, benthic invertebrates, and zooplankton. Although data on diets during 2004-2008 are not available, anecdotal information gathered from anglers and biologists who conducted assessment surveys indicate that round goby have become increasingly common in yellow perch stomachs since its invasion of the eastern basin in 2000 (DWE, personal observation). Growth rates of yellow perch in the eastern basin have been consistently high since the early 1990s (YPTG 2009).

In the eastern basin, yellow perch are considered to be one population for assessment and inter-jurisdictional quota management even though there may be small spawning stocks that are spatially insolated. Basin bathymetry and a large volume of cold water offshore may limit yellow perch distribution and account for differing recruitment patterns among various locations in the basin. Myers and Bence (2001) concluded that multiple stocks were likely present within the basin. However, a more-recent study by the OMNRF (OMNR 2006) re-affirmed treating yellow perch as a single population for quota management. Further research is necessary to elucidate stock structure on a local scale and determine the implications of that structure to management of yellow perch in the eastern basin.

The yellow perch population in the eastern basin has expanded considerably since the 1990s, and the expanded population has been relatively stable from 2000 through 2008 (Fig. 16). Abundance of yellow perch ≥age 2 ranged from 10 to 16 million fish during 2004-2008 compared to 0.5 to 4.6 million fish in the 1990s (YPTG 2009). Strong recruitment, coupled with high adult survival rates (~65%) due to a conservative harvest strategy (YPTG 2009), fostered a 10- to 15-year recovery of yellow perch in the eastern basin, the basin with the lowest biological productivity in Lake Erie.

The average annual yield of yellow perch to sport and commercial fisheries in the eastern basin increased from 43.2 to 124.9 thousand kg from 1999-2003 to 2004-2008. Annual yields during 2004-2008 ranged from 90.7 to 152.1 thousand kg and were the highest since 1990 but were less than half of the levels of the 1970s and 1980s (Fig. 16). Catch rates of yellow perch increased relative to 1999-2003 for all commercial and sport fisheries in the basin (YPTG 2009).

Fig. 16. Yellow perch abundance (millions of fish ≥age 2) and harvest (millions of kg) in the eastern basin of Lake Erie, 1975-2008 (YPTG 2009).



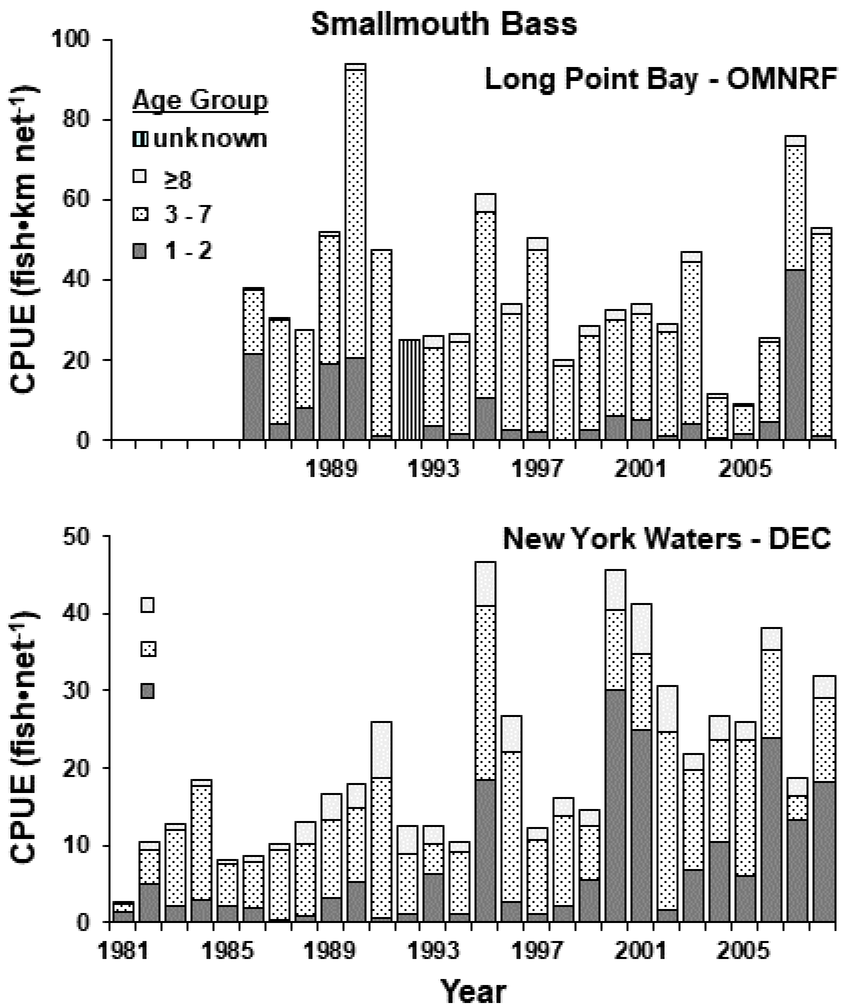
Smallmouth Bass

The diet of smallmouth bass in the eastern basin of Lake Erie changed from the 1990s to the 2000s (Crane and Einhouse 2016). During 1993-1998 (before the round goby invasion), adult smallmouth bass ate mostly (54%, frequency of occurrence) crayfish (*Decapoda* spp.), and fish (clupeids, *Morone* spp., and rainbow smelt) composed only about 10% of the diet. However, round goby quickly became the most-common diet item (73%, frequency of occurrence) following its establishment in eastern Lake Erie in 1999, and crayfish became only a minor (6%) diet item. Coincident with this diet shift, there was an increase in the mean size of smallmouth bass at ages 2, 3, and 4 (Einhouse et al. 2009; Crane and Einhouse 2016).

Little is known about the stock structure of smallmouth bass in the eastern basin of Lake Erie. At least two stocks exist on the Ontario side of the basin, one in the Long Point Bay area and the other near Port Colborne (OMNR 2006). Ontario tributaries along the north shore do not support any known spawning areas of lake-based smallmouth bass populations, whereas a few of New York's tributaries do support spawning of lake-based populations (Goodyear et al. 1982; New York State DEC, Lake Erie Fisheries Research Unit, unpublished data).

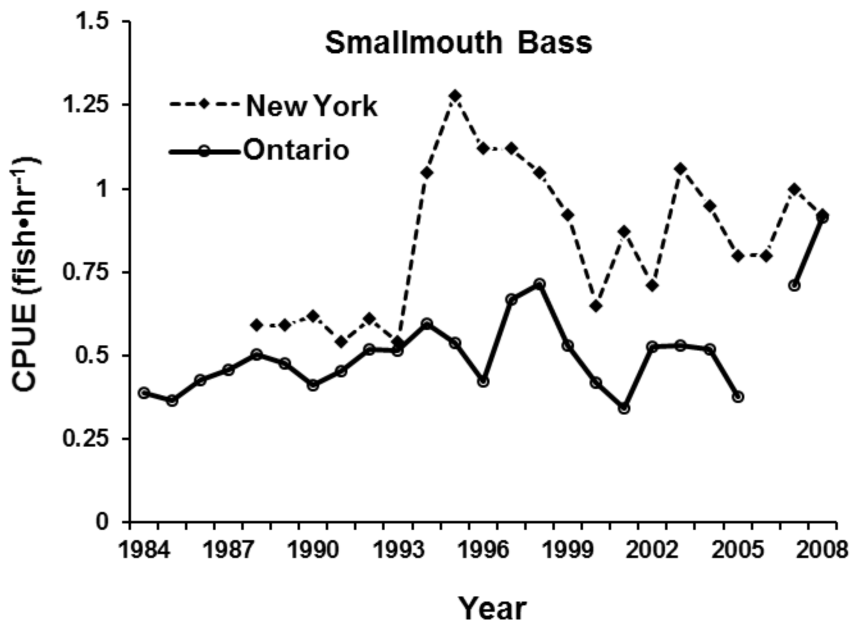
Annual gillnet assessments indicate that smallmouth bass numbers (all ages) remained relatively high during 2004-2008 as compared to earlier years in both New York and Ontario waters of the eastern basin (Fig. 17). Young (ages 1 and 2) and old (ages ≥8) fish made up a higher proportion of catches from New York waters than in catches from Ontario waters. Ontario assessments show a three-year period of decreased abundance from 2004 to 2006 followed by increased abundance in 2007 and 2008 (Fig. 17). Smallmouth bass recruitment during 2004-2008 was similar to, or higher than, historical levels in New York waters and similar to, or lower than, historical levels in Ontario waters.

Fig. 17. Relative abundance of various age groups of smallmouth bass in two areas of Lake Erie's eastern basin—Long Point Bay in Ontario and waters of the open lake in New York—based on catch-per-unit effort (CPUE; fish•km net^{-1} in Ontario and fish•net^{-1} in New York) in index gillnets, 1981-2008. Netting was conducted by the Ontario Ministry of Natural Resources and Forestry (OMNRF) in Long Point Bay and by the New York State Department of Environmental Conservation (DEC) in open New York waters of the basin.


Smallmouth Bass
Long Point Bay - OMNRF
Age Group
unknown
≥8
3 - 7
1 - 2
CPUE (fish•km net-1)
0
20
40
60
80
100
1989
1993
1997
2001
2005
New York Waters - DEC
CPUE (fish•net-1)
0
10
20
30
40
50
1981
1985
1989
1993
1997
2001
2005
Year

Angling effort and catch decreased across eastern-basin sport fisheries for smallmouth bass during 1999-2008. Smallmouth bass anglers in New York waters released 94% or more of bass caught, whereas anglers in Ontario waters released about 27%, on average, of the bass caught. Catch per hour of smallmouth bass by anglers was higher in New York than Ontario, particularly after 1994 when New York opened the previously closed spring months to bass fishing (Fig. 18).

Fig. 18. Catch-per-unit effort (CPUE; fish•hr^{-1}) of smallmouth bass by anglers in Ontario and New York waters of Lake Erie's eastern basin, 1984-2008. Note that New York instituted a spring catch and release fishery for smallmouth bass in 1994 that permitted a daily harvest of one bass ≥15 inches (1994-2006) or ≥20 inches (2007-2008) long.

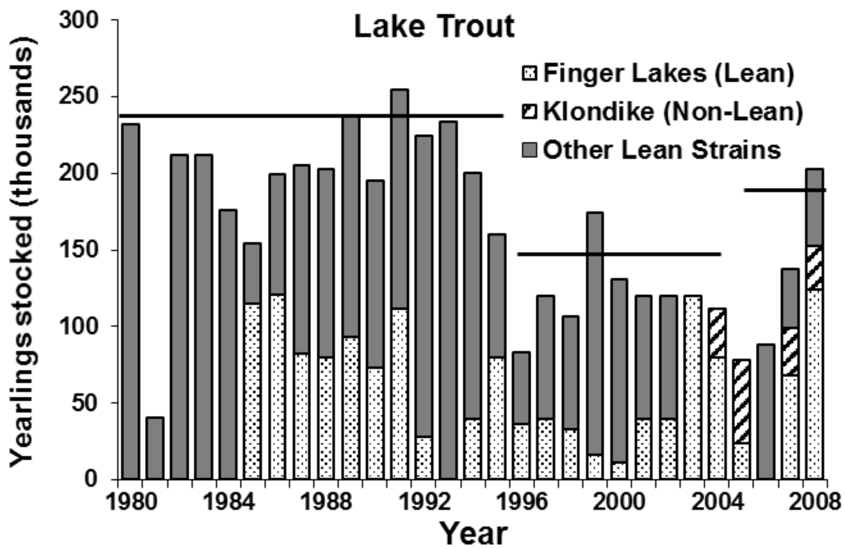


Lake Trout

Lake trout diets in the eastern basin during 2004-2008 differed from their diets in previous years. Prior to 2002, rainbow smelt was the predominant prey of lake trout. In 2002, round goby was first observed in lake trout diets, and its occurrence increased thereafter (CWTG 2009). During 2004-2008, lean-strain lake trout ate mostly rainbow smelt (55-88%, frequency of occurrence), but round goby increased from 15% to 55% (frequency of occurrence) during the five-year period. Non-lean (Klondike) strain lake trout ate fewer rainbow smelt (35-60%) and more round goby (35-65%) than lean-strain fish in 2004-2008. Despite the diet shift, lake trout growth was fast and condition was high, just as they have been since the early 1990s in eastern Lake Erie (CWTG 2009). Klondike-strain lake trout grew slower than lean-strain lake trout, and, at age 4, they were on average 51-mm shorter and 737-g lighter than lean fish (CWTG 2009).

No native stocks of lake trout are known to exist in Lake Erie. Decades of over-exploitation, pollution, loss of habitat, and invasive species caused their extirpation around 1965 (Hartman 1972; Christie 1974; Cornelius et al. 1995). Modern-day restoration efforts began in 1969 with the stocking of 17,000 yearlings by the Pennsylvania Fish and Boat Commission, but annual stockings and directed assessment programs did not begin until 1980 (Cornelius et al. 1995). The initial rehabilitation objective of establishing an adult lake trout population was successful due to annual stockings of 200,000 yearlings during 1980-1995 (Fig. 19) and sea lamprey control. Effective sea lamprey control and continuous stocking allowed the adult population to expand and, by the early 1990s, spawning occurred on nearshore reefs and in harbors (Culligan et al. 1995; Fitzsimons and Williston 2000). However, cuts to stocking in 1996 (Einhouse et al. 1999) and relaxation of sea lamprey control (Sullivan et al. 2003) during the mid-1990s caused adult abundance by 2000 to rapidly decline to levels witnessed before control began. Stocking has since increased in more-recent years (Fig. 19), but efficacious sea lamprey control remains elusive. A revised Lake Erie Lake Trout Rehabilitation Plan was completed in 2008 (Markham et al. 2008), and it provides population targets for restoring a viable population of lake trout.

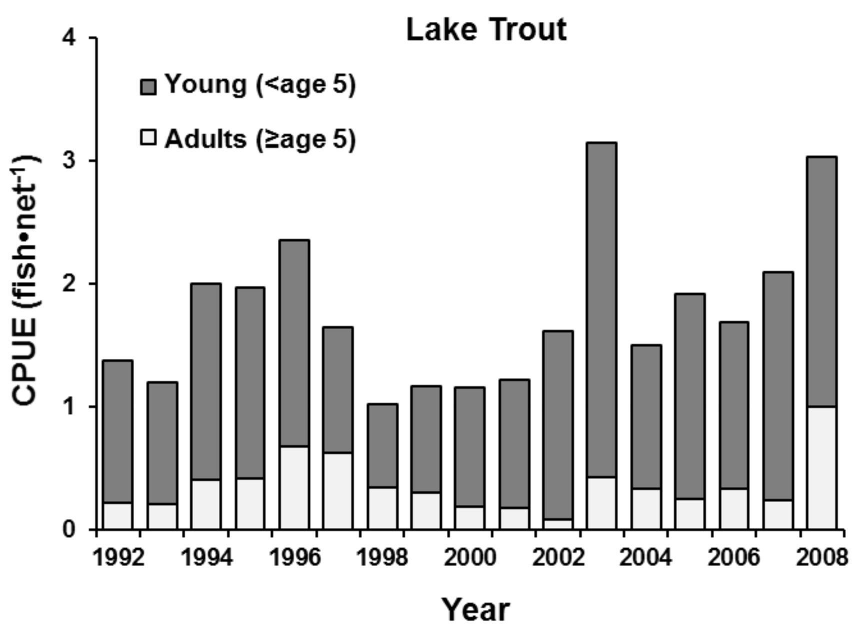
Fig. 19. Numbers of lean lake trout of various strains and non-lean lake trout of Klondike strain stocked in the eastern basin of Lake Erie, 1980-2008. Stocking numbers are shown as yearling equivalents. Nearly all lake trout were stocked as spring yearlings, and the numbers stocked as fall fingerlings were reduced by 59% to approximate an equivalent stocking of spring yearlings (fingerling to yearling survival for stocked lake trout in Elrod et al. 1988). Lean strains of lake trout stocked other than the Finger Lakes strain were Lake Superior, Lewis Lake, Clearwater Lake, Slate Island, Traverse Island, Lake Manitou, Lake Ontario, and Lake Erie. Horizontal black lines indicate stocking goals during 1980-1995, 1996-2004, and 2005-2008.



The abundance of lake trout steadily increased in the eastern basin after 2001 but was well below the rehabilitation target of 8 fish•net^{-1} (all ages) during 2004-2008 (Fig. 20). Abundance of adult (≥age 5) lake trout peaked in 2008 but remained well below the rehabilitation plan's goal of 2 adult fish•net^{-1}. After 2001, young (<age 5) lake trout dominated assessment

catches, and lake trout >age 10 composed <3% of the overall catch. Lake trout of all ages were more abundant in New York waters than in Pennsylvania and Ontario waters, coinciding with stocking locations and limited movement of stocked fish around the basin. Despite more than 25 years of stocking lake trout into Lake Erie's eastern basin, no naturally reproduced lake trout have been documented.

Fig. 20. Relative abundance of adult (≥age 5) lake trout and all lake trout in Lake Erie's eastern basin based on the sum of weighted catch-per-unit efforts (CPUE; fish•net-^{1}) in standard assessment gillnets set in three zones that comprise the cold-water sampling area, 1992-2008. The CPUE in each zone is weighted by the proportion of area >20 m deep in the eastern basin that lies within that zone: Pennsylvania waters (22%), Ontario waters (55%), and New York waters (23%).



Much of the increase in lake trout abundance in the eastern basin during 2004-2008 was due to lake trout of the Klondike strain, a deep-water spawning strain from Lake Superior first stocked into Lake Erie in 2004 (Fig. 19). These fish were the first stockings of a non-lean form of lake trout in the Great Lakes. Returns of Klondike-strain fish have been excellent through age 5, averaging more than two times higher than paired stockings of Finger Lakes strain lake trout. Klondike was the most-abundant strain of lake trout in 2008 cold-water assessments despite having been stocked in limited numbers since 2004.

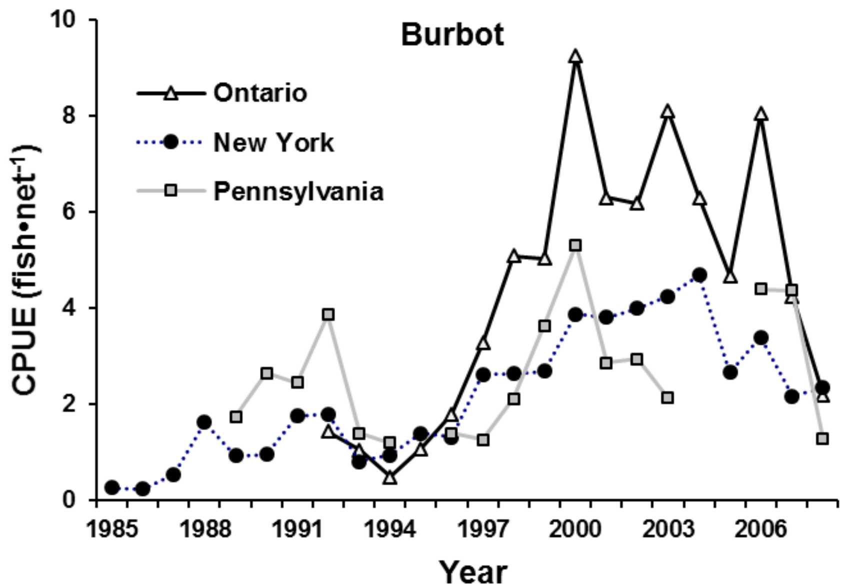
Angler harvest of lake trout in Lake Erie remains very low and appears to be decreasing (CWTG 2011). Average annual harvest from New York and Pennsylvania waters was lower during 2004-2008 (297 fish) than during 1999-2003 (324 fish). Much of the harvest during 2004-2008 occurred in 2004 (895 fish); thereafter, the annual harvest ranged from 108 to 214 fish. Lake trout remain a protected species for the commercial fishery in Ontario, and records of bycatch mortality are not available.

Burbot

Burbot diets in the eastern basin during 2004-2008 differed from diets in previous years due to the invasion of round goby. Prior to 2000, rainbow smelt dominated the diets of burbot with frequency of occurrence as high as 90% in August samples (CWTG 2009). Round goby was first detected in burbot diets in 2000, two years earlier than in lake trout diets, and goby became the main prey of burbot by 2003. During 2004-2008, round goby was found in 40-80% of burbot stomachs. Rainbow smelt remained a common prey, and emerald shiner, gizzard shad, alewife, and yellow perch were eaten occasionally. The shift in diet did not affect growth and condition of adult burbot.

Burbot made a startling recovery in eastern Lake Erie during the mid- to late 1990s due mainly to improved water quality and control of the sea lamprey population (Stapanian et al. 2006). In addition, the large numbers of adult lake trout during 1996-1997 buffered burbot from sea lamprey predation, increasing survival of young adult burbot to spawning age (Stapanian and Madenjian 2007). Annual gillnet surveys conducted by the OMNRF in partnership with the Ontario Commercial Fisheries' Association and by state agencies (Fig. 21) indicate that burbot abundance and biomass declined from 2003 to 2008 (CWTG 2009). This decline was attributed to the combined effects of an aging adult population and a severe reduction in recruitment after 2001 (Stapanian et al. 2010a).

Fig. 21. Burbot relative abundance in Ontario, New York, and Pennsylvania waters of Lake Erie's eastern basin based on gillnet catch-per-unit effort (CPUE; fish•net^{-1}), 1985-2008 (CWTG 2009).



Little is known about burbot reproduction in Lake Erie. Nearshore areas, such as Presque Isle and stream mouths in New York, appear to be important spawning habitats during late fall and winter. Stapanian et al. (2010a) speculate that recruitment declines from 2001 through 2008 were due to increased predation on burbot fry and eggs by an increasing yellow perch population, and/or the effects of warm-water temperatures in winter (i.e., reduced number of days for optimal spawning and egg development and increased destruction of eggs by turbulence because of little ice cover). Warm winters have been associated with lower reproductive success in burbot populations worldwide, particularly near the southern extent of its range (Stapanian et al. 2010b).

The average annual commercial yield of burbot declined 93% in the eastern basin from 1999-2003 (42,048 kg) to 2004-2008 (3,138 kg) (Table 6). However, yields during 1999-2003 were driven by the development of a new market such that over 183,000 kg of burbot were harvested commercially in 1999. The market did not persist. Annual yields fell from 15,000 kg in 2000 to <2,000 kg in 2004 and remained low through 2008 (Table 6). Burbot composed <1% of the total fisheries yield in the eastern basin during 2004-2008 compared to 2% in 1999-2003.

Table 6. Annual yield (thousands of kg) of various fish species from commercial and sport fisheries in Pennsylvania, New York, and Ontario waters of Lake Erie's eastern basin during 2004-2008. Also shown are the average annual yields for 1999-2003 and 2004-2008.

Species	Year					Averages	
	2004	2005	2006	2007	2008	2004-2008	1999-2003
Burbot	4	6	2	2	1	3	42
Channel catfish	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Freshwater drum	2	1	< 1	< 1	< 1	1	2
Lake whitefish	8	9	9	117	114	51	37
Rainbow smelt	1,744	929	788	2,037	1,312	1,362	1,680
Walleye	32	57	151	100	103	89	119
White bass	8	2	3	13	26	11	4
White perch	2	2	7	9	9	6	1
Yellow perch	91	132	152	108	142	125	43
Total	**1,894**	**1,140**	**1,116**	**2,388**	**1,709**	**1,647**	**1,927**

Steelhead

Steelhead are pelagic predators in the open waters of the eastern basin competing mainly with walleye in this niche. A lakewide study of steelhead diets in June-October 2004 showed that they are opportunistic feeders on fish and invertebrates (Clapsadl et al. 2006). About 93% of the 44 stomachs with food from the eastern-basin samples were collected in August and September. Eastern-basin steelhead ate mostly fish (>99% of dry weight biomass) and some (<5% frequency of occurrence) invertebrates (*Bythotrephes longimanus* (spiny water flea) and *Dreissena* spp.). Rainbow smelt was the most-common prey, occurring in 68% of the stomachs and making up 43% of diet biomass (dry weight). Round goby was found in 20% of the stomachs but provided 50% of diet biomass (dry weight) owing to a fish that ate 18 of them. Shiners made up about 5-10% (occurrence and biomass) of the diet. In general, rainbow smelt dominated steelhead diets in eastern Lake Erie, whereas shiners became increasingly important in more-westward areas. Round goby was a minor contributor to the diet lakewide but was more frequently eaten by steelhead in the eastern basin than by steelhead in the two other basins. Steelhead growth did not change throughout 2004-2008.

The non-indigenous steelhead was introduced into Lake Erie by the state of Michigan in 1882, and all jurisdictions were stocking this species by 1929 to support recreational fisheries (Kustich and Kustich 1999; Crawford 2001). Various strains of steelhead have been stocked (Crawford 2001). Pollution, invasive species, and nominal amounts of stocking kept steelhead populations low through the 1960s (Kustich and Kustich 1999). Successful results from stockings in 1975 prompted increased stocking by the early 1980s (CWTG 2004). About 568,000 yearling steelhead were stocked annually in U.S. streams and harbors of the eastern basin during 1999-2008 (CWTG 2009). Some natural reproduction occurs in several New York and Ontario streams (Gordon and MacCrimmon 1982; Einhouse et al. 2007), but natural recruitment is minimal and insufficient to sustain stocks owing largely to unsuitable habitat in the tributaries.

Eastern-basin tributaries are the core of Lake Erie's steelhead sport fishery, an increasingly popular fishery that provides exceptionally high catch rates. Creel surveys conducted in Pennsylvania (Murray and Shields 2004) and New York (Markham 2006; Markham 2008) confirm that the majority of steelhead angling occurs in the tributaries when fish move from the lake into the streams to spawn. During fall 2003 to spring 2004, total angling effort in New York tributaries was around 200,000 angler hours and, in Pennsylvania tributaries, nearly 600,000 angler hours. Catch rates of steelhead in both jurisdictions were nearly identical, hovering around 0.60 fish•hr^{-1} (Fig. 22). Since the late 1990s, steelhead catch rates of diary cooperators fishing New York waters have steadily increased in tributaries while catch rates in the open water of the eastern basin have remained steady (Fig. 23).

Fig. 22. Catch-per-unit effort (CPUE; fish•hr^{-1}) of steelhead by anglers in tributaries to, and the open waters of, Lake Erie's eastern basin, 1990-2008. Catch rates in New York (NY) are from angler diaries and tributary creel surveys conducted from fall to spring in 2003-2004, 2004-2005, and 2007-2008, whereas catch rates in Pennsylvania (PA) are from a tributary creel survey conducted from fall to spring in 2003-2004.

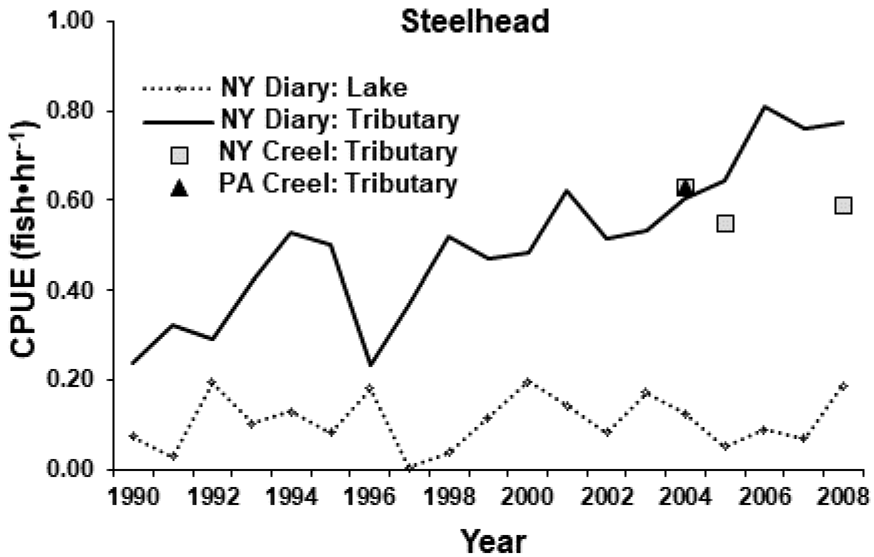
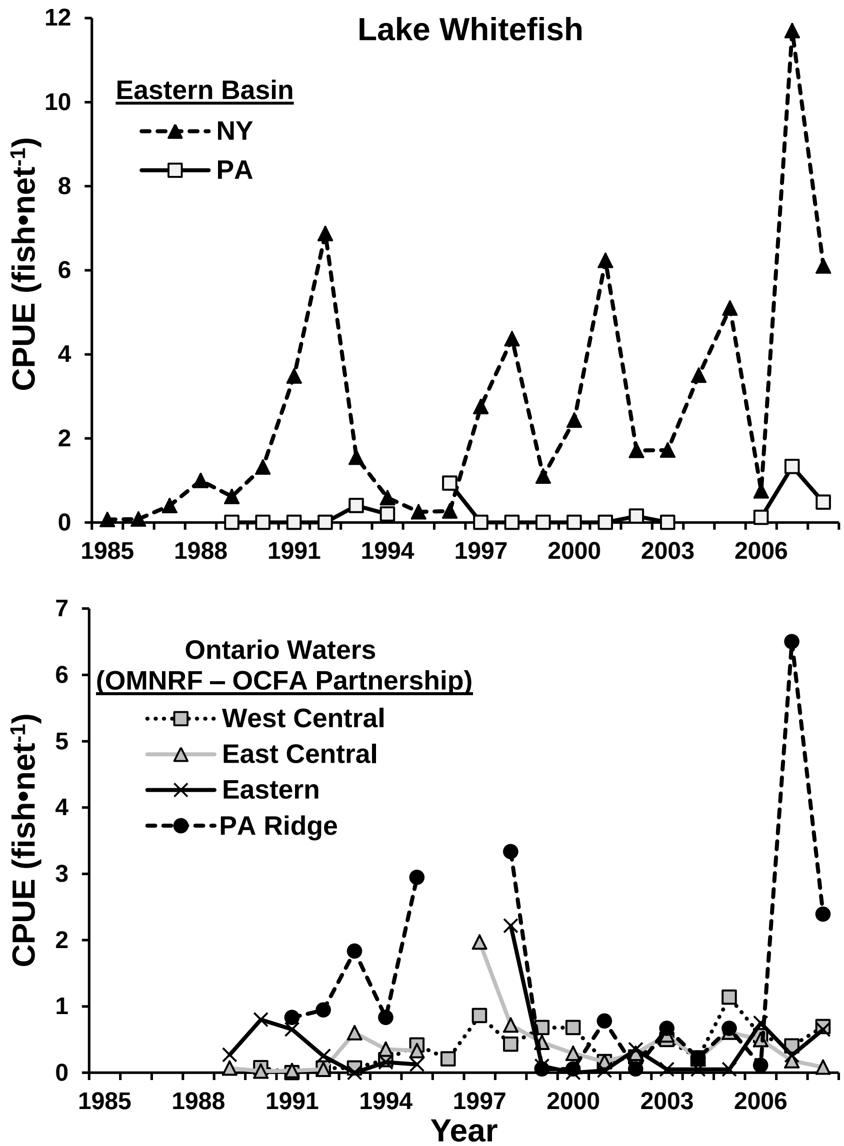


Fig. 23. Lake whitefish relative abundance in various areas of Lake Erie based on gillnet catch-per-unit effort (CPUE; fish•net^{-1}), 1985-2008. Top panel: relative abundance in New York (NY) and Pennsylvania (PA) waters of the eastern basin. Bottom panel: relative abundance in Ontario waters of the eastern basin, west and east central sub-basins, and along the Pennsylvania Ridge that separates the central and eastern basins. Assessments in Ontario waters were conducted by the Ontario Ministry of Natural Resources and Forestry (OMNRF) in partnership with the Ontario Commercial Fisheries' Association (OCFA). Note that scales of the two panels differ.


Lake Whitefish
Eastern Basin
NY
PA
CPUE (fish•net-1)
0
2
4
6
8
10
12
1985
1988
1991
1994
1997
2000
2003
2006
Ontario Waters
(OMNRF – OCFA Partnership)
West Central
East Central
Eastern
PA Ridge
0
1
2
3
4
5
6
7
Year

Lake Whitefish

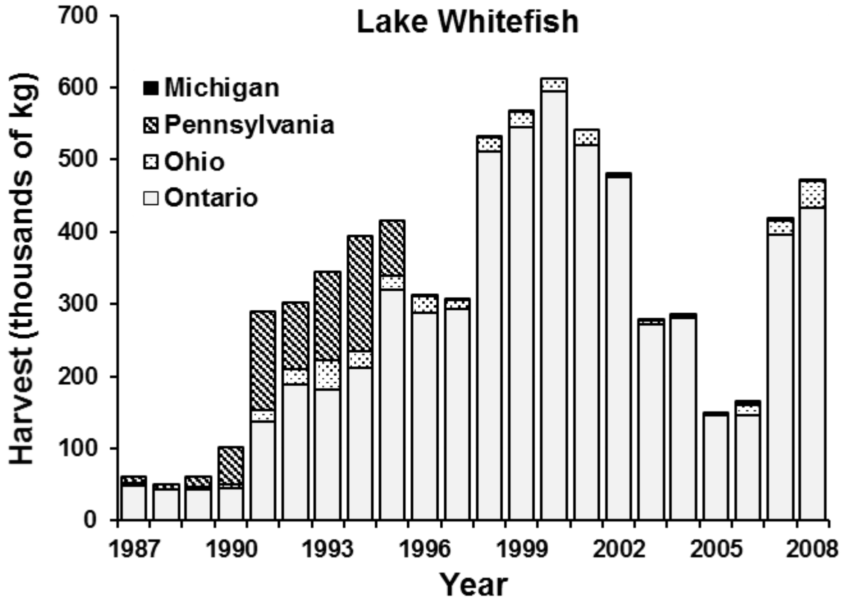
Diet information is scant for lake whitefish in the eastern basin. Data from Ohio waters of the central basin likely are representative of the eastern-basin diet during 1999-2008. Generally, lake whitefish of all ages were opportunistic feeders eating a variety of organisms in the central basin. Lake whitefish >360 mm total length were largely benthivorous feeding mainly on Chironomidae, Isopoda, Sphaeriidae, and *Dreissena* spp. (CWTG 2007). Round goby was a minor (<5% dry weight biomass) component of the lake whitefish diet (CWTG 2009). The relative importance of these prey to the diet varied among years with no obvious pattern during 1999-2008. However, mean condition (Fulton's K) for age-4 and older male and female lake whitefish declined during 2004-2008 after increasing during 1999-2003 and, during 2006-2008, was consistently below historical (1927-1929) values reported by Van Oosten and Hile (1947) for both sexes (CWTG 2009). The change in condition appears cyclic and may be a density-dependent response to a dominant 2003 year-class.

Lake whitefish spawn on shallow rocky substrates in late fall throughout Lake Erie (Goodyear et al. 1982). Major spawning aggregations and associated commercial fisheries persist in some of the areas used historically, such as in Michigan waters and in Ohio waters of Maumee Bay, Ohio, reefs in the western basin, various reefs around the western-basin islands (Ohio and Ontario waters), and near the mouth of the Detroit River. By 1900, many spawning runs had deteriorated due to over-exploitation and environmental degradation (Trautman 1981), and most fisheries collapsed by 1960 (Regier and Hartman 1973). Of the native salmonids, only lake whitefish has recovered to any extent following elimination of over-exploitation and improvement of the poor water quality after the early 1970s (Markham 2009).

Abundance of adult lake whitefish varies across seasons within each of Lake Erie's three basins. In fall, the fish migrate from the eastern basin to spawning grounds in the western basin and then return back to the cold hypolimnetic waters of the eastern basin by summer of the following year. Accordingly, fishery effort and harvest vary among seasons and basins. Standardized gillnet assessments of lake whitefish abundance are conducted along the Pennsylvania Ridge in the eastern basin and in the west central and east central sub-basins. In Ontario waters, lake whitefish abundance ($fish•net^{-1}$) was low during 1999-2003 at all sites before increasing in Pennsylvania Ridge assessments during 2004-2008 (Fig. 23). In New York waters, annual gillnet catches averaged 1-6 $fish•net^{-1}$ during 1999-2003 and 1-12 $fish•net^{-1}$ during 2004-2008 (Fig. 23). Assessments in Pennsylvania waters produced low catches (<1 $fish•net^{-1}$) of lake whitefish in all years except 1996 and 2007. Collectively, gillnet assessments indicated that lake whitefish abundance during 2007-2008 was among the highest since the mid-1980s and was higher in the eastern basin than in the central basin. Recruitment was inconsistent during 1999-2008 with a strong year-class produced in 2003 and moderate year-classes in 2001 and 2005 (CWTG 2009).

Commercial harvest of lake whitefish in Lake Erie was moderate in 2004-2008 relative to years since 1987 (Fig. 24). Lakewide, the annual harvest during 2004-2008 averaged 297,676 kg, similar to the mean harvest from 1987 to 2003 but only 60% of the average annual harvest in 1999-2003 (495,755 kg). A harvest of 470,587 kg in 2008 was the highest yield since 2000 when over 610,000 kgs were harvested. (CWTG 2009). In most years during 1999-2008, a majority (~50%) of the annual commercial harvest was taken with gillnets in Ontario waters of the western basin during fall, although harvest by a winter fishery in the west central sub-basin was at times similar in magnitude. Eastern-basin commercial harvest was >99% in Ontario waters where it made up 4% (1999-2003) to 14% (2004-2008) of the average annual yield of lake whitefish to Ontario fisheries lakewide. In Ohio, >90% of the average annual trapnet harvest of lake whitefish occurred in November, and harvest increased slightly from 14,200 kg in 1999-2003 to 15,400 kg during 2004-2008 but with a decadal peak of 37,600 kg in 2008. The Pennsylvania trapnet fishery typically harvested <1% of the lakewide yield of lake whitefish. Catch rates ($kg•km\ gillnet^{-1}$ or $kg•trapnet\ lift^{-1}$) generally declined during 1999-2003 and increased during 2004-2008 in Ontario and Ohio commercial fisheries (CWTG 2009).

Fig. 24. Total commercial harvest (thousands of kg) of lake whitefish from Lake Erie showing the amount of harvest from waters in Michigan, Pennsylvania, Ohio, and Ontario, 1987-2008. Gillnetting ceased in Pennsylvania waters in 1996, and commercial fishing resumed in Michigan waters in 2006 and 2007.



Rainbow Smelt

Rainbow smelt remain a valuable commercial species in Ontario waters of the eastern basin and is important in the food web as both predator and prey. Rainbow smelt have a broad diet, including zooplankton, macroinvertebrates, and fish larvae and juveniles and thus are a potential competitor and predator to other planktivores (Pothoven et al. 2009 and references within). Rainbow smelt undergo an ontogenetic diet shift from small zooplankton to larger zooplankton, macroinvertebrates, and finally to fish (Bidgood 1961; Pothoven et al. 2009). The composition of the diet of rainbow smelt in eastern Lake Erie has changed since the 1960s, reflecting food resource shifts in the zooplankton community due to phosphorus reductions and invasion of exotic species, such as *Bythotrephes longimanus* (Parker Stetter et al. 2005). Various studies have shown that, when abundant, the rainbow smelt has the ability to suppress or hinder the recovery of a variety of species, including lake whitefish (Hardy 1994), blue pike (Regier et al. 1969), and cisco (Leach and Nepszy 1976; Stockwell et al. 2009; Myers et al. 2009). Despite rainbow smelt abundance being much lower than it was during the 1970s, it remains sufficiently abundant to influence the eastern-basin zooplankton community and overall food web.

Bottom-trawl surveys conducted in New York and Ontario waters indicate decreases in the average density of adult rainbow smelt during 2004-2008 as compared to 1999-2003 (FTG 2009). Average adult density during 2004-2008 ranged from near zero to 550 fish•ha^{-1}. Acoustic assessments of fish density in the eastern basin conducted in 2007 and 2008 produced mean densities of 1,754 and 7,519 fish•ha^{-1}, respectively, of "rainbow smelt sized" fishes.

Rainbow smelt made up a majority (83-87% of the average annual yield) from eastern-basin fisheries during 2004-2008 and 1999-2003 (Table 6). During 2004-2008, the annual commercial harvest of rainbow smelt in the eastern basin averaged 1.4 million kg, roughly 19% lower than the average yield (1.7 million kg) during 1999-2003 and 40% less than the average commercial harvest of smelt in the central basin (2.2 million kg).

Sea Lamprey

Mortality from sea lamprey attacks hinders lake trout rehabilitation and affects other species such as burbot and lake whitefish. Over 20 years of binational sea lamprey control in Lake Erie have produced mixed results. A control program was first implemented on Lake Erie in 1986 and, by 1987, all major sea lamprey producing streams were treated with the selective lampricide, 3-trifluoromethyl-4-nitrophenol (TFM). Suppression of sea lamprey was nearly immediate with declines in lake trout marking rates and sea lamprey abundance and increases in lake trout survival by 1989 (Fig. 25; Sullivan et al. 2003; Sullivan and Fodale 2009). However, sea lamprey rebounded to near pre-control levels of abundance by the late 1990s due to changes in criteria for selecting streams for TFM treatment, new techniques for TFM application (adopted, in part, to reduce mortality of non-target organisms), reduced numbers of post-treatment assessments, and species shifts in the fish community that increased the number of hosts available to lamprey (Sullivan et al. 2003). Additionally, intentional efforts to reduce TFM use (Brege et al. 2003) likely contributed to a greater number of sea lamprey ammocoetes surviving stream treatments. More streams were treated with TFM during 1999-2002 causing a decline in the number of adult sea lamprey and lake trout marking. However, the number of adult sea lamprey returned to pre-control levels by 2005 and remained at these levels through 2007 (Fig. 25). Most streams with sea lamprey production were treated during 2005-2006, and, in 2008, the abundance of adult sea lamprey declined sharply.

Despite increases in treatment effort since 2000, sea lamprey abundance exceeded the target of 3,039 adults in three of the five years between 2004-2008 (Fig. 25). Average abundance of sea lamprey in Lake Erie increased from 7,140 to 11,452 spawning-phase adults between 1999-2003 and 2004-2008 (CWTG 2009).

Sea lamprey marking rates on lake trout have exceeded the target of 5 marks per 100 fish (>532 mm) since 2002 (Fig. 26; CWTG 2009). The average rate of sea lamprey marks (Type A, Stages I, II, and III marks; Ebener et al. 2006) on lake trout >532 mm increased slightly (12.0 to 13.0 per 100 fish) from 1999-2003 to 2004-2008, and, during 1999-2008, the target of <5 marks per 100 fish was achieved only in 2002 (CWTG 2009). In addition, the average frequency of Type A, Stage IV marks on lake trout rose from 18.2 to 43.0 marks per 100 fish from1999-2003 to 2004-2008. Marking rates on burbot were higher during 2004-2008 (0.5 to 16.0 per 100 fish) than in 2001-2003 (1.0 to 4.0 per 100 fish), but marking rates on lake whitefish in 2004-2008 (<0.2 to 1.5 per 100 fish) were similar to those in 2003 (0.9 per 100 fish) (CWTG 2009).

Fig. 25. Adult sea lamprey abundance (thousands ±95% confidence interval) in Lake Erie, 1980-2008. The horizontal lines show the target of 3,039 ± 1,000 for adult sea lamprey.

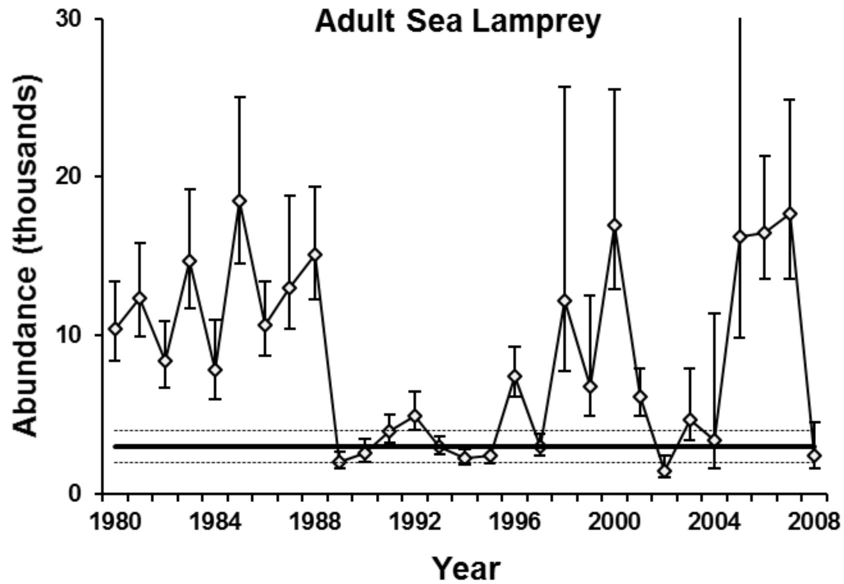
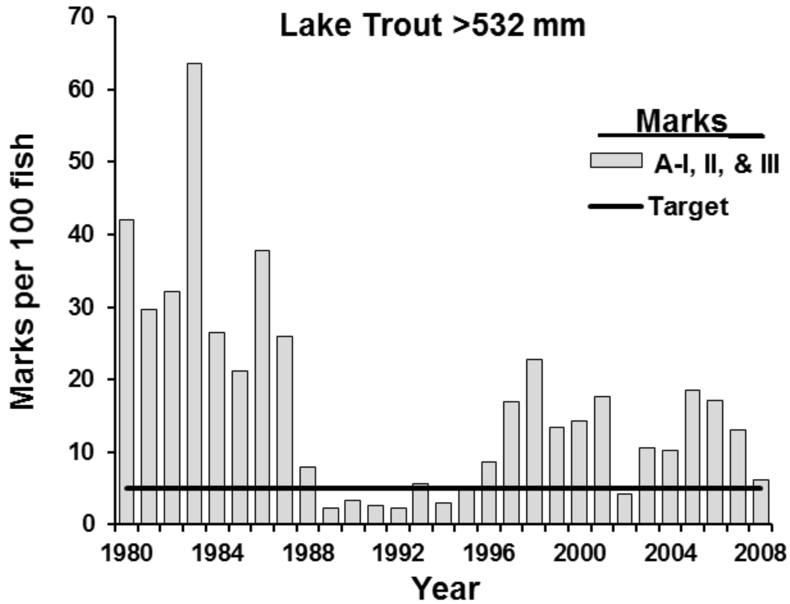


Fig. 26. Frequency of Type A, Stages I, II, and III marks (A-I, II, and III; Ebener et al. 2006) on lake trout >532 mm (21 inches) in the eastern basin of Lake Erie during August-September, 1980-2008. The horizontal line shows the target of 5 marks per 100 lake trout >532 mm.



The effect of the sea lamprey population is particularly evident in the adult lake trout population in the eastern basin of Lake Erie. Marking data from Lake Erie (CWTG 2009) validate sea lamprey preferences for large (>609 mm) hosts when available (Swink 2003). As a result, the abundance of sexually mature lake trout remains suppressed, hindering not only the prospects for successful natural reproduction but also of having a cold-water food web with a functionally important terminal predator.

A new back-to-back treatment strategy, similar to the very-successful strategy that was initially used to treat Lake Erie in 1986-1987, was implemented in 2008 to reduce sea lamprey abundance and lake trout marking to their targets. All nine sea lamprey producing tributaries were treated with TFM in the spring of 2008 and were scheduled for treatment again in the fall of 2009. The effects of this treatment strategy should be evident beginning in 2010.

Other Species

Targeted monitoring of other fish species (e.g., channel catfish, freshwater drum, white bass, and white perch) is not conducted by any Lake Erie Committee (LEC) agency in the eastern basin, but these species are harvested by basin fisheries (Table 6). Because most commercial or recreational fisheries do not target any of these fishes in the eastern basin, they are usually harvested as “bycatch,” and thus trends in yields to the fisheries provide only coarse indicators of their abundance. Average annual yield to eastern-basin fisheries declined from 1999-2003 to 2004-2008 for freshwater drum (1,878 to 600 kg) and channel catfish (328 to 275 kg,) but increased substantially for white perch (953 to 5,912 kg) and white bass (3,926 to 10,521 kg). Collectively, these four species accounted for <3% of the total annual yield of fishes in both five-year periods.

Progress: Eastern-Basin Fish Community Objectives

For the eastern basin, Tyson et al. (2009) recommended that the LEC of the Great Lakes Fishery Commission continue to: 1) support increases in lake trout stocking rates despite a lack of natural reproduction, 2) keep sea lamprey control as a management priority to achieve lake trout restoration and to minimize impacts on lake sturgeon and burbot, and 3) assess offshore habitats to determine how much is needed to support reef-spawning fishes, including walleye, coregonines, and offshore-spawning yellow perch. All of these recommendations were addressed to some extent during 2004-2008 and will be carried forward for 2009-2015 (see Recommendations section below). Specific examples of actions related to these recommendations include increases in stocking rates for lake trout from 2004 through 2008 (Fig. 19), the development of a Lake Erie Lake Trout Rehabilitation Plan in 2008, annual assessment of sea lamprey marks on lake trout and burbot, and mapping of Brocton Shoal (see Fig. 5 in Environmental Objectives and Habitat chapter in the full report). Other actions toward the recommendations of Tyson et al. (2009) are included in the following assessment of progress toward the fish community objectives.

Food-Web Structure and Forage-Fish Dynamics

When compared to the other two basins, the base of the eastern-basin food web was relatively stable through 2008, reflecting the top-down structuring influences of *Dreissena* spp. and less inter-annual variation in bottom-up (nutrient) influences (see Environmental Conditions chapter in the full report). Recent increases in phosphorus levels in the nearshore have moved the eastern basin into a mesotrophic range, and water clarity has declined to near the target level. In the offshore, the targeted oligotrophic status is generally being met for phosphorus and water clarity. Overall, the forage-fish community remained stable, abundant, and diverse through 2008, supporting cool-water and cold-water predators, and high predator growth rates.

Habitat Objectives

Actions to improve fish habitat, or access to habitats, in the eastern basin are summarized in Gorman and MacDougall (2017). Although these actions are important, nutrient management to maintain the nearshore in a mesotrophic condition remains a priority in the eastern basin in light of increasing total phosphorus loads to the lake and the presence of abundant *Dreissena* spp.

Fish Stocks and Genetic Diversity

The intent of the Genetic Diversity Objective is to protect or improve locally adapted indigenous fish stocks through management of habitat and fishery exploitation. Fine-scale stock structure may exist for several species in the eastern basin, including walleye, yellow perch, smallmouth bass, and lake whitefish, given the diverse nearshore habitats in the basin and a large hypolimnion that may act as a thermal barrier to movements of cool-water species. However, current understanding of stock structure is hampered by limited assessment data on stock structure and an inability to distinguish individuals from mixed-stock samples. Therefore, little knowledge was gained about biological, genetic, and behavioral differences among local stocks of any fish species during 2004-2008. Research on stock identification that is underway for walleye will help elucidate stock structure for that species, and any techniques that are successful may also be applicable to other species in the eastern basin. Efforts to address fish production from habitats and to maintain relatively conservative fishery exploitation are also considered partial achievement of the Genetic Diversity Objective.

Rare, Threatened, and Endangered Species

Collections of cisco in the eastern basin from 1995 through 2008 spurred the LEC to consider stocking to boost population recovery. Major actions toward the Rare, Threatened, and Endangered Objective during 2004-2008 included participation in a 2006 workshop that examined the Lake Superior model of cisco management, comparison of genotypes of current eastern-basin cisco with those from historic Lake Erie samples and extant Lake Huron fish, and charges from the LEC in 2007 to the Cold Water Task Group to develop a cisco rehabilitation plan. Sightings of lake sturgeon remain rare in eastern-basin assessments. However, divers frequently film lake sturgeon in the upper Niagara River, suggesting that lake sturgeon are more common than the assessments indicate. Lake sturgeon remained protected from harvest by all fisheries in Lake Erie during 1999-2008.

Productivity and Yield from Eastern-Basin Fisheries

Eastern-basin fishery yields averaged 1.6 million kg during 2004-2008 as compared to 1.9 million kg in 1999-2003 (Table 6). Most (>97%) of the yield was composed of high-value species (e.g., walleye, yellow perch, lake whitefish, rainbow smelt, and white bass) in 1999-2003 and 2004-2008. The decline in yield between five-year periods was entirely attributable to lower harvests of walleye (25%) and rainbow smelt (19%). On average, eastern-basin fisheries accounted for 11% of the 14.4 million kg lakewide yield of high-value species during 2004-2008 compared to 14% of 13.8 million kg in 1999-2003.

Recommendations

1. Continue development of a population model for eastern-basin walleye that accommodates extant knowledge of resident stocks, their movements, and their contribution to the lakewide fishery.

2. Continue research on quality spawning habitat and its availability for walleye, lake trout, yellow perch, burbot, and smallmouth bass, particularly to inform habitat improvement and fish-passage projects.

3. Maintain high levels of stocking of lake trout and distribute stockings more evenly around the eastern basin to promote use of all available spawning habitat.

4. Continue researching factors affecting walleye and yellow perch recruitment to better understand population responses to changes in environmental conditions, habitats, and forage.

5. Continue research to better understand the early life history of burbot and the reasons for poor recruitment in recent years.

6. Develop a rehabilitation plan for cisco that outlines a framework of impediments, tasks, and procedures and the benefits and impacts that restoration could have on the lake ecosystem and fisheries.

7. Continue long-term monitoring and assessment of lower trophic levels, forage fish, and top predators to better track their responses to invasive species and emerging habitat and fish community issues, such as offshore wind turbines and climate change.

8. Foster continued study of the distribution and abundance of *Dreissena* spp. in the eastern basin.

9. Continue comprehensive treatment of all nine tributaries to the central and eastern basins that support sea lamprey production so as to minimize lamprey mortality on lake trout, burbot, lake whitefish, and steelhead.

PROGRESS, EMERGING ISSUES, AND PRIORITIES[16]

James L. Markham[17], Ann Marie Gorman, Kevin A. Kayle, Stuart A. Ludsin, Jeffrey T. Tyson, and Roger L. Knight

In the preceding chapters, updates were provided on those changes in environmental conditions and habitats in 2004-2008 that affected food webs in the three basins of Lake Erie and that elicited detectable responses in fish communities and fisheries as a means of evaluating progress toward achieving the fish community objectives (FCOs) for the lake (Ryan et al. 2003) and developing recommended actions for the next five years. As of 2008, none of the 13 FCOs were fully attained. Seven FCOs that addressed ecosystem conditions, various habitats, contaminants, and genetic diversity of fish stocks were considered to be partially achieved. Six FCOs that addressed sustainable harvests of basin-specific fish stocks, food-web structure, protection of rare fish species, and fishery yield were judged to be mostly achieved. Next, we will evaluate progress through 2008 toward

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[16]Complete publication including map of place names, other chapters, scientific fish names, and references is available at http://www.glfc.org/pubs/SpecialPubs/Sp17_01.pdf.

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achieving the two over-arching fish community goals of the Lake Erie Committee (LEC) of the Great Lakes Fishery Commission (GLFC) identify emerging issues that may jeopardize future achievement of those goals, further assess the status of fishery yield, describe recent actions to address previously identified priorities (Tyson et al. 2009), and identify new priorities of the LEC for achieving its fish community goals and objectives during 2009-2013.

Progress toward Fish Community Goals

The LEC has two broad goals that essentially call for having mesotrophic and oligotrophic conditions in Lake Erie with habitats that support balanced, well-functioning fish communities and desired fishery yields. The underlying premise of the goals and supporting FCOs is that a well-functioning food web with interactions among co-evolved species will provide stable, resilient, predictable fish communities and desired fishery yields. Accordingly, an assessment of contributions from key organisms to the Lake Erie food web, particularly in support of top predators, is a barometer of stability and predictability in the fish community and its associated fisheries. Mesotrophic waters in the western, central, and nearshore eastern basins should provide habitats for a cool-water fish community with walleye as a top predator (Goal 1). Oligotrophic deep waters offshore in the eastern basin should provide habitat for a cold-water fish community with lake trout and burbot as top predators (Goal 2).

Environmental conditions were taxing for cool-water fishes in the western half of Lake Erie during 2004-2008 following major increases in productivity to eutrophic levels after the mid-1990s, but conditions were suitable (e.g., mesotrophic) for cool-water fishes in the nearshore eastern basin. Abundance of cool-water forage fishes increased from 1999-2003 to 2004-2008 in all basins of Lake Erie. Spiny-rayed fishes increased in all basins, most noticeably age-0 white perch in the western basin. Clupeids decreased in all basins but especially in the western basin. *Notropis* and other soft-rayed fishes remained stable or increased in all basins but were more abundant in eastern Lake Erie than in the western half of the lake. Prey shifts occurred initially in the western basin (where total phosphorus (TP) increases first occurred and were strongest) followed by shifts in the central basin and lastly in the nearshore eastern basin where increases in productivity were more recent. The decline in gizzard shad is unusual given its ability to prosper in eutrophic conditions and previous abundance in western Lake Erie. Stable if not increasing populations of *Notropis*, rainbow smelt, and round goby were important to sustain the high growth rates of predators during 2004-2008, especially with increasing numbers of less-preferred spiny-rayed fishes and declining numbers of more-preferred clupeids.

The abundance and diversity (e.g., major contributions from key species) of cool-water predators increased from 1999-2003 to 2004-2008 in the central and eastern basins of Lake Erie but declined in the western basin. The standing stock of walleye in the western basin, boosted by an exceptional 2003 year-class, increased during 2004-2008, but this boost will only be temporary due to weaker recruitment from the 2004-2006 year-classes. Increases in walleye abundance in the eastern basin were attributed (in part) to improved recruitment from resident stocks. Yellow perch abundance was below-average and recruitment was weak in the western basin during 2004-2008, but perch abundance was among the highest on record in the central and eastern basins. Smallmouth bass abundance was above average in the eastern basin but low in the western basin. All three of these cool-water predators were reproducing, feeding, growing, and surviving sufficiently to support fisheries in all basins but most optimally in the mesotrophic areas of the lake.

Goal 1 was partially met in 2004-2008. The cool-water fish community persisted with walleye as the top predator lakewide and was generally stable (if not improving) in the mesotrophic nearshore of the eastern basin. However, in the eutrophic western basin, shifts in the forage-fish community and recruitment patterns for all key predators suggested an increasingly unstable food web. Improvements in environmental conditions through management of TP loads in the western basin and continued habitat restoration are needed to completely fulfill this goal. The increasing presence of white perch and round goby, both invasives, warrants further study, particularly regarding their effects on food-web structure, growth, and recruitment of cool-water predators in the presence of relatively low gizzard shad abundance.

Goal 2 was also only partially met during 2004-2008. Despite the persistence of generally suitable oligotrophic conditions in the eastern basin, the cold-water fish community lacked stability in top predator populations. Overall lake trout abundance was low but slowly improving, adult abundance remained well below rehabilitation targets, and natural recruitment was not detected. Burbot abundance was high but rapidly declining owing to failing recruitment. High mortality from sea lamprey remained an issue for lake trout and burbot. Lake whitefish were abundant, but recruitment was declining. Steelhead abundance was high due to intensified stocking in the central and eastern basin. Only lake whitefish and steelhead supported fisheries of acceptable magnitude. Cold-water predators were dependent on rainbow smelt, emerald shiner, and round goby in the absence of *Diporeia* spp. and cisco. Restoration of a naturally reproducing and abundant lake trout population and improved recruitment of burbot are needed to fulfill Goal 2. Cisco restoration also would improve food-web functionality but may require lower abundance of rainbow smelt (Tyson et al. 2009).

Fishery yield is the ultimate expression of the state of Lake Erie. The LEC's yield objective is an annual sustainable harvest of 13.6-27.3 million kg of high-value fish—walleye, yellow perch, lake whitefish, white bass, and rainbow smelt. The average annual yield of high-value species from commercial and recreational fisheries in Lake Erie during 2004-2008 was 14.4 million kg (12.9-15.0 million kg), or about 5% higher than the average annual yield (13.8 million kg) during 1999-2003. The average yield during 2004-2008 comprised 4.5 million kg of walleye, 4.4 million kg of yellow perch, 3.6 million kg of rainbow smelt, 1.6 million kg of white bass, and 0.3 million kg of lake whitefish. Relative to the average annual yields from 1999 to 2003, yields during 2004-2008 were higher for yellow perch (28%) and walleye (10%) and lower for lake whitefish (38%), rainbow smelt (9%), and white bass (7%). Most (57%) of the yield of high-value species during 2004-2008 occurred in the central basin followed by the western (31%) and eastern basins (11%), which was similar to the average distribution of yield during 1999-2003. Although the average annual yield (14.4 million kg) exceeded the minimum value (13.6 million kg) of the LEC objective during 2004-2008, annual yields fell below the objective in 2005 (12.9 million kg) and 2006 (13.2 million kg). However, annual yield estimates were not available for some species (lake trout and steelhead), fisheries (Ontario recreational), seasons (winter), and areas (various tributaries and connecting channels). Therefore, our estimates of yield are conservative.

Results from our evaluation support the contention that "maintenance of mesotrophic conditions across much of Lake Erie will provide optimal environmental conditions for a more balanced, stable, and predictable fish community with maximum potential benefits for fisheries" (Ryan et al. 2003). Further, these results support the necessary actions previously identified by Ryan et al. (2003) to address the FCOs of the LEC, e.g., "Restoration of fish-community stability can be best achieved through management to promote healthy stocks of top predators, reduction in and/or prevention of the establishment of aquatic nuisance species, and protection and/or restoration of important coastal nearshore and tributary habitats." Unfortunately, nutrient reduction in the western basin has again become a priority necessary for restoring mesotrophic conditions and allowing for effective management. In light of environmental conditions in Lake Erie during 2004-2008, stakeholder support for management of exploitation (e.g., LEC 2004; Locke et al. 2005) will be increasingly challenging but necessary to achieve long-term stability of fish populations and fisheries.

Emerging Issues

Tyson et al. (2009) identified double-crested cormorants (*Phalacrocorax auritus*) and climate change as major emerging issues from the 2004 State of the Lake Conference. Increasing numbers of double-crested cormorants in the Great Lakes region, particularly in and around Lake Erie, increased the potential for the birds to suppress fish stocks through predation. Implementation of control programs on double-crested cormorant colonies in Ohio waters of Lake Erie, Georgian Bay-Lake Huron, and various locations in Michigan during 2004-2008 has lowered LEC concerns about cormorant effects on fisheries pending continued implementation of these programs. An understanding of how climate variables (e.g., spring warming rate, precipitation, and wind speed) affect Lake Erie percid recruitment remains an important research question, especially in the western basin that, due to shallow waters, responds relatively quickly to weather events.

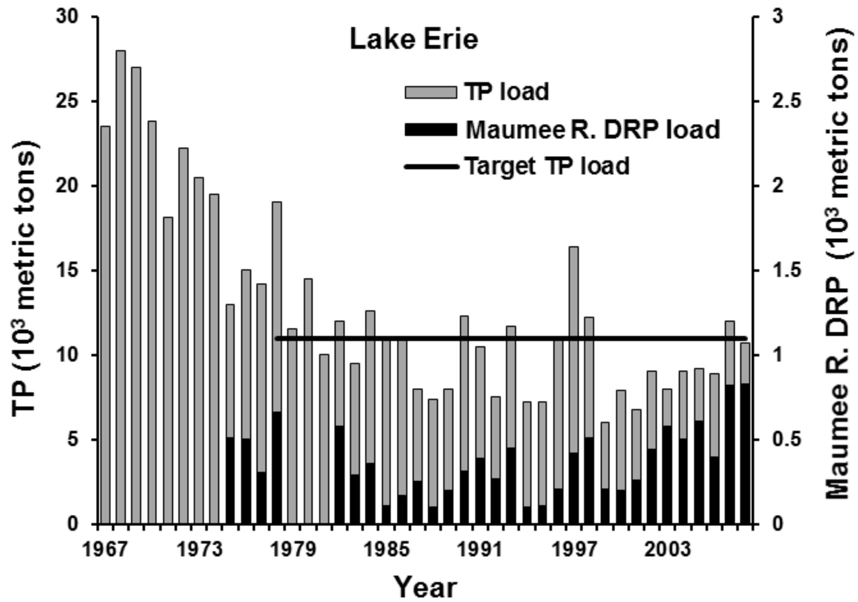
Emerging issues identified at the 2009 State of Lake Erie Conference (and discussed below) include increases in dissolved reactive phosphorous (DRP) that have precipitated harmful algal blooms; hypoxia; fish disease, in particular, viral hemorrhagic septicemia virus (VHSV); and wind-power development.

Dissolved Reactive Phosphorus and Harmful Algal Blooms

Blue-green algae (cyanobacteria) are not a new issue in Lake Erie (Anderson et al. 2002); their blooms can affect the health of humans and other aquatic organisms and thus are considered harmful. In the 1950s and 1960s, Lake Erie experienced extensive blooms of blue-green algae associated primarily with phosphorus loading from sewage treatment facilities and industrial sources. Phosphorus reduction through the Great Lakes Water Quality Agreement (GLWQA) caused the algal blooms to largely disappear by the 1980s (IJC 1987). Since the late 1990s, however, harmful algal blooms (in particular, *Microcystis aeruginosa*) have re-occurred in the western basin. Although all causes of the reappearance are not entirely clear, one factor is excess phosphorus in western-basin waters.

The TP loading to Lake Erie is not increasing, but the DRP component (as measured in the Maumee River, Ohio, and in other tributaries) has increased since 1995 (Fig. 27; Baker and Richards 2002). Increases in DRP appear to be driving the increased incidence of harmful algal blooms in the western basin. During 1999-2008, trends in mean TP concentrations in Ohio waters of the western basin (Fig. 4) tracked trends in DRP loadings from the Maumee River (Fig. 27). The overall effect of increased harmful algal blooms on the Lake Erie fish community is unknown, but eutrophic conditions generally are suboptimal for walleye (Leach et al. 1977), and walleye recruitment has waned since 2003. Whether diminished recruitment is associated with changes in trophic status of the western basin, the direct impacts from *Microcystis* or other unrelated factors remain an important research question.

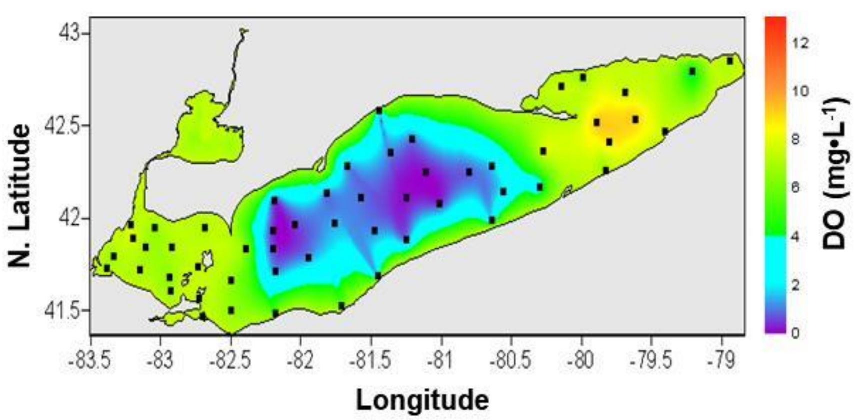
Fig. 27. The annual load (thousands of metric tons) to Lake Erie of total phosphorus (TP) during 1967-2008 (redrawn from Fig. 1 of Scavia et al. 2014) and of dissolved reactive phosphorus (DRP) from the Maumee River during 1975-2008 (redrawn from Fig. 9 of Ohio EPA 2010). The horizontal line is the target TP load of 11,000 metric tons established in the Great Lakes Water Quality Agreement of 1978. Note that scales of the two axes differ.



Hypoxia

Hypoxia is a natural condition of the central basin that occurs annually (Reynoldson and Hamilton 1993). The severity of hypoxia in the central basin has varied over the past 50 years. From the 1950s through 1970s, excessive TP loads from point sources, large algal blooms, and high detrital deposition caused frequent and extensive hypoxia in the central basin (Britt et al. 1968; Burns and Ross 1972). Nutrient loading into Lake Erie was reduced after implementation of the GLWQA in 1972, and targeted reductions in phosphorus loading were achieved in the mid-1980s (IJC 1987). Consequently, algal blooms in the western basin and hypoxia in the central basin were greatly reduced during the 1980s through the mid-1990s. In the 2000s, however, the extent and severity of hypoxia in the central basin increased (Roberts et al. 2009). Results from the International Field Year on Lake Erie (IFYLE), conducted in 2005, indicated that the aerial extent of hypoxia in the central basin was about 10,000 km^2 or >50% of the basin. (Fig. 28).

Fig. 28. Map of Lake Erie showing the estimated dissolved oxygen concentration (DO; $mg•L^{-1}$) in near-bottom waters during September 7-11, 2005, in the course of the International Field Year on Lake Erie. Locations where DO was measured are denoted by black rectangles. Sources: S. Ludsin, Great Lakes Ecological Research Laboratory, National Oceanic and Atmospheric Administration, Ann Arbor, MI; T. Johengen , Cooperative Institute for Limnology and Ecosystems Research, University of Michigan, Ann Arbor, MI.



Hypoxia can affect food webs and fisheries. During IFYLE, Roberts et al. (2009) determined that anoxia and hypoxia caused short-term changes in the vertical distribution of yellow perch and rainbow smelt, reducing their food consumption, condition, and growth (smelt only). Hypoxia may affect fishery catch rates by altering the amount of available habitat and, therefore, the distribution or density of targeted species. To better understand the long-term effects of hypoxia on fisheries, further research is needed to determine the effects of hypoxia on the thermal and feeding preferences of fish and, ultimately, on production. Reducing the severity of hypoxia in the central basin will require less algal deposition and that, in turn, will require reducing DRP loads into the western basin.

Fish Health

Pathogens and parasites other than sea lamprey affect fishes in Lake Erie, including VHSV, botulism, spring viremia of carp, dermal sarcoma, lymphocystis, and *Heterosporis* sp., but none are addressed in the LEC's fish community goals and objectives. Major fish kills from VHSV occurred in Lake Erie during 2004-2008. A large outbreak in 2006 of a newly identified unique variety of VHSV (Elsayed et al. 2006) caused mortality of numerous freshwater drum and yellow perch in western and central Lake Erie and of muskellunge in Lake St. Clair. In 2007-2008, smaller outbreaks killed gizzard shad, emerald shiner, and round goby. Walleye tested positive for VHSV, but no large mortalities were observed. Following these outbreaks, the U.S. Department of Agriculture and Ontario Ministry of Natural Resources and Forestry enacted restrictions on the movement of live fish, which affected transport of fish used for bait and other purposes, as well as on hatchery egg collections and production. Cursory modeling of the potential impacts of VHSV outbreaks on yellow perch stocks suggests that the outbreak in 2006 was a relatively small, episodic event with compensatory effects on the stocks (Yellow Perch Task Group, unpublished results). More fish health issues were detected in 2004-2008 than in 1999-2003 when notable events included a minor outbreak of a *Piscirickettsia*-like virus that affected muskellunge in Lake St. Clair, and Type E botulism (*Clostridium botulinum*) that killed numerous fishes and birds in the eastern basin of Lake Erie. The potential exists for large-scale effects on Lake Erie fish communities from new and emerging issues related to fish health, and, therefore, all jurisdictions should support additional research on and assessment of fish health.

Wind Power

Development of offshore wind energy in the Great Lakes has recently emerged as an issue that could potentially affect the LEC's ability to achieve its FCOs. Lake Erie is considered highly suitable for development of offshore wind power because it is shallow with sustained (14-20 mph) offshore winds and is near the electrical grid and major population centers. Concerns about wind-power development include effects on navigation, fishing, recreation, shoreline property value, migratory birds, endangered species, and fish habitat and production. The science to support or refute these concerns is lacking with most studies being limited to a few ocean-based developments. Potential impacts to the fish community and fisheries identified by these and other studies include short-term effects related to noise and vibration during construction, resuspension of contaminated sediments during cable trenching, and burying of benthic communities. Long-term effects of offshore wind-power development may include increased noise and vibrations that may affect fish distribution, increased areas of hard substrate, effects of electromagnetic fields on fish distribution, and changes to hydro-dynamics in the vicinity of offshore installations. Fisheries may be affected through restricted access to wind-farm areas. The LEC is preparing a position statement on the development of offshore wind power, and several agencies are preparing siting guidelines for offshore turbines.

Priorities

Actions on Priorities for 2004-2008

During 2004-2008, in response to priority recommendations from Tyson et al. 2009, actions were taken to:

1. Minimize additional introductions of invasive organisms from ballast water through communications coordinated by the Council of Lake Committees and GLFC.

2. Continue all existing interagency monitoring programs, including that on forage fishes with bottom trawls in the western basin and with hydro-acoustics in the eastern basin and of lower trophic levels in all three basins.

3. Continue modeling efforts with the Quantitative Fisheries Center at Michigan State University to improve percid stock assessments.

4. Initiate research at several universities on genetic and microchemistry techniques to identify discrete percid stocks.

5. Develop environmental objectives in support of the LEC's FCOs.

6. Complete a LEC position statement in 2005 related to the effect of changing water level on Lake Erie and Lake St. Clair and initiate work on a position statement on offshore wind power.

7. Develop and implement a new LEC fishery-management plan for walleye.

Priorities for 2009-2013

1. LEC agencies will work with relevant partners to reduce DRP loads to levels that prevent harmful algal blooms and minimize hypoxia in the western and central basins.

2. Agency siting criteria for potential projects to develop offshore wind power should be distributed to the LEC for consideration of a common understanding of risks to shared fisheries.

3. Continue efforts to attain the LEC's environmental objectives and address habitat issues throughout the lake basin.

4. In each basin, support research on percid stock discrimination and behavior (tagging), recruitment mechanisms, and mechanisms affecting food webs and fish community structure.

5. Support sea lamprey control to attain targets for adult lamprey abundance and lake trout marking rates.

6. Develop a rehabilitation plan for cisco that outlines a framework for restoration.

7. Continue to develop sustainable harvest policies on walleye and yellow perch stocks that meet FCOs and stakeholder needs while accounting for changing environmental conditions and highly variable recruitment.

8. Explore opportunities in the St. Clair-Detroit River system and upper Niagara River to improve fish habitats of potential use by Lake Erie fish stocks.

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