THE STATE OF LAKE ERIE IN 2004

SPECIAL PUBLICATION 09-02

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June 2009

THE STATE OF LAKE ERIE IN 2004

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ABSTRACT

In this first state-of-the-lake for Lake Erie, we, reporting on behalf of the Lake Erie Committee, comprising representatives of the five fisheries-management agencies of New York, Pennsylvania, Ohio, Michigan, and Ontario, gauge progress over 1999-2003 toward achievement of the fish-community goals and objectives formally established in 2003.

The Lake Erie Committee (LEC) identified two broad goals, the first of which seeks "to secure a balanced, predominantly cool-water fish community with walleye as a key predator…." Walleye (*Sander vitreus*) remains a key predator in the western, central, and nearshore waters of the eastern basin, despite recent variability in recruitment. The cool-water fish community continues to exhibit diversity, especially recently, with valuable fisheries for walleye, yellow perch (*Perca flavescens*), white bass (*Morone chrysops*), smallmouth bass (*Micropterus dolomieu*), and anecdotal evidence of increases in abundance of some nearshore species. Both nearshore habitat alterations and invasive species (namely, zebra mussel (*Dreissena polymorpha*), round goby (*Neogobius melanostomus)*, and sea lamprey (*Petromyzon marinus*)) have modified lower and upper trophic levels. In turn, the combined effects of phosphorus abatement and dreissenid mussel proliferation in the western basin has caused dramatic changes in its physical (e.g., enhanced water clarity, reduced bottom anoxia) and biological (e.g., reduced phytoplankton and zooplankton biomass, recovery of benthic mayflies) attributes. These changes, in turn, have influenced yellow perch recruitment and walleye dynamics, likely through bottom-up effects on lower trophic-level production. Even so, the round goby invasion is not without positive impacts, namely, their use by predators has opened a pathway for nutrients and energy, historically lost to zebra mussels, back to top predators. Consequently, given the myriad responses to ongoing changes to both the physical and biological attributes, challenges remain for continued progress toward the LEC's goal of a balanced, predominantly cool-water fish community with walleye as a key predator. With respect to the second broad goal, "to secure a predominantly cold-water fish community in the deep, offshore waters of the eastern basin with lake trout (*Salvelinus namaycush*) and burbot (*Lota lota*) as key predators," the LEC has made less progress. No evidence exists for natural lake trout reproduction, likely a function of continued sea lamprey predation and

possibly thiamine deficiency. However, the dramatic recovery of burbot and a modest recovery of lake whitefish (*Coregonus clupeaformis*), although still well below historical population levels, indicate some progress toward this goal.

With regard to ongoing changes in fish habitat that impede achievement of fish-community objectives, the LEC has used several strategies, including position statements (which serve to inform other agencies of fisheries-management objectives), environmental objectives (which foster communication among multiple agencies), and habitat restoration (although lagging, these targeted projects benefit fishes directly). These strategies have met with some, but limited, success.

Emerging issues relevant to fish-community objectives include resurgence of the double crested cormorant (*Phalacrocorax auritus*) population (which argues for regional control), climate change (which argues for indicators that anticipate its effects), and ongoing ecosystem changes (which argues for an anticipatory, active research program well in tune with management needs).

In our view, the state of Lake Erie is improving in some areas. Substantial attention has been paid to issues such as habitat, managing for sustainable fisheries, and lake trout rehabilitation, even though more needs to be done. What is clear from all quarters is that enhancing the lake's productive capacity and understanding how change impacts productive capacity will require cooperation and coordination across disciplines and among agencies, institutions, and stakeholders. To that end, while walleye and yellow perch continue to be managed by an interagency quota system, other warm- and cool-water species such as white bass, white perch (*Morone americana*), channel catfish (*Ictalurus punctatus*), freshwater drum (*Aplodinotus grunniens*) and common carp (*Cyprinus carpio*) are harvested by jurisdictions without an interagency management protocol, a change that likely should be made. Other issues facing the health of warm- and cool-water species include expansion of aquatic nuisance species, increased exploitation, inconsistent recruitment, increased pathogens and parasites (including sea lamprey), and loss of habitat due to human-induced effects, including changes in water levels, climate, nutrient input, and contaminant loading.

In the future, LEC agencies need to do a more-effective job of transforming their position statements, environmental objectives, and targeted restoration into regional policy-level actions that meet the needs of the fish community. Additionally, the LEC agencies need to more explicitly define habitat-related activities and outcomes that would promote achievement of fish-community objectives. The dynamic nature of Lake Erie, as outlined herein, means that managers should continue their efforts in these traditional arenas and incorporate more ecosystem-based perspectives as the lake continues to change.

INTRODUCTION

This report describes changes in the status of the Lake Erie fish community from 1999-2004, evaluates progress toward achieving fish-community objectives (FCOs) (Ryan et al. 2003), and identifies new and emerging issues that will affect future management of the lake. The intent of this initial state-of-the-lake report is to provide an early sense of major components of the fish community with topics of likely interest for management.

International fishery management on the Great Lakes is coordinated through the Great Lakes Fishery Commission (GLFC). FCOs for the lake (Ryan et al. 2003) were established in response to the original version of *A Joint Strategic Plan for Management of Great Lakes Fisheries* (Joint Plan) adopted in 1981 (GLFC 1981). The lake committees are the groups that implement the Joint Plan on each Great Lake. The Lake Erie Committee (LEC) comprises one fishery manager each from the Michigan Department of Natural Resources (DNR), New York State Department of Environmental Conservation (NYSDEC), the Ohio DNR, the Ontario Ministry of Natural Resources (OMNR), and the Pennsylvania Fish and Boat Commission. The FCOs are intended to define the objectives for the structure of the fish community and to provide means for measuring progress toward their achievement. The LEC charges its Standing Technical Committee to produce a state-of-the-lake report documenting progress every five years, as called for in the revised Joint Plan (GLFC 2007).

In surface area, Lake Erie is the shallowest and southernmost of the Laurentian Great Lakes and is generally considered mesotrophic, although key embayments in the western basin (e.g., Maumee Bay and Sandusky Bay (Fig. 1)) are eutrophic and the eastern basin tends toward oligotrophy. Basin morphometry, hydrology, and limnology were summarized in Ryan et al. (2003). The lake encompasses three distinct basins: the western, central, and eastern. The lake is divided into management units used for reporting on and management of walleye and yellow perch (an alphabetical list of common fish names and their corresponding scientific names is given in Table 1) (Figs. 2, 3). Lake St. Clair connects to Lake Huron via the St. Clair River and connects to Lake Erie via the Detroit River; the fishes of these connecting waters are managed as part of Lake Erie. In turn, the Niagara

River connects Lakes Erie and Ontario. The portion of the Niagara River above Niagara Falls is managed as part of Lake Erie. The lake's shoreline is heavily populated and serves as a prime fishing and boating destination for both U.S. and Canadian recreational anglers. Commercial fishing is a major activity in Canadian waters.

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

Common name	**Scientific name**
alewife	*Alosa pseudoharengus*
bloater	*Coregonus hoyi*
bluegill	*Lepomis macrochirus*
blue pike	*Stizostedion vitreum glaucum*
bowfin	*Amia calva*
brown trout	*Salmo trutta*
brook trout	*Salvelinus fontinalis*
burbot	*Lota lota*
channel catfish	*Ictalurus punctatus*
Chinook salmon	*Oncorhynchus tshawytscha*
cisco (formerly lake herring)	*Coregonus artedi*
coho salmon	*Oncorhynchus kisutch*
common carp	*Cyprinus carpio*
crappies	*Pomoxis* spp.
deepwater sculpin	*Myoxocephalus quadricornis*
emerald shiner	*Notropis atherinoides*
freshwater drum	*Aplodinotus grunniens*
gars	*Lepisosteus* spp.
gizzard shad	*Dorosoma cepedianum*
lake sturgeon	*Acipenser fulvescens*
lake trout	*Salvelinus namaycush*

Table 1, continued.

Common name	**Scientific name**
largemouth bass	*Micropterus salmoides*
Mottled sculpin	*Cottus bairdi*
muskellunge	*Esox masquinongy*
ninespine stickleback	*Pungitius pungitius*
northern pike	*Esox lucius*
Pacific salmon	*Oncorhynchus*, spp.
pumpkinseed	*Lepomis gibbosus*
rainbow smelt	*Osmerus mordax*
rainbow trout	*Oncorhynchus mykiss*
rock bass	*Ambloplites rupestris*
round goby	*Neogobius melanostomus*
sauger	*Stizostedion canadense*
sea lamprey	*Petromyzon marinus*
silver chub	*Macrhybopsis storeiana*
smallmouth bass	*Micropterus dolomieu*
spottail shiner	*Notropis hudsonius*
steelhead (see rainbow trout)	
sunfishes	*Centrarchidae* spp.
trout-perch	*Percopsis omiscomaycus*
walleye	*Sander vitreus*
white bass	*Morone chrysops*
white crappie	*Pomoxis annularis*
white perch	*Morone americana*
yellow perch	*Perca flavescens*

Fig. 1. Map of Lake Erie showing major geographical features.

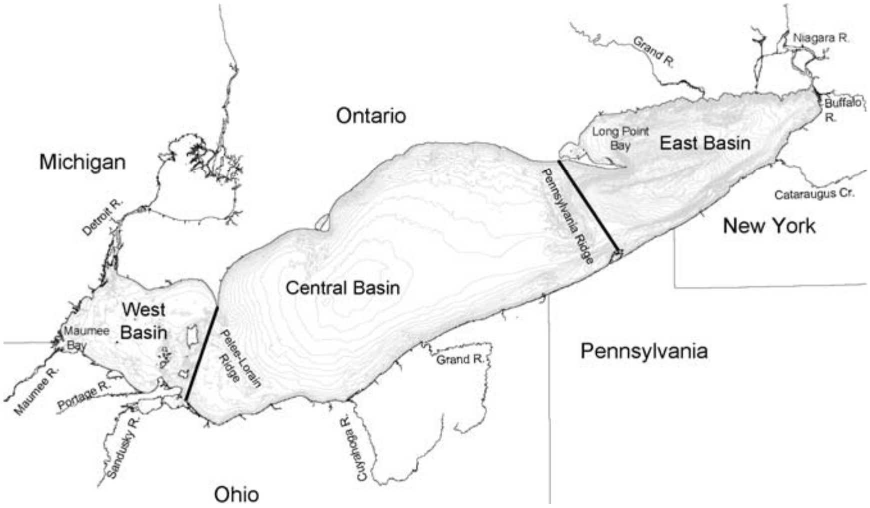


Fig. 2. Map of Lake Erie showing major geographical features and walleye management units.

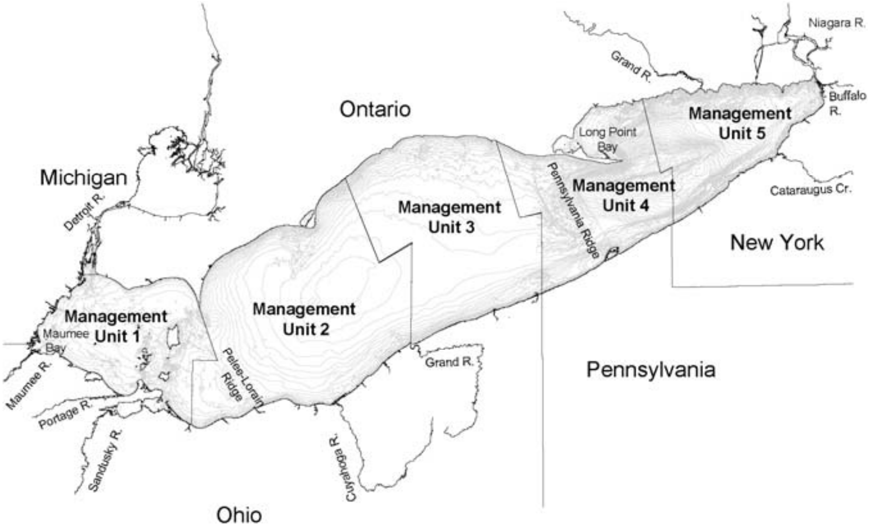
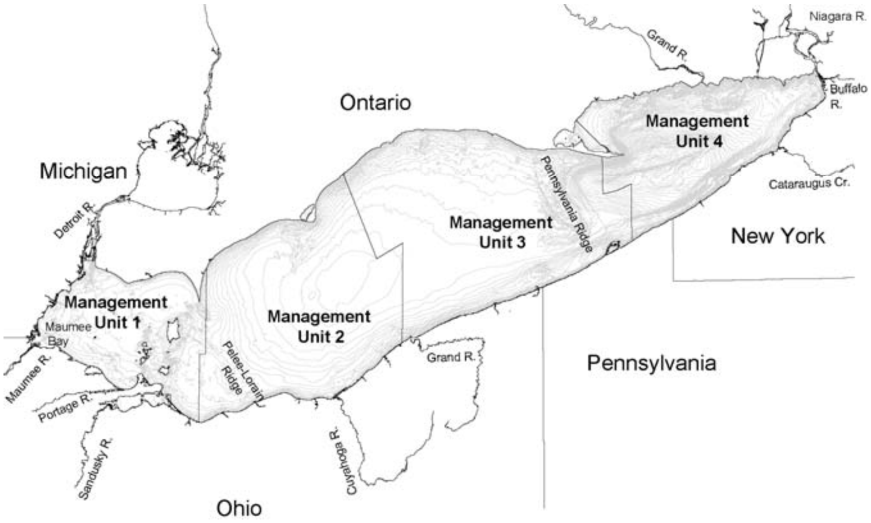


Fig. 3. Map of Lake Erie showing major geographical features and yellow perch management units.



Before 1950, walleye and blue pike were the dominant predators in the western and central basins of the lake. Before 1900, lake trout was the dominant predator in the eastern basin of the lake, with walleye and burbot as subdominants. The prey community in the western and central basins was dominated by emerald shiner, spottail shiner, and gizzard shad. In the eastern basin, the prey community was dominated by cisco (formerly lake herring). The structure and function of the fish community began to change in the early 1900s and became radically changed by 1960 through invasions of sea lamprey, alewife, and rainbow smelt; over-exploitation of important species, including the extinction of the blue pike; and declines in water quality and habitat degradation in nearshore areas and tributaries (Burns 1985). Other reports documented changes made before 1970 and between 1970 and 1999 (Munawar et al. 1999).

The overarching management objectives for Lake Erie are to secure a balanced cool-water fish community in the western and central basins, with walleye as a key predator, and to secure a cold-water fish community in the eastern basin, with lake trout and burbot as key predators (Ryan et al. 2003). Important aspects of this vision include self-sustaining indigenous and naturalized fish stocks that occupy diverse habitats, provide valuable fisheries, and reflect a healthy ecosystem. Specifically, the LEC seeks fish stocks capable of sustaining the potential annual harvest of 13.6-27.3 million kg of highly valued fish, primarily walleye and yellow perch (Ryan et al. 2003). Historically, total sport- and commercial-fishery yield has been relatively stable (between 14 and 27 million kg). However, composition of the yield has changed markedly through time. During the early to mid-1900s, fishery harvests were dominated by cisco and blue pike. Since the loss of blue pike and cisco stocks, both sport- and commercial-fishery harvests have been dominated by walleye, yellow perch, and an assortment of other native (e.g., white bass, freshwater drum, lake whitefish) and non-native species (e.g., rainbow smelt, common carp, and white perch).

Key losses to the fish community included the extirpation of lake trout by the early 1900s, the strong decline of cisco and lake whitefish during the 1940s and 1950s, extinction of the blue pike by 1960, and the strong decline of walleye by 1970 (Ryan et al. 2003). These losses were mediated by a combination of overfishing, habitat modification, and impacts of invasive species such as sea lamprey, white perch, and rainbow smelt. Since the 1980s, the fish community appears to be relatively unchanged, although the relative abundance of species varies annually. Additional changes in the food web associated with more-recent invaders will be discussed in more detail in subsequent chapters. Unlike the other Great Lakes, the primary fisheries in Lake Erie are sustained by naturally reproducing fish. The primary exception is the rehabilitation effort applied to lake trout.

Commercial fisheries operate in all jurisdictions of Lake Erie except Michigan. Large- and small-mesh gillnets are used only in Ontario waters of Lake Erie, the largest commercial fishery on the lake. Other commercial fisheries in U.S. waters fish primarily with trapnets. Percids, primarily walleye and yellow perch, dominate the commercial yield. However, in most years, more than 50% of the commercial yield comprises other species. The commercial yield of percids has varied between 4 million and 9 million kg since 1980 and has averaged 6.3 million kg. Percid yields in the 1980s were dominated by yellow perch. After the collapse of the yellow perch population in the early 1990s, percid yields were dominated by walleye. In recent years (2000-2004), with the recovery of yellow perch populations, yellow perch harvest has again dominated commercial percid yields. Lake whitefish also contribute to the yield to some degree.

Recreational fishing tends to be concentrated across the western basin and within 10-15 km of ports in the central and eastern basins, but bigger and safer boats have made most of the western and central basins and the entire shoreline accessible for recreational fishing. Recreational yield of percids has varied between 2 million and 8 million kg since 1980 and has averaged 3.1 million kg over this period. Walleye has dominated the recreational yield although not the commercial yield throughout the time series. Other important recreational species include yellow perch, white bass, channel catfish, and steelhead trout (hereafter, rainbow trout). A thriving catch-and-release fishery for smallmouth bass is also present. In the central basin, many anglers catch both rainbow trout and walleye while trolling.

Subsequent chapters of this report address, in order, the base of the food web, linkages between oligotrophication and percid dynamics, warm- and cool-water fishes, the salmonine community, burbot, habitat-related objectives, sea lamprey control efforts, options for control of round goby, the potential impact of thiamine deficiency on some key fishes, and botulism. The report ends with our overall conclusions and considerations for the future.

BASE OF THE LAKE ERIE FOOD WEB

Timothy B. Johnson[1]

Phytoplankton, Zooplankton, and Benthic Macroinvertebrates

Changes in Lake Erie's lower trophic levels have been reasonably well documented since 1980. Relative to the pre-dreissenid (pre-1987) period (before invasions of zebra *Dreissena polymorpha* and quagga *D. bugensis* mussels), phytoplankton biomass has declined 68-86% (Makarewicz 1993a; Johannsson and Millard 1998) while primary production has declined 22-55% (Millard et al. 1999). Phytoplankton biomass and seasonal photosynthesis are both below potentials set by phosphorous loading in nearshore areas of the eastern basin (Millard et al. 1999), a consequence of dreissenid mussels (Hecky et al. 2004). Overall zooplankton biomass continues to decline in all basins, both when comparing pre- and post-dreissenid periods and when comparing 1993-1994 and 1998 studies (Makarewicz 1993b; Makarewicz et al. 1999; Johannsson et al. 1999; MacDougall et al. 2001). Current zooplankton production is close to that predicted from primary production, although new production by veligers and shifts in mean zooplankton size associated with fish predation are resulting in observations below the prediction (Johannsson et al. 2000). Mills et al. (1987) suggest that zooplankton mean length (ZML) of 0.8 mm, as determined with a 153-µm net, was characteristic of a well-balanced fish community. When Lake Erie data are standardized to a 153-µm net, ZML falls below the index, indicative of heavy predation by planktivores (Fig. 4). ZML was trending upwards in recent years, but it was poorly correlated with fish biomass (Fig. 4).

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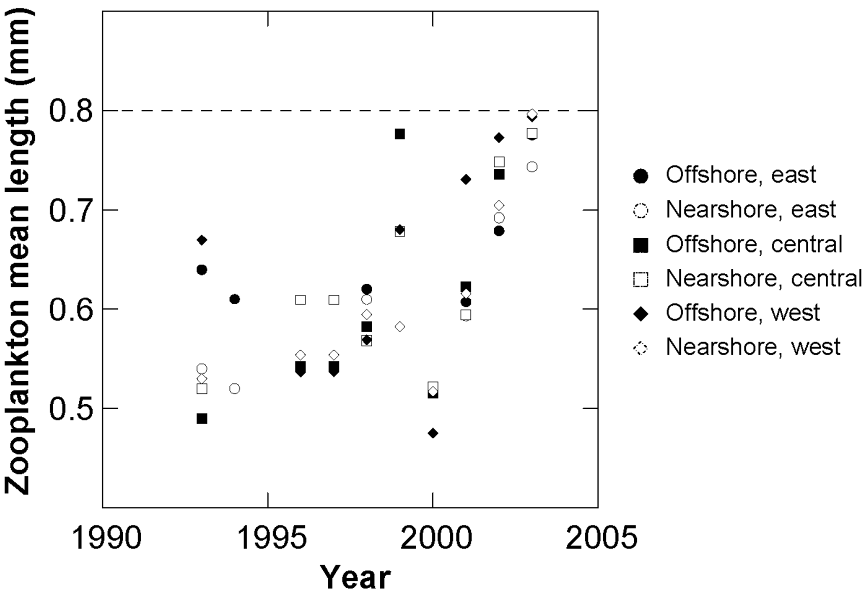
Fig. 4. Mean size of crustacean zooplankton, standardized to a 153-µm net for reference sites in the eastern, central, and western basins of Lake Erie, 1993-2003.



Benthic biomass has greatly increased following the arrival of dreissenid mussels in 1987; however, non-dreissenid biomass has remained largely unchanged (Johannsson et al. 2000; MacDougall et al. 2001). Since 1992, zebra mussel density and biomass have declined, especially in the western basin, whereas quagga mussel density and biomass have increased, especially in the eastern basin (Jarvis et al. 2000; Patterson et al. 2005). *Hexagenia* spp. mayflies recolonized the sediments of the western basin in the 1990s, reaching average densities of >100/m^2, but low oxygen may be limiting their recovery in the central basin (Scholesser et al. 2000; Krieger et al. 2007). *Diporeia* spp. have not been observed in Lake Erie since 1993 (Dermott and Kerec 1997). Oligochaetes and chironomids also account for substantial portions of the non-dreissenid biomass and production in all basins (Johannsson et al. 2000; MacDougall et al. 2001). Barton (D. R. Barton, personal communication, 2004) reported a profound loss in benthic biodiversity in nearshore waters, which he attributed to predation by round goby and dreissenid effects.

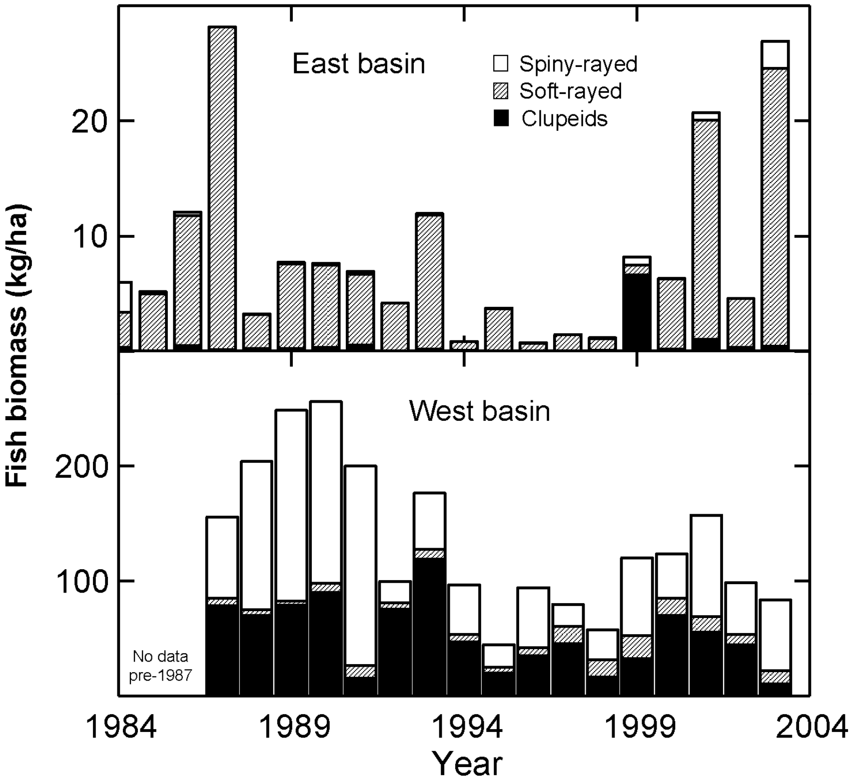
The establishment of the lakewide lower trophic-level assessment program by Lake Erie agencies (FTG 2004) is intended to provide annual monitoring of important lower trophic-level parameters that will aid scientists and resource managers in assessing the current state of the lake. Monitored parameters include profiles of temperature and dissolved oxygen, Secchi depth, total phosphorous, phytoplankton, chlorophyll *a*, zooplankton, and benthos.

Forage Fish

Small fishes (<200 mm) are important ecological components, consuming zooplankton and benthos and, in turn, providing food for larger predatory fish and waterbirds. Small-fish abundance is assessed in two ways in Lake Erie. All agencies use bottom trawls of various designs to sample the small-fish community in all basins (FTG 2004). The trawl programs are biased toward more demersal species, as these programs were designed initially to generate indices of percid recruitment. The Lake Erie Forage Task Group (FTG) has worked to harmonize these programs by establishing standardized reporting units (no./ha and kg/ha), and has recently undertaken a trawl comparison exercise to generate fishing power corrections so vessel catches can be compared more directly (Tyson et al. 2006). In addition to the bottom-trawl programs, hydroacoustics has been employed in the eastern basin since 1993, the central basin since 2000, and the western basin as a pilot survey in 2004 (FTG 2004).

Biomass of forage-sized fishes in eastern Lake Erie peaked in 1987, with other dominant years in 2001 and 2003 (Fig. 5). In both the eastern and central basins, dominant forage includes rainbow smelt, emerald shiner, alewife, and round goby (Zhu et al. 2008; FTG 2004). Midwater trawling, used to ground truth the hydroacoustic surveys, suggested that almost all pelagic targets are rainbow smelt in the eastern basin, while rainbow smelt and emerald shiners dominate the targets in the central basin (FTG 2004). Alewives tend to be poorly represented in the trawls, but they contribute >50% of the numbers of fish caught in canned gillnets fished through the OMNR-OCFA Partnership gillnet index (OMNR 2004). In the western basin, forage-fish biomass peaked in 1990 at ~255 kg/ha (Fig. 5), nearly an order of magnitude higher than peak biomass in eastern Lake Erie (Fig. 5). Interannual variability in biomass is driven by variable recruitment of age-0 spiny-rayed fishes (white perch, white bass, yellow perch, walleye, and freshwater drum) and, to a lesser degree, age-0 clupeids (gizzard shad and alewife). Abundance of small soft-rayed species (cyprinids, silver chub, troutperch, rainbow smelt, and round goby) is less variable and contributes ~10% of the total abundance, on average. Round goby density declines from east to west, with a mean lakewide density (soft substrate only) of 224/ha (2001-2003 average) (FTG 2004).

Fig. 5. Estimated biomass (kg/ha) of various functional types of small fishes (<200 mm) in the eastern and western basins of Lake Erie from 1984 to 2003 based on bottom trawling. The eastern-basin data are based on Ontario Ministry of Natural Resources offshore outer Long Point Bay surveys, while the western-basin data are based on the Ohio DNR-OMNR interagency trawling.



Predator Diets

Few comprehensive descriptions of predator diets exist for Lake Erie fishes. Stomach contents of angler-caught walleye have been described for New York waters since 1993 (NYSDEC 2006), and rainbow trout diets are the focus of a current multi-agency initiative (Clapsadl et al. 2003). The OMNR has conducted diet analyses of certain predators during the OMNR-OCFA Partnership index in 1995-1996 (Cook et al. 1997) and again during 1999-2001 (Mullowney 2004). However, the most-continuous diet series for Lake Erie fishes has been collected by the Ohio DNR (ODNR 2004). Since 1994, stomach contents have been described for walleye, yellow perch, white bass, smallmouth bass, and burbot for fish caught in trawls (summer and fall) and gillnets (fall) in the central and western basins (Johnson et al. 2005; C. Knight, unpublished data). Walleye diets are dominated by rainbow smelt and clupeids throughout the time series, with cyprinids becoming increasingly important in recent years. Yellow perch diets are dominated by zooplankton and benthos, although round goby have contributed ~25% of the diet (by volume) since 1998. Smallmouth bass and burbot also rely on round goby, reducing their dependency on rainbow smelt and the young-of-the-year white perch, yellow perch, freshwater drum, and silver chub). White bass diets were most diverse and variable across years.

Bioenergetics

The FTG has used bioenergetic models (Hanson et al. 1995) to estimate predator demand (Einhouse et al. 1999; FTG 2002). Dominant predators include walleye, burbot, lake trout, and rainbow trout. General data needs include abundance and weight-at-age, mortality, thermal occupancy, diet, and energy content of predator and prey. Unfortunately, data are incomplete for lake trout (lacking adequate population size, mortality, and diet data), burbot (population size, mortality, diet, and growth rate), and rainbow trout (population size, diet, and growth rate). The Coldwater Task Group (CWTG) is addressing these deficiencies in a newly assigned charge from the LEC. Data for walleye are largely complete, allowing for a 21-year (1980-2000) simulation of consumption for the entire lakewide population (ages 1-12+) (FTG 2002). This stock migrates between basins experiencing specific temperatures and diets seasonally; the migration pattern was characterized using monthly shifts in targeted effort for walleye, assuming commercial fishers were allocating their effort in proportion to fish abundance.

Walleye consumption rose to a peak in 1987 or 1988 before declining to about 30% of the maximum level in 2000 (Fig. 6). This pattern of consumption strongly paralleled trends in population size. Total consumption was highest in the western basin and lowest in the eastern basin. Age-0 clupeids (alewife and gizzard shad) were the primary prey lakewide, although rainbow smelt were proportionately more important in the central and eastern basins.

Total prey-fish consumption was compared with estimated prey-fish biomass for the eastern (hydroacoustics) and western (bottom trawls) basins. In the east basin, the combined losses of rainbow smelt to walleye consumption and a trawl fishery ranged from 20-110% of the estimated smelt biomass during 1994-2000 (Fig. 7).

Fig. 6. Estimated total annual consumption of prey by walleye in Lake Erie during 1980-2000. Separate panels are provided for each basin. Note the differences in scale.

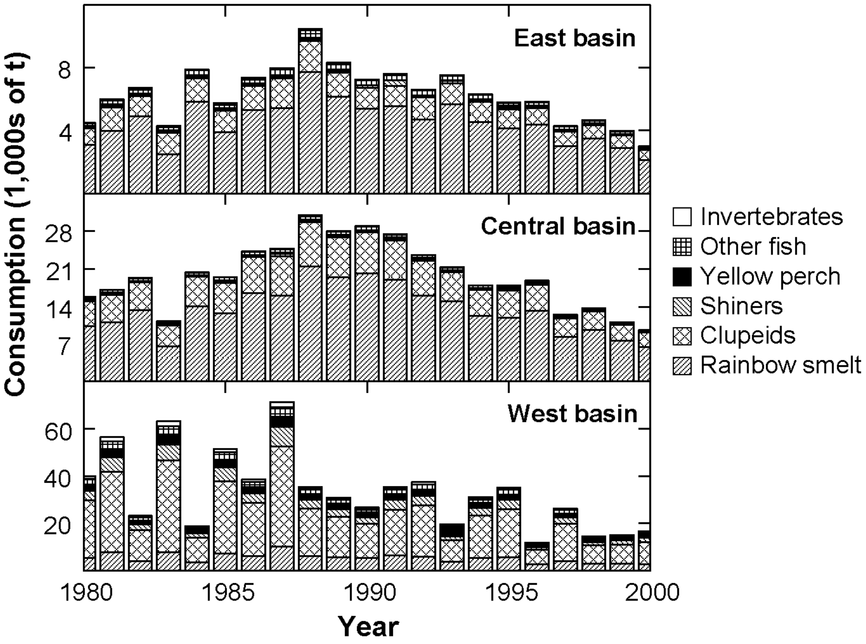
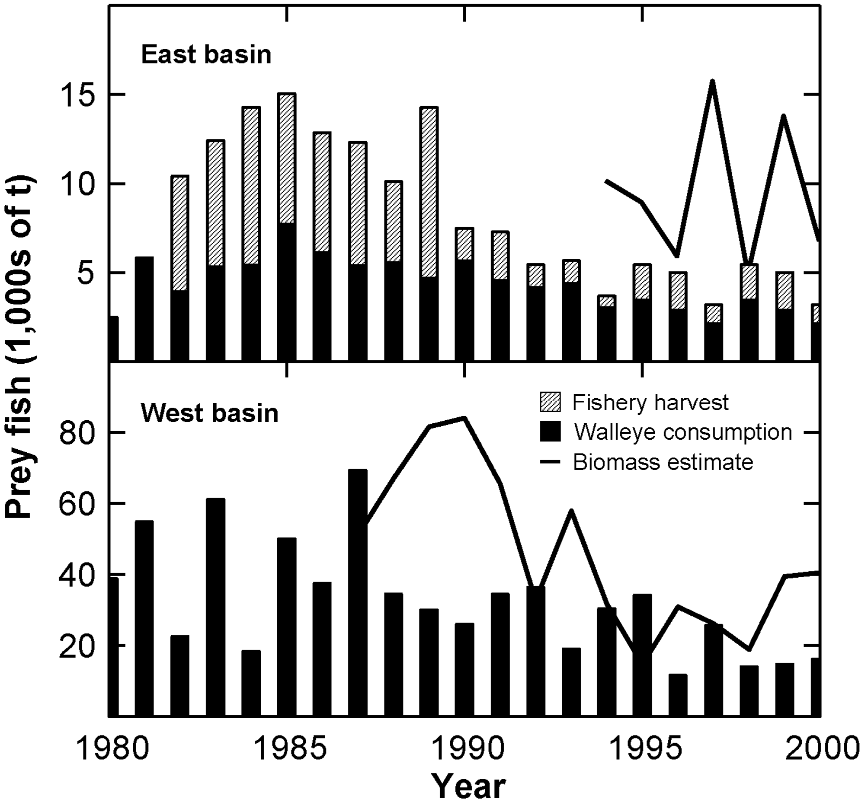


Fig. 7. Estimated demand (fishery harvest and consumption by walleye) vs. supply (biomass) of prey fishes in the east and west basins in Lake Erie during 1980-2000. Eastern-basin prey-fish biomass was estimated from hydroacoustics and is assumed to be all rainbow smelt. Western-basin prey-fish biomass was estimated from interagency bottom trawls and comprises sizes vulnerable to walleye predation (<200 mm). No prey-fish biomass estimates are available for the east basin prior to 1994 and the west basin prior to 1987.



In the west basin, walleye consumption accounted for 31-234% of the estimated prey-fish biomass during 1987-2000. Given that these estimates are for a single predator, walleye, clearly a heavy demand exists on the available prey fish in Lake Erie. However, lack of evidence of declining growth or condition of predators confounds the analysis. Subsequent analyses will be improved through improved estimates of lake trout, burbot, and rainbow trout abundance and mortality, enhanced diet analyses, and the ongoing development of the central basin hydroacoustic survey (FTG 2006).

General Conclusions

Instability is pervasive throughout the Lake Erie food web: dreissenids are affecting phytoplankton and zooplankton production, forage fishes are imparting a high predation pressure on zooplankton, and predators are imparting high pressure on prey fishes. Round goby prey heavily on benthic resources and are consumed by many predatory fishes. Recent modelling suggests round goby may be increasing the energy pool for goby-consuming predators (Johnson et al. 2005). Monitoring across trophic levels, with particular attention to the impact of invasive species, is necessary to fully understand the lake's prey resources and productivity. The establishment of the Lake Erie Interagency Lower Trophic Level Monitoring Program (FTG 2006) will provide a temporally and spatially intensive description of nutrients, zooplankton, and benthic invertebrates that will complement existing federal biomonitoring programs. Ongoing efforts by LEC agencies to standardize sampling and reporting and to establish new programs will help address data gaps/deficiencies with respect to prey-fish and predator abundance, predator diets, and predator growth rates. Additional efforts by academic and agency partners to assess and describe patterns and trends in nutrients, phytoplankton, zooplankton, benthic invertebrates, and fishes will continue to improve our understanding of the dynamics of the food web.

The LEC endorsed the maintenance of mesotrophic conditions for much of Lake Erie with walleye serving as the dominant predator in the west and central basins and lake trout in the east (Ryan et al. 2003). Management of nutrients and fish exploitation has, in part, achieved that objective, but ongoing invasions and limited progress in restoring important nearshore and tributary habitat will prevent full achievement and may negate earlier progress. A healthy and productive fish community will require cooperation and coordination across disciplines and among agencies and stakeholders.

LINKAGES BETWEEN OLIGOTROPHICATION AND PERCID DYNAMICS IN LAKE ERIE

Stuart A. Ludsin[2], David M. Dolan, R. Peter Richards, Jeffrey T. Tyson, Kevin A. Kayle, Timothy B. Johnson, and Roy A. Stein

Background

Ecosystem approaches have become especially relevant in Lake Erie during recent years, owing to planned phosphorus abatement programs implemented as part of the U.S.–Canada Great Lakes Water Quality Agreement (GLWQA) and the unplanned invasion of dreissenid mussels.

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Both perturbations have led to the oligotrophication (a return to former oligotrophic conditions) of Lake Erie, as exhibited by reduced phytoplankton biomass (Nicholls and Hopkins 1993), enhanced water clarity (Ludsin et al. 2001), reduced zooplankton biomass (Johannsson et al. 2000), and recovery of once-important benthic macroinvertebrate prey for fishes (e.g., *Hexagenia* spp.) (Tyson and Knight 2001). These changes in habitat and prey availability have, in turn, led to shifts in fish-community composition, wherein species tolerant of eutrophic conditions decreased in abundance and were being replaced by species more tolerant of oligotrophic/mesotrophic conditions (Ludsin et al. 2001). Owing to reduced point-source loading of phosphorus into Lake Erie, the relative contributions of watershed-derived, stochastic tributary inputs of phosphorus also have increased (Dolan 1993; Baker and Richards 2002). Importantly, these nonpoint-source inputs of phosphorus from the Maumee River (Ohio), a west-basin tributary (Fig. 1) that drains a largely agricultural watershed, have driven interannual variation in lakewide ($R^2 = 0.69$, $p < 0.0001$) and west basin ($R^2 = 0.76$, $p < 0.0001$) phosphorus loading levels during 1983-2000. Indeed, springtime (April-May) Maumee River total phosphorus load (Gg/yr) and spring/early summer (May-June) copepod abundance (number of individuals/l) are positively correlated in Ohio waters of western Lake Erie ($r = 0.85$, $p < 0.001$). Most certainly, enhanced food (zooplankton) production would benefit zooplanktivorous fish, and previous modeling research in Lake Erie has suggested linkages between external watershed inputs of phosphorus and fish community and recruitment dynamics (Hobbs et al. 2002; Ludsin et al. in press). While the combined effects of oligotrophication on Lake Erie's percid community (i.e., yellow perch and walleye) have not been well studied, one might expect oligotrophication to lead to a more stable and productive percid community, as yellow perch and walleye have been shown to fare best in mesotrophic conditions throughout north-temperate systems (Leach and Nepszy 1976).

Yellow Perch Recruitment

Although omnivorous during juvenile and adult life stages, yellow perch feed exclusively on zooplankton as larvae (Ludsin 2000). Given that copepods dominate zooplankton biomass during spring in western Lake Erie (JTT, unpublished data) and that larval yellow perch in western Lake Erie feed almost exclusively on copepods (Ludsin 2000), tributary inputs of phosphorus may also indirectly drive yellow perch recruitment variation via its food (copepod) supply. For western Lake Erie, SAL, JTT, TJB, and RAS developed a simple empirical model that predicts (two years ahead) the number of yellow perch that will recruit into the fishery as a function of spring (average flows during March through May) discharge from the Maumee River (i.e., high river flows during spring are correlated with enhanced recruitment events, $R^2 = 0.88$, $p < 0.001$. Interestingly, the positive relationship between springtime Maumee River discharge and yellow perch recruitment is not valid for the time period before dreissenid mussels became established (ca 1988) ($R^2 = 0.06$, $p < 0.40$). Thus, only during recent years, when phosphorus availability has been low and driven largely by Maumee River discharge, has yellow perch recruitment been strongly related to spring discharge. No relationship exists with yellow perch recruitment for other months or seasons (SAL, unpublished data), signifying the potential importance of spring tributary discharges for yellow perch recruitment. Further, yellow perch population size at age 2 can be predicted from an index of yellow perch alive during August at age 0 ($R^2 = 0.75$, $p < 0.001$ during 1987-2001) (SAL, JTT, and TBJ, unpublished data). Thus, if river discharge is truly influencing yellow perch recruitment, it is doing so prior to August, which again is when larvae and young juveniles feed strictly on copepod zooplankton (Ludsin 2000).

Precisely how phosphorus inputs regulate yellow perch recruitment variation is important and not understood, which limits the ability of fisheries-management agencies to use our model to forecast future recruitment. For example, Maumee River discharge may benefit yellow perch recruitment via enhanced turbidity that reduces predatory mortality on larvae, and phosphorus inputs may be unimportant. If sediment inputs—and not phosphorus inputs—from the Maumee River regulate yellow perch recruitment, then different types of watershed management plans would be necessary. Identifying those ecological mechanisms underlying the river discharge-recruitment model would allow management agencies to better anticipate when the model might fail, help guide decisions regarding annual harvest regulations, and explore different watershed management plans that could be used as a lever to influence yellow perch dynamics.

Walleye Growth

Walleye is the most-abundant top predator and most-economically important fish sought by commercial and sport fishers in Lake Erie. Owing to gape limitations, larger juvenile and adult walleye feed selectively on small-bodied prey fishes, such as age-0 clupeids (alewife, gizzard shad), age-0+ rainbow smelt, and age-0+ shiners (emerald shiner, spottail shiner) (Knight et al. 1984). Similar to yellow perch's zooplankton prey base, the walleye prey-fish base has undergone major changes, which appear linked to oligotrophication. Specifically, we documented a shift from a prey-fish community dominated by preferred (from a walleye's perspective) zooplanktivores of high caloric value (i.e., shiners, alewife) to a prey assemblage dominated by less-preferred benthivores of low caloric value (primarily invasive white perch and round goby (Ludsin and Stein 2001). While we can only speculate, this shift appears related to reduced phosphorus loading, which caused crustacean zooplankton biomass to decrease (Johannsson et al. 2000) and oxygen levels to increase, allowing once-important benthic macroinvertebrates, such as burrowing mayflies, to increase (Tyson and Knight 1984). Conceivably, dreissenid mussels also contributed to this switch from a zooplanktivorous to benthivorous prey-fish assemblage by filtering phytoplankton and microzooplankton from the water column, and "shunting" energy to benthic regions and to Lake Ontario via the Niagara River (Fig. 1) (Hecky et al. 2004).

Enhanced dependence of Lake Erie on tributary inputs of phosphorus may also have altered mechanisms that regulate availability of preferred, zooplanktivorous fishes, such as emerald and spottail shiners and alewife. Most notably, total phosphorus inputs into western Lake Erie are now (1987-2000) more important for explaining variation in preferred forage fish (i.e., age-1+ shiners and alewife) abundance during fall ($r = 0.68$, $p = 0.008$) (SAL, unpublished data) than predatory walleye population size (age-3+), which was strongly, negatively related to forage fish (i.e., age-1+ shiners and alewife) abundance during 1969-1986 ($r = -0.73$, $p = 0.001$) (SAL, unpublished data). Moreover, fewer shiners and alewife during 1987-2000 apparently resulted in slower growth (total length) for age-0, age-1, and age-2 walleye than during 1969-1986 (*t*-test: all $t \geq 2.06$, all $p \leq 0.03$). Thus, we suggest that reduced phosphorus inputs (via abatement effects) and availability in the water column (via dreissenid mussel effects) have caused bottom-up processes to become more important than top-down processes in structuring the juvenile walleye prey-fish community, and, in turn, juvenile walleye growth.

Management Implications

Our research suggests that managing phosphorus inputs to create a mesotrophic Lake Erie may not be sufficient for producing strong percid communities (sensu Leach and Nepszy 1976), as juvenile walleye growth (production) and yellow perch recruitment declined with a shift from eutrophic to mesotrophic conditions. These unexpected responses may have multiple causes, including the establishment of dreissenid mussels, continued habitat alteration/degradation in coastal margins (including spawning tributaries), and the loss of once-important food-web components (e.g., cisco). Most certainly, each of these perturbations holds the potential to alter food-web structure and perhaps negatively affect the flow of energy through Lake Erie's food web, which, in turn, may negatively affect percid production.

Our results also suggest that Lake Erie's oligotrophication has led to clear tradeoffs that must be recognized by resource-management agencies (Ludsin and Stein 2001). On one hand, oligotrophication has led to whole-scale ecosystem rehabilitation: water clarity has improved, bottom anoxia has declined, and important macroinvertebrate prey species and macrophytes have begun to recover. In turn, these changes appear to have allowed a variety of once-important recreational and commercial fishes to begin to recover, including smallmouth bass, rock bass, lake whitefish, and burbot (Ludsin et al. 2001). On the other hand, ecosystem rehabilitation has its costs, which appear to have come in the form of reduced yellow perch abundance and juvenile walleye growth. Given these findings, we recommend that constituents (i.e., anglers) be educated about changes in Lake Erie's fish communities and their potential causes. Certainly, this approach would go a long way toward helping agencies manage user-group expectations with regard to percid production and also help anglers recognize that oligotrophication can bring about other viable fishing opportunities.

STATUS OF WARM-WATER AND COOL-WATER FISH SPECIES IN LAKE ERIE

Kevin A. Kayle[3]

Introduction

I use the concept of feeding guilds of fishes (Keast 1985) to interpret agency trawl and gillnet data by basin and thermal habitat. This approach is consistent with the fish-community goals and objectives for Lake Erie (Ryan et al. 2003), which recognized the thermal structuring of the fish community as per Hokansen (1977):

- Warm-water habitat (>28°C)—most of the western basin
- Cool-water habitat (20-28°C)—the central basin and inshore waters of the eastern basin
- Cold-water habitat (<20°C)—deeper waters of the central basin and offshore waters of the eastern basin

Fishes associated with warm-water habitat include:

- Centrarchids, such as smallmouth bass, largemouth bass, sunfishes, and crappies
- White bass
- White perch
- Ictalurids, such as channel catfish and bullheads
- Various cyprinids

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- Clupeids
- Round goby
- Lake sturgeon
- Catostomids (white sucker and redhorses)
- Bowfin
- Gars

Fishes associated with cool-water habitat (during summer temperature maxima) include:

- Percids (walleye, sauger, and yellow perch)
- Esocids (northern pike and muskellunge)
- Freshwater drum
- Cyprinids
- Rainbow smelt

Fishes associated with cold-water habitat (not discussed here) include lake whitefish, lake trout, and burbot.

Status of Warm-Water and Cool-Water Fishes

As a prelude to more-detailed accounts for individual fishes, I offer the following generalizations, by feeding guild, for the lake's warm-water and cool-water fishes.

Warm-Water Fishes

- A decline in abundance of omnivorous fishes in the western basin, which began in the 1990s, stopped in 2003. During this period, the abundance of planktivorous fishes in the western basin increased.
- The abundance of planktivorous fishes in the central basin increased from 1989 to 2003, but variation was high. The abundance of omnivorous and benthivorous fishes in the central basin declined during the same period, reversing a trend of previous years.

- All feeding guilds in the eastern basin appear to have experienced declines in abundance in the 1990s, owing possibly to oligotrophication.

Cool-Water Fishes

- The abundance of benthivorous and omnivorous fishes in the western basin increased from 1989 to 2003. During this same period, piscivore abundance, which had been trending downward, leveled off.
- The abundance of omnivorous and benthivorous fishes in the central basin increased from 1989 to 2003. During the same period, abundance of planktivorous fishes in the central basin varied without trend, while abundance of piscivores remained low and variable.
- The abundance of omnivorous and planktivorous fishes in the eastern basin was highly variable during 1989-2003, and the trend was uncertain.
- The abundance of piscivorous and benthivorous fishes in the eastern basin declined in 2002-2003 following upticks in abundance during the 1990s.

Overall, abundance of the benthivorous fishes increased throughout the lake from 1989 to 2003 as energy was shunted to the lakebed through the filtering activities of dreissenids. At the same time, piscivores have undergone reductions in exploitation, but recruitment did not increase. The year 2003 was exceptional for reproduction across thermal habitats and feeding guilds, and, if these young fish survive in good numbers, the overall abundance of non-benthivorous fishes may stabilize or improve.

Status of Important Fishes

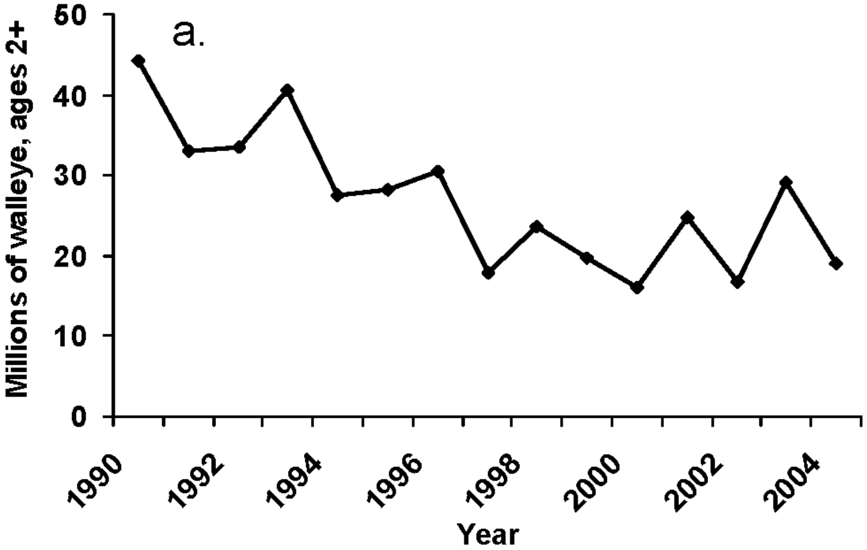
Walleye

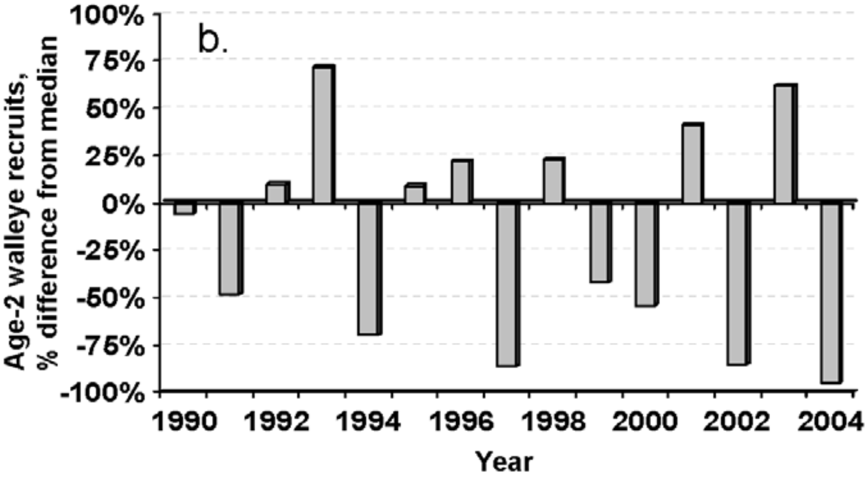
Growth of adult walleye, tracked by the mean length of age-4 fish, has increased from 1989 to 2003 (WTG 2004), indicating adequate forage-fish densities during this time period. The recently introduced round goby now appears regularly in walleye diets and, in part, accounts for the recent growth increases.

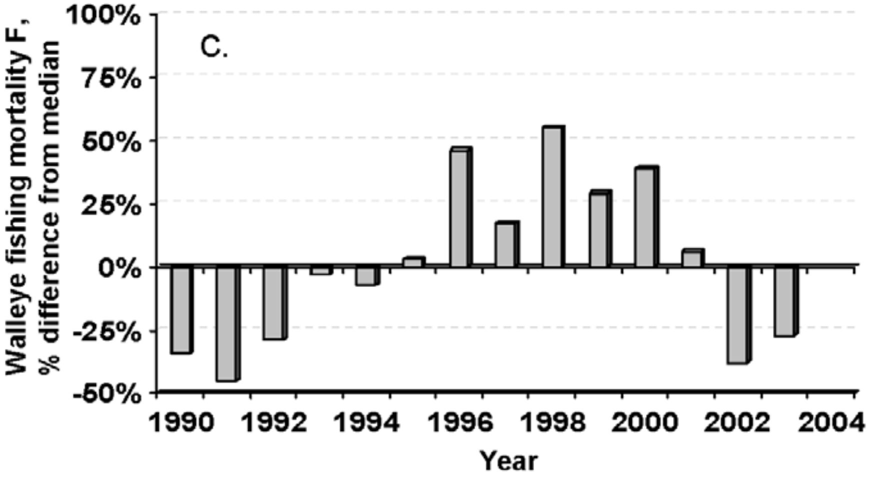
Abundance of walleye during the early 2000s has declined. Owing to recent trends of below-average recruitment and higher long-term average fishing mortality, the number of walleye at the start of the 2003 fishing season was 19-million age-2+ fish, whereas the comparable number in 1990 was 45 million (Fig. 8). Numbers will increase appreciably as the much stronger 2003 year-class recruits, but gains will only be short-term if another above-average year-class is not soon formed.

Trends in abundance were similar for both the west-central and eastern basin quota-management units. The eastern basin population comprises older fish, so any indications of population improvement may take longer to occur than in the west. Harvest and quotas have been constrained for population rehabilitation during the institution of a Coordinated Percid Management Strategy (CPMS) and until the completion of the Walleye Decision-Analysis and Walleye Management Plan (WTG 2004).

Fig. 8. Estimates for Lake Erie walleye based on AD Model catch-at-age analysis, 1990-2004: a) population size for ages 2+; b) year-to-year difference in abundance of age-2 recruits; c) year-to-year differences in fishing mortality, F.



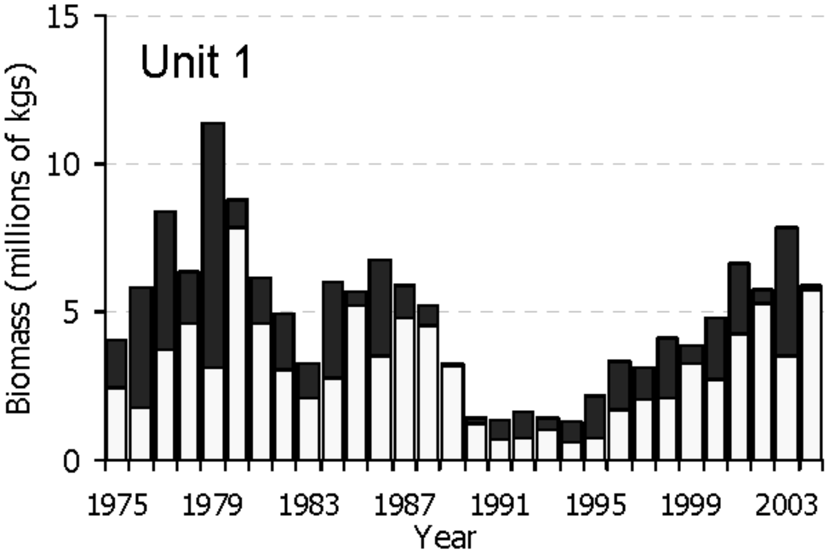

b.
Age-2 walleye recruits, % difference from median
100%
75%
50%
25%
0%
-25%
-50%
-75%
-100%
1990
1992
1994
1996
1998
2000
2002
2004
Year

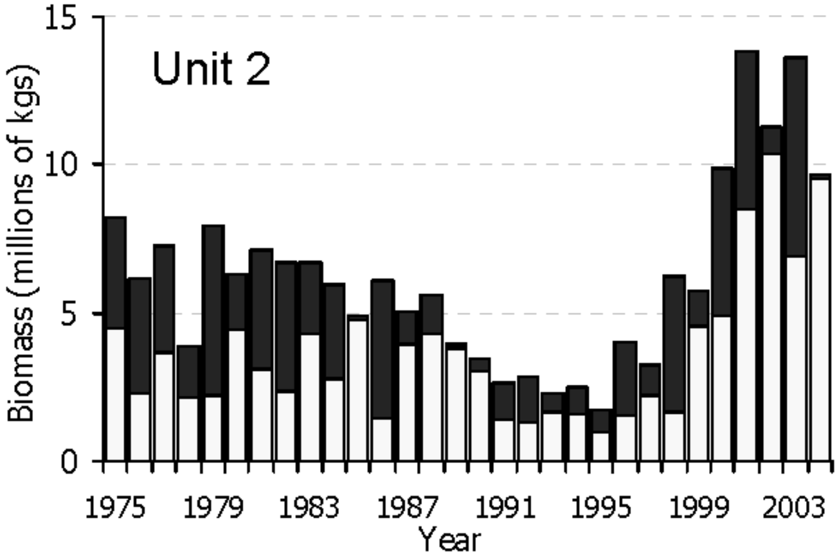

c.
Walleye fishing mortality F, % difference from median
100%
75%
50%
25%
0%
-25%
-50%
1990
1992
1994
1996
1998
2000
2002
2004
Year

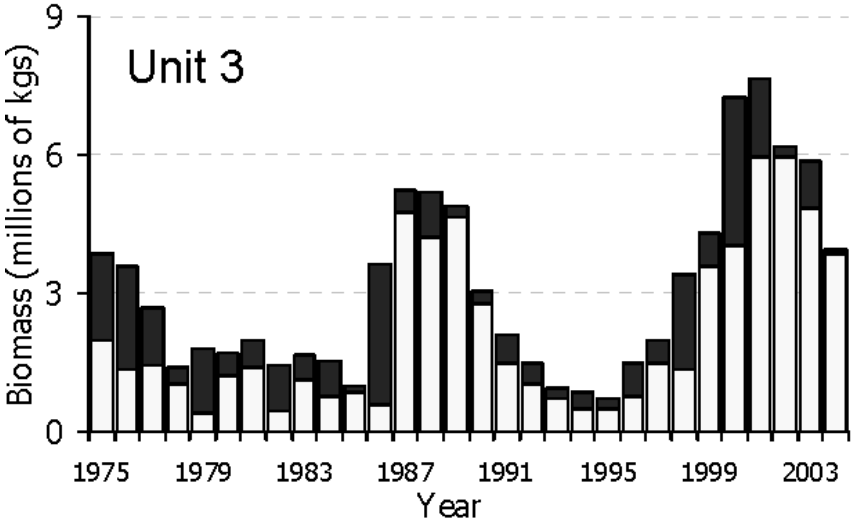
Yellow Perch

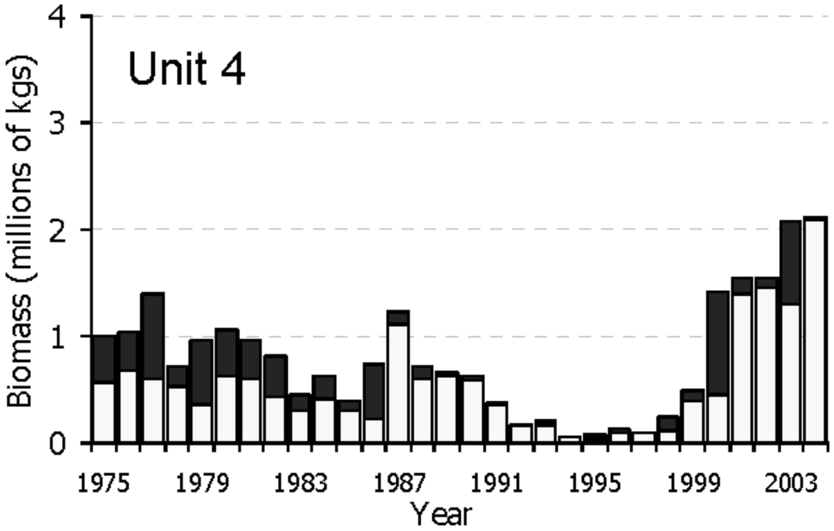
Abundance and biomass of yellow perch across all four management units (Fig. 3) appear to have rebounded from the mid-1990s (Fig. 9). Comparisons of biomass harvested with estimated biomass at the start of the fishing year indicates reduced exploitation after the late 1980s and early 1990s. Recruitment remains uneven, with the years 2000, 2002, and 2004 being strong and 1998, 2001, and 2003 being weak. Growth rates were improved recently from lows seen during the late 1990s (YPTG 2004). An analysis of exploitation risk and modeling of recruitment are being used to determine appropriate exploitation rates and quotas (YPTG 2004). The CPMS and the Yellow Perch Management Plan have been initiated. A rehabilitation plan for Canadian waters of the eastern basin is under development.

Fig. 9. Biomass of Lake Erie yellow perch by management unit (depicted in Fig. 3) for age 2 (dark bars) and ages 3+ (light bars), 1975-2004, based on population modeling.




Unit 2
Biomass (millions of kgs)
15
10
5
0
1975
1979
1983
1987
1991
1995
1999
2003
Year


Unit 3
Biomass (millions of kgs)
9
6
3
0
1975
1979
1983
1987
1991
1995
1999
2003
Year



White Bass

The abundance of white bass increased after the mid-1990s, countering the previous trend of successive poor year-classes that began in the late 1980s. Better-than-average year-classes were produced in 1996, 1999, and 2001; a strong year-class was produced in 2003. The commercial harvest of white bass peaked in 2002, following a steady increase from the lows seen in the early 1990s. Sport fishing for white bass has declined recently as anglers favored percids and smallmouth bass. The growth rate of adult white bass has changed little during the last decade.

White Perch

White perch abundance increased modestly during the 2000s, as compared to the lows seen in the mid- to late 1990s, owing to recruitment of several strong year-classes; abundance in the 2000s has not reached the highs observed during the late 1980s and early 1990s. Growth of age-3 white perch peaked in 2001, after which it declined during the next two years. Overwinter mortality may be limiting this species insomuch as few individuals survive past age 5; trawling in early spring typically produces dead white perch. The commercial and sport fisheries for white perch in the 2000s have declined from the high levels seen in the late 1980s and early 1990s (ODNR 2004; OMNR 2004).

Smallmouth Bass

Trends in smallmouth bass abundance, exploitation, and growth are difficult to characterize due to smaller, localized sport fisheries, which are hard to sample and that typically practice catch and release, and to the lack of an interagency sampling protocol. Commercial harvest of largemouth and smallmouth bass on Lake Erie is prohibited. Sport effort and harvest of smallmouth bass has declined lakewide from peaks in the mid- to late 1990s. Angler catch rates remain high in the eastern basin, but have been declining elsewhere since the mid-1990s. Catch rates of juvenile smallmouth bass in surveys have declined since the mid- to late 1990s, except for Pennsylvania and New York waters where a sizable 1999 year-class benefited the fisheries. Growth of juvenile and adult smallmouth bass has increased in the early 2000s, reversing the declining trend of the 1990s. Increased natural mortality of smallmouth bass during nesting, caused by round goby (Steinhart et al. 2004), is a concern as are summer kills in the eastern basin due to type E botulism and in the central basin due to upwellings.

Freshwater Drum, Channel Catfish, and Common Carp

These three fishes are sought primarily in commercial fisheries, and their harvest has declined since the mid-1990s, suggesting either a decline in market demand, fishery interest, or declining abundance. Interagency surveys have documented a decline in common carp abundance and increases in abundance of channel catfish (strong) and freshwater drum (slight). These trends in abundance occurred primarily in the western basin and in the warmer waters of the central basin (ODNR 2004; OMNR 2004). All three of these fishes may have recently experienced increased natural mortality due to disease outbreaks (spring viremia of carp, channel catfish viral disease, and type E botulism).

Progress in Meeting Fish-Community Objectives

All of the major warm-water and cool-water fishes discussed in this chapter remain at sustainable population levels, as called for in the lake's fish-community goals and objectives (Ryan et al. 2003). Healthy stocks of walleye, the key cool-water predator, have been maintained despite irregular production of cohorts. Walleye management features a risk assessment aimed at avoiding over-exploitation. Yellow perch populations have rebounded in all basins owing to improved recruitment and to imposition of safe harvest levels. A diversity of forage fishes has been maintained at levels commensurate with demand from predators and for direct human use. Total harvest for 2003 in Ontario and Ohio waters alone exceeded 14 million kg, which exceeded the lower bound of the objective for the whole lake.

Minor cool-water and warm-water fishes may not be at sustainable levels and may need careful rehabilitation. In particular, lake sturgeon and cisco numbers remain low, and both species appear only occasionally in fishery and assessment catches. Northern pike, muskellunge, sunfishes, crappies, and largemouth bass remain at low abundances from impairments to nearshore habitats. Actions, such as dam removal, watershed land management, and control of dredging, have been undertaken and should enhance such populations.

Recommendations

Here I identify seven issues that need to be addressed by the LEC and in ongoing assessment and research programs:

- Aquatic Nuisance Species (ANS)—the impacts of exotics, which appear to be yet expanding their ranges, need to be quantified and taken into account. Unilateral action should be taken to stop the addition or establishment of new ANS (Ricciardi 2001).
- Double-crested cormorants—research is needed to determine their impact on important harvested fishes. An effective regional control strategy that involves all jurisdictions with nesting cormorant colonies needs to be developed.

- Overharvest and overcapitalization—because of the CPMS, recruitment of one strong year-class should not lead to a major intensification of fisheries. Risk-based strategies and broad-based management plans should be implemented for all harvested species at risk of stock depletion due to poor recruitment and over-exploitation. Exploitation strategies that incorporate ecosystem health indices should be developed to stabilize the fish community and the fisheries.
- Pathogens and parasites—the impacts of diseases and parasites, such as type E botulism, *Heterosporis*, spring viremia virus of carp, largemouth bass virus, *Lymphocystis*, sea lampreys, parasitic copepods, and *Eustrongylides*, on stocks needs further research.
- Water levels—management agencies should explore strategies to capitalize on opportunities for habitat restoration owing to water-level changes.
- Climate change—global warming is likely already impacting the fish community; assessment of its potential effects in Lake Erie should begin.
- Nutrient cycling—dreissenid mussels and round goby have greatly affected nutrient cycling; the associated effects need to be quantified and taken into account by managers.

PAST AND PRESENT SALMONID COMMUNITY OF LAKE ERIE

James L. Markham[4]

Introduction

Less than 100 years ago, native salmonids, such as lake trout, cisco (formerly herring), and lake whitefish, were important components of the Lake Erie fish community and supported a major commercial fishery. Lake Erie has since experienced substantial ecosystem changes that forever changed the fish community. Most recently, aquatic invaders such as dreissenid mussels and round goby have kept the ecosystem in a state of flux. Lake Erie is considered to be a cool-water lake dominated by percids, such as walleye and yellow perch. However, rehabilitation of a balanced cold-water fish community, where lake trout are restored as the dominant predator and coregonines (ciscoes and lake whitefish), burbot, and sculpins are important ecologically, is a goal for the eastern basin of Lake Erie (Ryan et al. 2003). Below I present the current status and recent population trends of both native and non-native salmonids in Lake Erie, along with a description of their past history.

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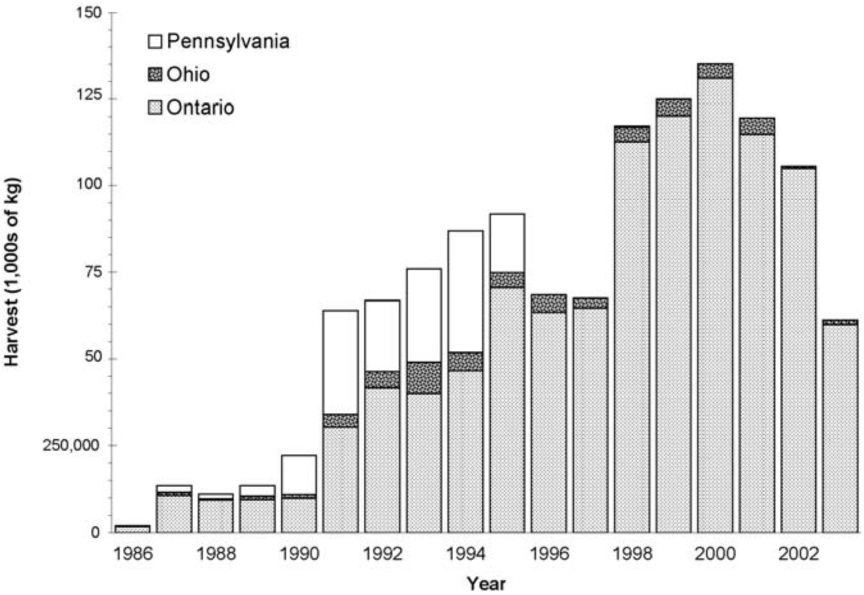
Native Salmonids

Whitefish, lake trout, cisco, and lake sturgeon (a non-salmonid) were considered the "Big Four" of commercial fishing in the Great Lakes (Bogue 2000). Historical accounts from fisheries documents, customs summaries, and newspaper articles (Cox 1992) reveal the extent of this fishery and include a 75-pound (34-kg) lake trout caught off Dunkirk, New York, in 1859; a harvest of 8 million kg of fish taken in 500-pound (staked) nets from the Detroit River in 1875; a quotation from 1893 that "whitefish all out of Lake Erie, and we are after the herring now"; and cisco catches of 24.5 million kg in only seven days off Lorain, Ohio. By the late 1950s, Lake Erie's cold-water fish community had completely changed from one dominated by lake trout, lake whitefish, and cisco to one without lake trout and with greatly reduced numbers of lake whitefish and cisco (Cornelius et al. 1995).

Lake Whitefish

Whitefish were, and still are, one of the most sought-after commercial species in the Great Lakes. Commercial harvest of whitefish in Lake Erie began in the 1850s and peaked around 1890 (Regier and Hartman 1973). Many spawning runs had deteriorated by 1900 due to over-exploitation and environmental degradation (Trautman 1981). By 1960, the whitefish fishery had collapsed (Regier and Hartman 1973). Of the native salmonids, only whitefish has recovered to any extent following over-exploitation and poor water quality that were present through the early 1970s. Commercial harvest of whitefish on Lake Erie has risen steadily since the mid-1980s and peaked in 2000 at >0.6 million kg (Fig. 10). The commercial harvest declined since then and amounted to a little more than 230,000 kg in 2003. The whitefish population remains stable with multiple age-classes of adults; a strong year-class was produced in 2003 (CWTG 2004). Body condition and size remain stable despite changes in the benthic food web.

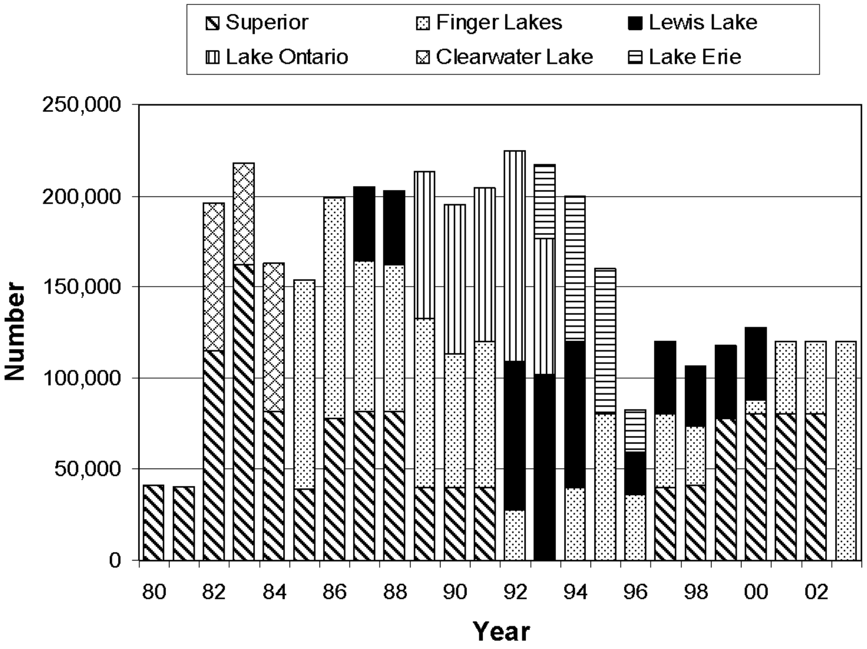
Fig. 10. Commercial harvest of whitefish during 1986-2003 by jurisdiction. Pennsylvania ceased gillnetting in 1996.



Lake Trout

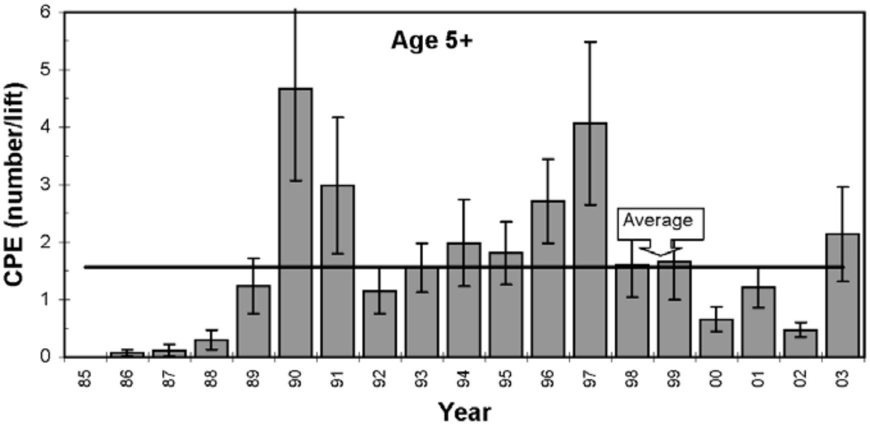
Intensive exploitation of lake trout began as whitefish stocks declined in the late 1800s (Bogue 2000). Annual catches exceeded 45,000 kg by 1900, and the species was over-exploited quickly owing to its slow growth and late maturity (Hartman 1972). A directed fishery continued into the 1930s, but catches made thereafter were generally bycatch in the whitefish and cisco fisheries. Lake trout were extirpated from Lake Erie around 1965 (Cornelius et al. 1995). Modern lake trout rehabilitation efforts began in 1969, when 17,000 yearlings were stocked by the PFC; stocking continued without the benefit of a focused plan through 1982 (Cornelius et al. 1995). Beginning in 1982, the Fish and Wildlife Service, in conjunction with the NYSDEC and the PFC, committed to an annual production and stocking of at least 160,000 yearlings annually (Fig. 11).

Fig. 11. Number of yearling lake trout by strain stocked in the eastern basin of Lake Erie, 1980-2003.



The initial rehabilitation objective of establishing an adult lake trout population was successful. Adult lake trout abundance peaked in 1990 (Fig. 12) in response to the initial treatments of sea lamprey producing streams in 1986 and 1987 and to annual stockings of 200,000 yearlings. These adults apparently spawned on nearshore reefs and around harbors (Culligan et al. 1995; Fitzsimons and Williston 2000). The adult population declined quickly as stocking was reduced from 200,000 yearlings per year before 1994 to 120,000 yearlings per year after 1996 due to concerns about inadequate forage (Einhouse et al. 1999). As stocking numbers were cut, sea lamprey control measures were relaxed (Sullivan et al. 2003). By 2000, adult lake trout abundance had declined to levels near those seen before lamprey treatments began, and it remained low thereafter (Fig. 12).

Fig. 12. Relative abundance (number/152.4 m of variable-mesh gillnet set overnight) of age-5 and older lake trout in New York waters of Lake Erie, August 1985-2003. Error bars are ±2 standard errors.



Successful natural reproduction of lake trout has yet to be documented (CWTG 2004). Lake trout growth and condition remain stable with condition coefficients well above 1.0 (CWTG 2004). Overall, the objectives established in the Lake Erie Lake Trout Rehabilitation Plan (LTTG 1985) are not being met, and, most importantly, sustainable natural reproduction has yet to occur. A revised 1985 plan that includes revised goals and objectives is needed to deal with the realities of a reduced lake trout stock and to meet the FCO of restoring “a self-sustaining population of lake trout to historical levels of abundance” (Ryan et al. 2003).

Cisco

Cisco was the dominate planktivore in eastern Lake Erie and the most-important food for lake trout. It was an extremely important commercial fish in Lake Erie through the mid-1920s (Hartman 1972). A resurgence occurred in 1945 and 1946, marking the last time that cisco were of commercial importance (Hartman 1972). Cisco are considered extirpated from Lake Erie, although commercial fishermen have recently reported occasional catches from the area around the Pennsylvania Ridge and the western basin shoals (Ryan et al. 1999; CWTG 2004). The recent recovery of other native cold-water fishes (burbot and whitefish) and the decline in abundance of rainbow smelt may create an opportunity for cisco rehabilitation in Lake Erie. Ryan et al. (2003) call for protection of rare species like cisco to prevent extinction. Restoration of cisco as the dominant planktivore in the cold waters of the eastern basin would serve to improve community structure and stabilize the forage base. Although cisco may yet be extant in Lake Erie, stocking and habitat improvements should be considered to expand the stock.

Brook Trout

Brook trout was never part of the salmonid community in the open waters of Lake Erie and, therefore, was not considered in Ryan et al. (2003). It was, however, the only native trout present in Lake Erie tributaries, occupying nearly every coldwater stream in the eastern United States and Canada during pre-colonial times (Trout Unlimited 2006). Populations declined and some were extirpated as water quality deteriorated owing to impacts from agriculture, forest cutting, and other human development (Trout Unlimited 2006). Native brook trout populations persist in the basin, mostly in isolated headwater streams. Range expansion remains limited due to competition with exotic trout (brown and rainbow trout) and poor water quality.

Non-Native Salmonids

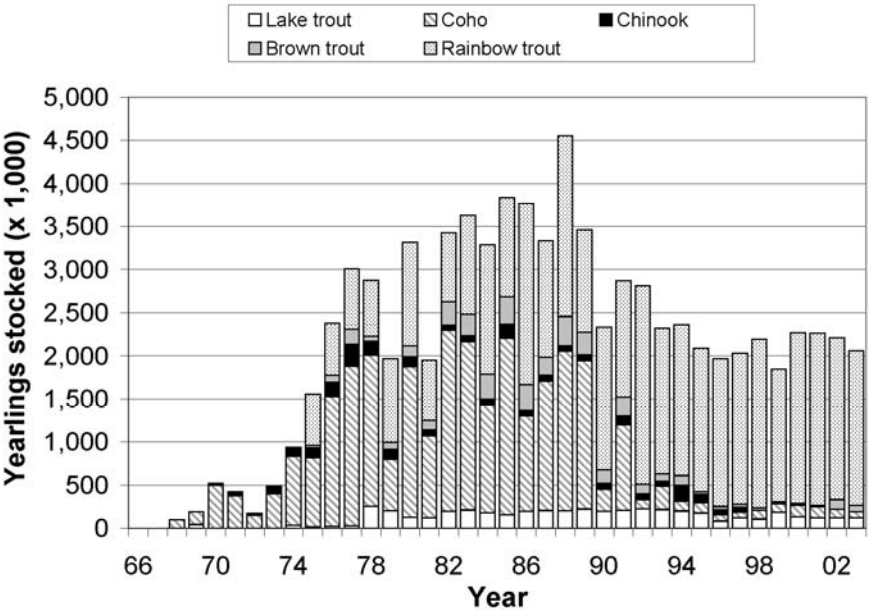
Non-native salmonids such as rainbow trout and Pacific salmon were introduced into the Lake Erie ecosystem in the late 1800s, but salmon did not establish until reintroduced in 1975 (Emery 1985). Non-native salmonids have been stocked extensively in Lake Erie since 1975, and stocking of rainbow trout has been very successful, with this fish becoming economically and ecologically important.

Rainbow Trout

In the Great Lakes, rainbow trout were stocked first in Lake Erie by Michigan in 1882. All jurisdictions were stocking this species by 1929 (Kustich and Kustich 1999; Crawford 2001). Various strains of rainbow trout have been stocked, primarily to support recreational fisheries (Crawford 2001). Pollution and exotic species kept rainbow trout populations low through the 1950s and 1960s (Kustich and Kustich 1999).

Stocking of rainbow trout resumed in Lake Erie in 1975 to fill the offshore niche created by the extirpation of the native lake trout (Fig. 13); good returns led to increased stocking by the early 1980s (CWTG 2004). Rainbow trout are the most-successful non-native salmonid in the fish community (Ryan et al. 2003). Nearly 2-million yearling rainbow trout are stocked annually lakewide, and natural reproduction has been documented in several New York streams (Mikol 1976; Culligan et al. 2004; Goehle 1998). Creel and angler diary surveys conducted over the past two decades indicate increasing trends in angler catch rates in New York and Pennsylvania streams (CWTG 2004; Murray and Shields 2004).

Fig. 13. Annual stocking of non-native salmonids in Lake Erie, 1966-2003. Numbers stocked are given in yearling equivalents.



Pacific Salmon

Chinook and coho salmon were first stocked in Lake Erie in the 1870s, but initial recoveries were poor and stocking ceased. Additional stockings occurred in the 1930s (Scott and Crossman 1973; Crawford 2001). Extensive stocking of Pacific salmon was resumed in the mid-1970s to fill an open-water niche, create recreational fisheries, and consume exotic prey, such as alewife and rainbow smelt (Crawford 2001). The initial results of these stockings were considered successful, but returns dwindled over time despite continued high stocking rates (Fig. 13). Interest in salmon declined in the late 1980s owing to poor returns, and stocking then began to shift to rainbow trout. All salmon stocking ended in Lake Erie by 2003. A few wild Chinook salmon are occasionally caught in New York tributaries (Markham 2006) and in the open lake (Culligan et al. 2004), but their impact on the fish community is negligible.

Brown Trout

Brown trout were introduced into Lake Erie around 1890, but stocking was sporadic thereafter. Brown trout were not widely accepted until native brook trout populations declined due to habitat degradation (Crawford 2001). Reproduction has never been extensive in any of the Great Lakes (Mills et al. 1993). Brown trout are a minor species and stocking of this species remains low (<80,000 fish per year), although it does provide additional recreational opportunities in the open lake and in tributaries, usually for anglers targeting rainbow trout.

Progress in Achievement of Fish-Community Goals and Objectives

Lake trout and burbot remain the key top predators in the offshore waters of the eastern basin, as called for in Ryan et al. (2003). However, the objective of achieving a self-sustaining population of lake trout is far from a reality, as discussed earlier. Lake whitefish are at sustainable population levels following a recovery in the mid-1980s. Cisco are essentially a rare species that will require a major effort to make it, once again, an important part of the lake's fish community.

Future Outlook for Salmonids

The future of the Lake Erie salmonid community remains in question. Efforts continue to rehabilitate native salmonid species, such as lake trout and cisco, but ecosystem changes have resulted in substantial impediments to both species. Although the lake whitefish population has undergone a resurgence, its abundance remains far below historical levels. Rainbow trout populations continue to be supported by stocking and natural reproduction, and they are expected to continue to contribute to the structuring of the lake's offshore pelagic fish community.

BURBOT IN LAKE ERIE

Martin A. Stapanian[5]

Introduction

In four of the five Great Lakes, burbot populations collapsed between 1930 and the early 1960s (Stapanian et al. 2007a). Collapses in Lakes Michigan, Huron, and Ontario were associated with sea lamprey predation, whereas the collapse in Lake Erie likely derived from a combination of over-exploitation, reduced water quality, and habitat degradation. In Lake Superior, burbot population density has remained relatively low and stable since 1978. Burbot populations recovered in Lakes Michigan, Huron, and Erie during the 1980s and 1990s as a result of sea lamprey control. Declines in alewife abundance appeared to be a second requirement for burbot recovery in Lakes Michigan and Huron (Eshenroder and Burnham-Curtis 1999; Madenjian et al. 2002; Stapanian et al. 2007a). Alewives have been suspected of interfering with burbot reproduction in Lake Michigan by consuming the pelagic fry of burbot and possibly by outcompeting the burbot fry for food (Wells and McLain 1973; Eshenroder and Burnham-Curtis 1999). Although sea lampreys have been effectively controlled in Lake Ontario, burbot populations have yet to recover, apparently due to an abundant alewife population (Stapanian et al. 2007a).

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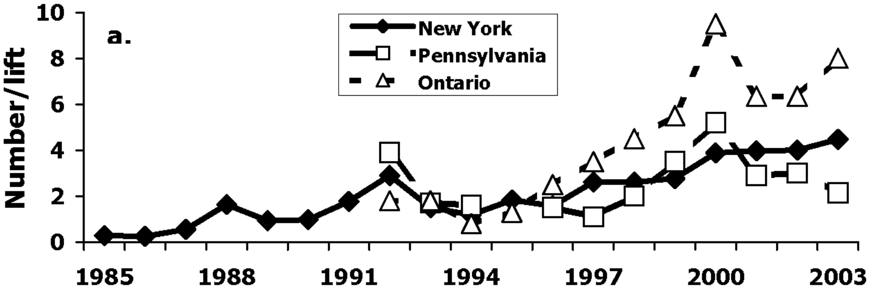
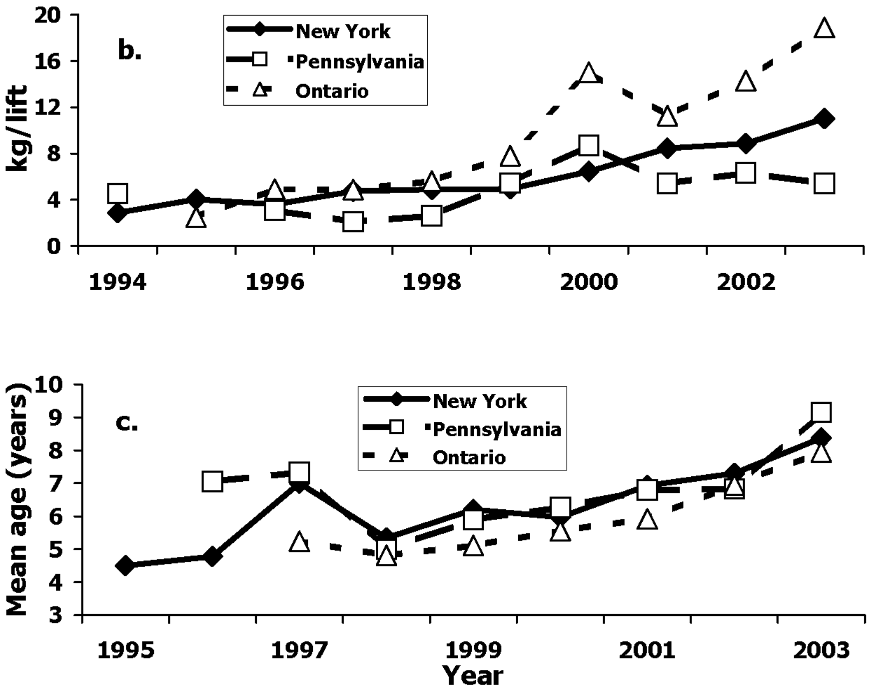
Current Status

Burbot in Lake Erie exhibited a strong recovery during 1985-2003, and the population increased most dramatically in Ontario waters, primarily during 1994-2000 (Figs. 1a, b) (CWTG 2005; Stapanian et al. 2006). Phosphorus loadings had substantially decreased and water quality had improved in Lake Erie more than ten years before the large increases in burbot abundance occurred (Stapanian et al. 2006 and references therein). However, the burbot population did not increase until after large reductions occurred in the sea lamprey population. A secondary reason for the burbot recovery was the "buffering effect" of a comparatively large population of adult lake trout during the few years when sea lamprey control was reduced (Stapanian and Madenjian 2007).

Fig. 14. (a) average number-per-lift, (b) average kg-per-lift, and (c) mean age (years) of burbot caught in annual gillnet assessments in three jurisdictions of eastern Lake Erie, 1985-2003 (CWTG 2005; Stapanian et al. 2006).





Alternative hypotheses for the Lake Erie recovery have also been tested, including reduced competition with lake trout, increased prey abundance, and reduced interference with burbot reproduction by alewife. However, none of these hypotheses were supported by the data (Stapanian et al. 2006). Total available energy of the main prey species of burbot did not increase during the period (Stapanian et al. 2006). Adult alewife density in eastern Lake Erie was extremely low in nearly all years of the survey, exhibited no temporal trend, and may always have been sufficiently low to allow for a burbot recovery (Stapanian et al. 2006).

A comparatively large lake trout population buffered the burbot population in Lake Erie against predation by sea lampreys during the few years (ca. 1996-1999) when lamprey control was reduced (Stapanian and Madenjian 2007). Mortality of burbot, based on catch-curve analysis, was lower during the period of reduced lamprey control than during the period of full control.

Burbot in Lake Erie achieve sexual maturity when they are 3 or 4 years old at a total length of about 500 mm (Stapanian et al. 2006; Stapanian and Madenjian 2007), which is smaller than the preferred prey size for sea lampreys (Swink and Fredericks 2000). The combined effects of the buffering effect by the lake trout population and the relatively early age and small total length at which burbot achieve sexual maturity enabled growth of the burbot population during the brief period when lamprey control was reduced (Stapanian and Madenjian 2007; Swink and Fredericks 2000). This buffering effect of lake trout against sea lamprey predation was shown previously for the burbot population in Lake Huron (Swink and Fredericks 2000) and for the lake whitefish population in Lake Michigan (Madenjian et al. 2002).

Mean total lengths at ages 4-9 were generally greater for burbot caught in New York waters than for those caught in Ontario or Pennsylvania waters of Lake Erie (Stapanian et al. 2007b). Similarly, mean weights at ages 4-6 were greater for burbot caught in New York waters than for those caught in Ontario or Pennsylvania waters. Further, total length at ages 4-10 were generally greater for burbot caught during 1994-2003 than those from published studies of other large lakes in North America and for Lake Erie in 1946 (Stapanian et al. 2007b).

One possible explanation for greater length- and weight-at-age of burbot caught in New York waters may be greater abundance of prey fishes, particularly rainbow smelt and round goby in New York waters, as compared with Ontario waters (Stapanian et al. 2006, 2007b). However, this hypothesis remains to be tested. Different vessels were used to determine prey abundance in New York and Ontario waters, and no calibration between the vessels (Tyson et al. 2006) was performed. The commercial fishery for rainbow smelt in Ontario waters may have affected prey abundance as well (Stapanian et al. 2006, 2007b). Alternatively, these regional differences in size-at-age may have been due to density-dependent effects on growth. Burbot abundance (measured both by number/gillnet lift and kg/gillnet lift) was greatest in Ontario waters in all years after 1995 (Fig. 14a, b) (Stapanian et al. 2006), and fish growth is inversely related to fish density (Pothoven et al. 2001; Madenjian et al. 2002). Future research will include bioenergetics studies that quantify prey consumption.

Mean age of burbot caught in annual assessment gillnets (CWTG 2005) increased steadily from approximately 5 years in all three jurisdictions in 1998 to, by 2003, approximately 8 years in Ontario and New York and 9.2 years in Pennsylvania (Fig. 14c) (Stapanian et al. 2007). By 2003, low recruitment resulted in the shift to older ages (Stapanian and Madenjian 2007). Future research will include developing population models in which age structure is a major component.

Conclusions

A goal of the Lake Erie Committee is 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). The recovery of the burbot population suggests that this goal has, in part, been achieved, and recovery should increase the stability of the deepwater food web of the eastern basin through top-down predation effects (Ryan et al. 2003).

PROGRESS TOWARD HABITAT-RELATED FISH-COMMUNITY OBJECTIVES

Jeffrey T. Tyson[6]

Introduction

The Lake Erie fish community has undergone extensive changes associated with nutrient enrichment, water-level fluctuations, fishery exploitation, and habitat degradation during the last century (Hartman 1973) and is undergoing recovery from its most-degraded state in the 1960s, thanks, primarily, to implementation of the GLWQA and to fisheries-management strategies to control exploitation. However, habitat degradation continues to be the primary factor responsible for changes in fish-community structure (Koonce et al. 1996). Specifically, the degradation of spawning and nursery habitat in tributaries and the nearshore environment continues to impede recovery of numerous species (Koonce et al. 1996). Habitat degradation continues to affect the ability of the LEC to achieve its fish-community goals and objectives (Ryan et al. 2003). The LEC recognizes that "maintenance of quality habitat is fundamental to fish and fish-community conservation; preservation and restoration of habitat must be the foremost concern for achieving the Fish Community Objectives." The specific goals and objectives for Lake Erie fish habitat are:

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- Nearshore habitat—maintain nearshore habitats that can support high quality fisheries for smallmouth bass, northern pike, muskellunge, yellow perch, and walleye
- Riverine and estuarine habitat—protect and restore self-sustaining, stream-spawning stocks of walleye, white bass, lake sturgeon, and rainbow trout
- Fish habitat—protect, enhance, and restore fish habitat throughout the watershed to prevent degradation and foster restoration of the fish community

The LEC has approached these habitat-related goals and objectives with three areas of emphasis. First, it has released position statements that establish direction with respect to restoration of fish habitat (HTG 2005). These position statements address issues beyond the scope of member management agencies. Second, in accordance with the Joint Plan (GLFC 2007), fisheries managers are developing environmental objectives that identify environmental and habitat conditions required to support achievement of the fish-community goals and objectives (Davies et al. 2005). Third, the LEC, on behalf of its member agencies, has been involved in several initiatives that address specific habitat components of the goals and objectives. The achievements in these three areas of emphasis are detailed below.

Position Statements

The LEC can release position statements concerning issues that are beyond the jurisdictional scope of member management agencies, and this authority is important to the well-being of the lake. Through 2004, the LEC has issued five such statements. Two of the statements, the Lake Erie Lakewide Management Plan (LaMP) rehabilitation statement and the draft water-level position statement, relate directly to achievement of habitat-related goals and objectives (HTG 2005).

In 2002, the LEC released a position statement (LaMP rehabilitation of nearshore habitat and lower tributaries) that endorsed the Lake Erie LaMP initiative promulgated under the GLWQA, and, in so doing, recognized that degraded fish communities in the nearshore waters and tributaries of Lake Erie indicate environmental degradation and a need for rehabilitation. LEC member agencies at all levels of organization have been involved in the development of the LaMP and continue to recognize the LaMP as a critical step for implementing programs that will assist the LEC in achieving its goals and objectives.

The LEC is currently developing a water-level position statement (HTG 2005) that will recognize the importance of the free migration of the shoreline below the ordinary high-water elevation, as well as the impacts that this free migration and associated re-vegetation of the shoreline will have on the member agencies' ability to restore a healthy fish community in nearshore and tributary habitats (Chubb and Liston 1985; Casselman 2002). This position statement recognizes that >90% of the southern shoreline of the western basin has been modified and extensively armored, thus altering physical energy in these areas and reducing the potential for establishment of submerged macrophytes (Ohio Environmental Protection Agency 2004). However, as the shoreline recedes from this armoring (due to decadal changes in lake level or climate change), the potential to re-establish nearshore submerged and emergent vegetation, thus contributing to restoration of natural coastal processes and connectivity, which allows for natural rehabilitation of habitat (Junk et al. 1989; Poff et al. 1997).

Environmental Objectives

The LEC is developing environmental objectives that outline issues or environmental/habitat conditions necessary to achieve the goals and objectives (GLFC 2007). The draft environmental objectives recognize that habitat conditions at three spatial scales influence fish-habitat relationships (Rabeni and Sowa 1996), including:

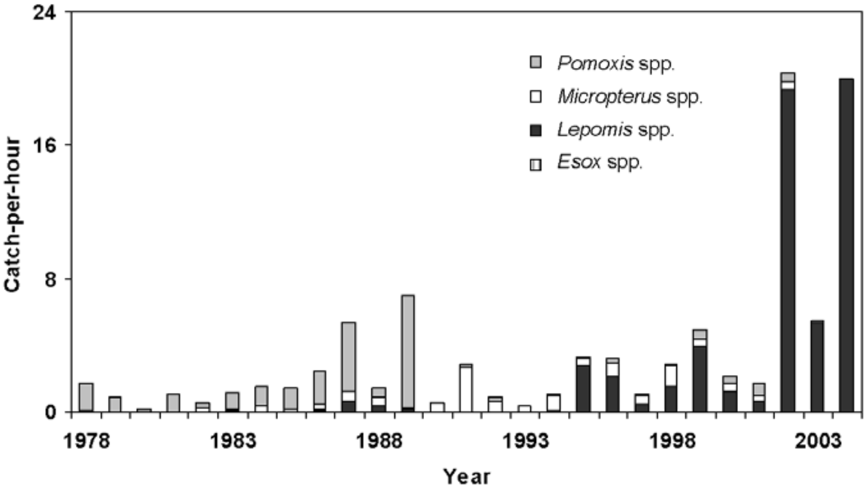
- Local-scale instream habitat/stream flows as they influence spawning habitat and outwelling zones (Odum 1980)
- Meso-scale nearshore zones influenced by tributary inflows, bays, lake-effect zones of rivers, and the interactions between these and coastal features
- Broad-scale offshore water masses defined by gyres, open-lake hydrodynamics, and large-scale inflows

To achieve fish-community rehabilitation and restoration, actions at multiple scales need to be considered. Ten environmental objectives for Lake Erie have been drafted (Davies et al. 2005), and they identify important environmental structures, processes, or conditions that must be addressed, if the fish-community goals and objectives are to be achieved. Several of the environmental objectives identify the need for mapping products that permit ecosystem monitoring and allow for targeted protection and restoration efforts. To this end, the LEC has actively supported the development of the Lake Erie Geographic Information System (LEGIS). The LEGIS is a geographic information system that provides scientists and managers with a centralized collection of spatially referenced data, which span jurisdictional and habitat boundaries (GLFC 2007). The LEGIS will be useful for identification of habitat features, monitoring of basin status, and development of targeted protection and restoration efforts, all of which address key habitat issues.

Nearshore Habitat

The LEC's member agencies have been involved in several initiatives that begin to address specific components of the fish-community goals and objectives. To address the goals and objectives dealing with nearshore habitat, several of the LEC agencies have begun quantifying the nearshore fish community by tracking changes in composition and abundance, as well as in habitat associations. One such program, the Ohio DNR's western basin trawling at <6-m depths, has documented substantial improvements in nearshore fish-community composition and abundance during the past decade (Fig. 15) (ODW 2007). These changes likely occurred owing to increases in water clarity (associated with dreissenid mussel invasion and phosphorus reductions), declining lake levels, and re-establishment of submerged aquatic macrophytes in harbor and bay areas along the southern shoreline. In particular, abundance of phytophilic species such as pumpkinseed and bluegill increased, while abundance of turbidity-tolerant species (e.g., white crappie) has declined. Few directed habitat protection and rehabilitation projects have been implemented in nearshore areas; therefore, these responses are likely a function of natural rehabilitation processes responding to invasive species and phosphorus abatement. The LEC is presently exploring ways to enhance this recovery through policy actions, as well as through directed restoration projects.

Fig. 15. Arithmetic mean catch-per-hour of nearshore fishes for western-basin bottom trawling in <6-m depths, Ohio waters, 1978-2004. Dressenid mussels were noticeable in 1986.



Riverine and Estuarine Habitat

LEC member agencies have sought to rehabilitate self-sustaining stream-spawning stocks of walleye by protecting and restoring tributary and estuarine habitats. The OMNR has developed an east basin rehabilitation plan, which recognizes the importance of the Grand River walleye stock to east basin fisheries. The plan focuses on rehabilitation of water quality and habitat in the lower reaches of the Grand River (Fig. 1). In 1994, the NYSDEC developed a Lake Erie walleye spawning-stream rehabilitation plan, which included habitat remediation, control of exploitation, and stocking of fingerling walleye (NYSDEC 1994). To implement the plan, Cattaraugus Creek (Fig. 1) was selected for rehabilitation, and actions included restrictions on fishing and gravel mining and stocking of juvenile walleyes. During 1994-2000, extensive monitoring suggested that the stocking effort had expanded the Cattaraugus Creek spawning population, however, some confounding factors do exist (NYSDEC 2003). The NYSDEC will continue monitoring the results of its effort in Cattaraugus Creek and extend rehabilitation to the Buffalo River (Fig. 1) in the near future.

Progress and Recommendations

Many perturbations continue to influence the LEC's ability to achieve its fish-community goals and objectives. With respect to those relating to habitat, progress has been made, particularly through advocacy (position statements) and collaboration (participation in the LaMP), mapping initiatives (LEGIS), and fish-community monitoring (nearshore and tributary). However, substantial work remains, particularly with respect to re-establishing self-sustaining stocks historically important in the nearshore fish community. The LEC's position statements have elicited positive responses from stakeholders, as well as from state/provincial/federal agencies; however, these statements have not been used effectively in the policy arena. The LEC should continue to develop position statements and seek to more rigorously use them. As geospatial data become available, they should be integrated into the LEGIS, thereby keeping it current. Proprietary issues with respect to GIS data need to be resolved to better make such information available to fisheries management and research communities. In addition, LEC agencies should integrate LEGIS data into management strategies and expand research that directs rehabilitation and restoration in areas of greatest return.

Progress is being made on a site-specific basis, but large-scale projects that enhance the productivity of the fish community have yet to come to fruition (e.g., GLWQA). Indeed, some perturbations are beyond the control of fisheries-management agencies (e.g., water-level changes, climate change); however, LEC member agencies should continue to pursue protection and enhancements despite these changes, particularly when opportunities present themselves. LEC member agencies should collaborate more to increase an understanding of how tributary and nearshore habitat influence commodity and heritage species. The LEC should continue to support modeling that uses spatially explicit physical/process information in support of restoration and exploitation strategies. Member agencies also should continue to support ecosystem-based fisheries management and the associated modeling that incorporates watershed-level effects in fish-community dynamics. Lastly, the LEC should more clearly define direction relating to habitat-related goals and objectives, and outline a strategy for implementation. Many of the habitat-related fish-community goals and objectives have poorly defined measures and targets. The development of the LEGIS should assist the LEC in developing more-explicit goals and objectives and in targeting locations for future restoration of the aquatic community.

PAST, PRESENT, AND FUTURE OF INTEGRATED SEA LAMPREY MANAGEMENT IN LAKE ERIE

W. Paul Sullivan[7] **and Michael F. Fodale**

Introduction

Sea lampreys were first observed in Lake Erie in 1921 (Dymond 1922). At the time, poorly regulated exploitation of lake trout had been ongoing for decades (Cornelius et al. 1995), and sea lamprey predation is thought to have played a minor role in their extirpation from the lake (Hartman 1972). A lack of preferred prey, coupled with degraded water quality and habitat in nursery streams and eutrophication of the lake, likely limited sea lamprey abundance in Lake Erie for many decades (Pearce et al. 1980; Sullivan et al. 2003).

An upturn in sea lamprey abundance in Lake Erie during the 1970s coincided with the signing of the GLWQA and the advent of programs to restore lake trout in the eastern basin and to provide a sport fishery for Pacific salmonids. While water quality had improved sufficiently to permit survival and growth of stocked salmonids, mortality induced by an expanding population of sea lampreys imposed limits to their success (Kenyon 1978; Cornelius et al. 1995).

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Implementation of Sea Lamprey Control in Lake Erie

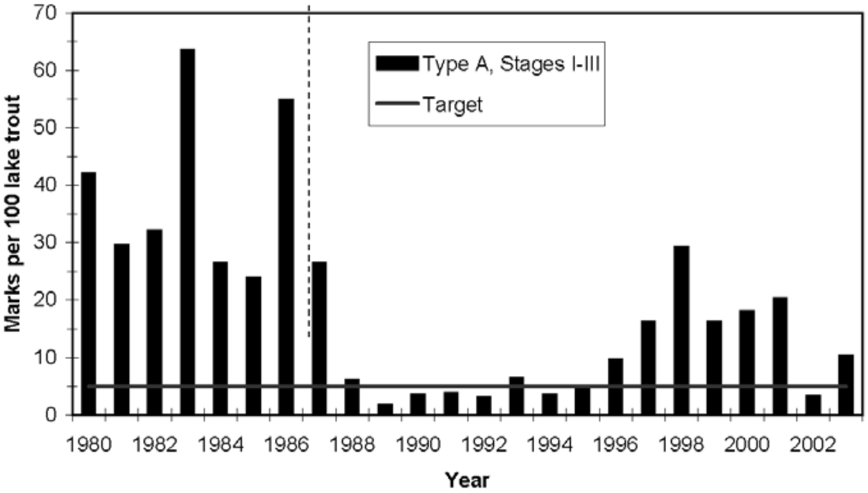
The GLFC approved the Sea Lamprey Management Plan for Lake Erie in 1985 following completion of the Strategic Plan for the Rehabilitation of Lake Trout in Eastern Lake Erie. Progress was to be measured against the following suppression targets:

- Fresh sea lamprey marks on lake trout should be <5%
- Catches of spawning-phase sea lampreys should be <10% of pre-treatment levels (roughly 1,700)
- Nest counts of sea lamprey should be <2 per km of stream spawning habitat adjusted to a standard

Sea lamprey control consists primarily of the application of the selective lampricide 3-trifluoromethyl-4-nitrophenol (TFM) to kill larvae in their natal streams, and treatments of infested tributaries began in 1986. By fall 1987, 18 of 20 known stream producers had been treated. In addition, seven low-head barriers were constructed in Canadian tributaries during 1988-1996 to prevent spawning-phase sea lampreys from reaching suitable spawning habitat. The need for treatments was eliminated in four of the seven streams and greatly reduced in the other three. At the same time, trapping operations began on 4-5 tributaries to intercept spawning-phase sea lampreys during their upstream migration. In addition to reducing reproduction, trapping provides sea lampreys for mark-recapture studies used to estimate lakewide abundance (Mullet et al. 2003).

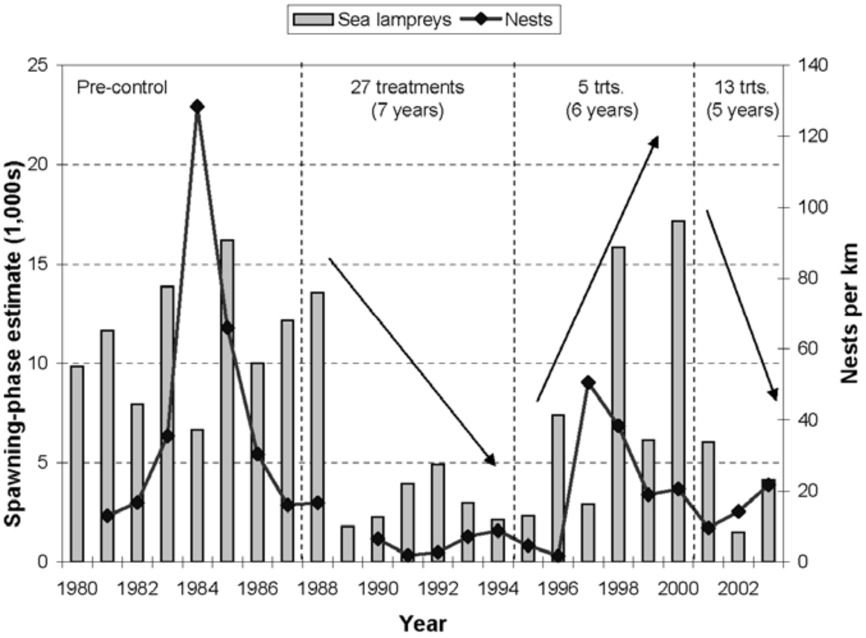
Early control efforts on Lake Erie reduced dramatically the sea lamprey population. The number of parasitic-phase lampreys collected in 12 commercial fisheries in Canadian waters of the lake declined precipitously from 1986 to 1990, after which monitoring was terminated because of a lack of captures (Sullivan et al. 2003). During the same period, fresh marking rates (Type A, Stages I-III combined) on lake trout in New York waters of the eastern basin declined from 54.9 to 3.6 per 100 lake trout (Fig. 16), lakewide abundance of spawning-phase sea lamprey fell from 10,007 to 2,283 (Fig. 17), and nest counts in New York tributaries dropped from 10.0 to 1.2 per standard stream section (Fig. 17). Also encouraging were the results of re-establishment surveys, which showed that only 9 of 18 treated streams became re-infested with larvae.

Fig. 16. Type A, Stages I-III sea lamprey marks per 100 lake trout >532 mm total length, New York waters of Lake Erie, 1980-2003 (data from Einhouse et al. 2004). Dashed vertical line shows when treatments of sea lamprey producing streams began.



Unfortunately, successful suppression, after treatments began in 1986, was followed by increased sea lamprey abundance and marking rates, beginning in 1996 (Figs. 16, 17). Sullivan et al. (2003) have hypothesized that several control-practice changes during the 1990s compromised suppression efforts in Lake Erie. In 1991, a new lampricide treatment protocol, which used stream pH (rather than alkalinity) as a basis for determining TFM application rates, was implemented (Brege et al. 2003). Based on laboratory studies aimed at providing greater safety for nontarget organisms, the new protocol reduced the mean lethal concentration used during treatments by 31%. At about the same time, the GLFC's *Strategic Vision of the Great Lakes Fishery Commission for the Decade of the 1990s* (GLFC 1992) called for a 50% reduction in lampricide use to reduce the reliance on expensive lampricides and to respond to an environmentally conscious public that was perceived as becoming less tolerant of pesticides. Last, in 1996, the Empirical Stream Treatment Rank model was implemented to rank streams across the Great Lakes basin as priorities for treatment using data generated by quantitative larval assessments (Christie et al. 2003). Treatment rankings were determined by dividing projected treatment costs by the number of larvae anticipated to undergo metamorphosis in the year of treatment. Lower production of metamorphosing sea lamprey in Lake Erie meant that few of its streams ranked well against those in other Great Lakes, and, consequently, few were treated. The net result of these changes in control was that, during 1993-1998, only five stream treatments were made, whereas 27 treatments had been made in the previous 7 years (Fig. 17). Average annual TFM application from 1993 to 1999 was about one-half of the economic injury level target for the lake, which had been projected to drive the population down to 1,500 sea lampreys (Sullivan et al. 2003).

Fig. 17. Abundance of spawning-phase sea lamprey (Markham et al. 2004) and mean nest counts per km of standard stream section (Einhouse et al. 2004) for Lake Erie, 1980-2003. The era of control (1989-2003) is divided into three time periods to better show the relationship between the number of treatments and sea lamprey abundance. Period boundaries incorporate a two-year lag between treatment of larval populations in streams and impact on spawning-phase abundance.



By 1998, marking rates on lake trout approached pre-control levels (Fig. 16). Larvae that had survived sub-lethal exposure to lampricide or found refuge in untreated portions of streams, in addition to those originating from tributaries where the interval between treatments was excessive, were theorized to be the primary contributors to the lake's parasitic population (Sullivan et al. 2003). The subsequent decline in lake trout survival as a result of sea lamprey-induced mortality, combined with a reduction in lake trout stocking begun in 1996 (Murray et al. 2000), made achievement of lake trout rehabilitation objectives in Lake Erie unlikely. In recognition of this turn of events, 13 stream treatments were made during 1999-2003, and assessment efforts on larvae were intensified. Greater emphasis was placed on evaluating residual populations surviving treatment and on identifying untreated sources. By 2001, these measures began to reduce the sea lamprey population (Figs. 16, 17).

Future Direction

Of the five Great Lakes, Lake Erie has the fewest suitable sea lamprey nursery streams, and, theoretically, effective control should be simplest to achieve. However, a relatively small lake trout population is confined mostly to the eastern basin, where small increases in sea lamprey production or survival can have major negative impacts. Undoubtedly, the sea lamprey population has benefited from improved water quality (Ferreri et al. 1995; Zint et al. 1995) and greater abundance of prey (Cornelius et al. 1995; Stapanian et al. 2006).

Achievement of the lake's economic injury level (GLFC 2001) will require accurate mapping of the distribution of larvae in streams, such that lampricides can be applied with the greatest effect. Also promising, beginning in 2004, lake-specific fish-damage estimates will become part of the treatment ranking process and may result in more treatments. Existing sea lamprey barriers and traps will continue to be maintained and operated, and plans for new construction will be evaluated. Potential alternatives to lampricide application may include the use of pheromones to improve trapping or disrupt spawning migrations. Researchers have identified sea lamprey-specific migratory and sex pheromones that elicit strong behavioral responses in laboratory studies (Sorensen and Vrieze 2003; Li et al. 2003).

Field testing and synthesis of these chemicals are the next steps toward providing additional control methodologies for Lake Erie.

CAN THE INVASIVE FISH, THE ROUND GOBY, BE CONTROLLED?

Lynda D. Corkum[8], W.J. Arbuckle, Andrea J. Belanger, Donald B. Gammon, Weiming Li, A.P. Scott, and Barbara Zielinski

Introduction

Efforts in Great Lakes jurisdictions seek to control the entry of invasive species introduced through ballast water, canals, and recreational boating (Vásárhelyi and Thomas 2003). However, few practices exist to control established invasive species without affecting nontarget species or resulting in environmental damage, although sea lamprey control in the Great Lakes comes closest to this ideal (GLFC 2007). Control of the sea lamprey involves lampricides, stream barriers, and sterile-male release, and a pheromone strategy is being developed (Jones et al. 2003; Sorensen and Stacey 2004).

Pheromone-based communication is critical to the maintenance of many fish populations through its effect on mating behavior (Stacey and Sorensen 2002). Additionally, the GLFC has identified pheromone control as one of the more-promising techniques for the future (GLFC 2001). Here, we explore the potential use of a pheromone-based control for introduced round goby.

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Native to the Black and Caspian seas, the round goby likely was introduced to the Great Lakes in ballast water (Jude et al. 1992). First reported in 1990, it quickly spread to all five of the Great Lakes and has begun to invade the Mississippi River basin (Charlebois et al. 2001). Reasons for its proliferation include its broad diet and availability of molluscan prey (adults eat mainly dreissenids), aggressiveness, high fecundity, multiple spawning (up to six episodes per year), and male parental care (Corkum et al. 2004). The round goby competes with native fish, such as mottled sculpin (Dubs and Corkum 1996; Janssen and Jude 2001), feeds on eggs and fry of native fishes (Nichols et al. 2003; Steinhart et al. 2004), and alters ecological function by changing energy and contaminant pathways (Morrison et al. 2000; Kim 2007; Southward-Hogan et al. 2007). Round goby alter the movement of contaminants through the food web by feeding on dreissenids (Ray and Corkum 1997). Dreissenids take up contaminants by filtering particles onto which contaminants are sorbed. Because round goby are prey of piscivorous fishes, contaminants continue to be transferred and magnified up the food chain. Thus, despite reduction of PCB inputs in the Great Lakes, PCBs are being recycled in the environment (Stow et al. 1995). The contaminant transfer from dreissenids to piscivores by the round goby presents a challenge for the Lake Erie FCO of reduced contaminants, eliminating advisories for human consumption of fishes (Ryan et al. 2003).

Based on our observations that a single male attracts up to 15 females to deposit eggs in its nest (MacInnis and Corkum 2000), we hypothesized that reproductive male round goby release sex pheromone(s) to attract reproductive females. Understanding how female round goby are attracted to a nesting reproductive male is the first step in developing a pheromone-based strategy that could be used to disrupt the reproductive habits of the round goby. To test our hypothesis, we compared the behavioral and physiological responses of reproductive and non-reproductive female round goby to odours of conspecific reproductive and non-reproductive males in conditioned water (male washings).

Methods

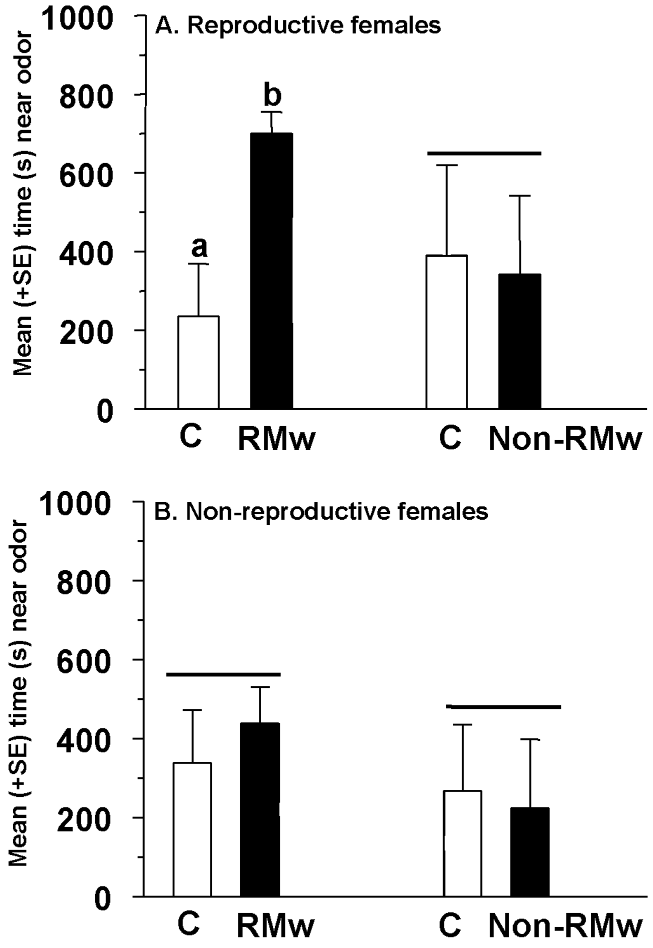
We first collected and concentrated water into which potential pheromones from male round goby were released. Each donor fish was placed alone in 1 L of dechlorinated aerated tap water for 4 h, and each donor fish was used only once. After 4 h, 500 mL of this "conditioned" water was used for trials. Next, we conducted laboratory experiments to determine if both reproductive and non-reproductive females spent more time near an odor source released by reproductive males, as compared with non-reproductive male round goby. Each trial was 75 min and consisted of three sequential periods: a 30-min acclimation period in which no water was added, a 15-min control period in which dechlorinated (control) water was added, and a 30-min stimulus period in which either conditioned water or control water was added. Our expectations were that female (especially reproductive female) round goby should respond more to male odors than to control water.

We also quantified electro-olfactogram (EOG) activity by females in response to both reproductive and non-reproductive male-conditioned water before and after extraction with solid-phase octadecysilane (C18) cartridges and after separation on reverse-phase high-performance liquid chromatography (HPLC). Fractions of 1 min were collected between 18 and 68 min, i.e., the range over which steroids elute.

Results

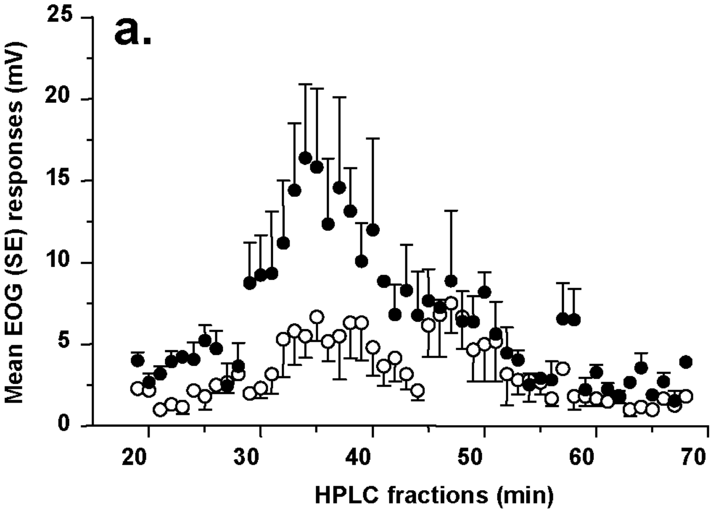
As expected, reproductive females spent more time (mean ± SE) near the source water when odors from reproductive males (700 ± 56 s) were delivered, compared with odors from control water (237 ± 133 s) (1-tailed *t*-test$_{(df=8)}$ = 3.214, $P < 0.01$). Time spent near the source for reproductive females did not differ between non-reproductive-male (342 ± 201 s) and control-water (390 ± 230 s) trials. Non-reproductive females did not distinguish between odors from reproductive or non-reproductive males when each was compared with control water (Fig. 18).

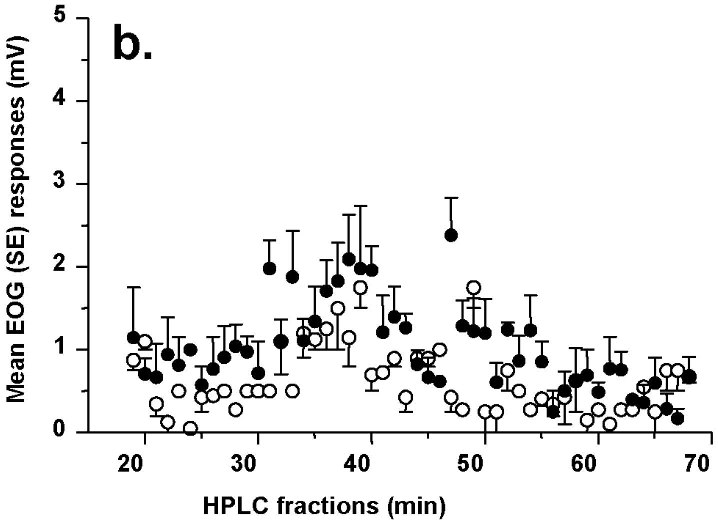
Fig. 18. Mean time (s) spent by reproductive females (A) and non-reproductive females (B) in response to control water (open bars) and water conditioned by males (solid bars). RMw is reproductive male water, and Non-RMw is non-reproductive male water. Numbers a and b in the graph indicate significant differences ($t = 3.214$, $P < 0.01$) between times spent near the input odor source. The solid line above the bars indicates that there were no significant differences in response (adapted from Corkum et al. 2006 with kind permission of Springer Science and Business Media).



Reproductive females exhibited EOG responses to all HPLC fractions of methanol eluate trapped from C-18 filtration of reproductive male water. Each fraction was presented to females in a random order to test for a response. Specifically, reproductive females had higher EOG responses to reproductive male HPLC fractions than to non-reproductive male HPLC fractions (Hotelling's *t*-test, $T^2 = 39.6$, $P < 0.0001$). The largest differences in mean EOG activity exhibited by reproductive females to male odor occurred between HPLC fractions 30 and 40 min (Fig. 19), which is interesting because most conjugated steroids tend to elute in fractions between 20 and 40 min (Vermeirssen and Scott 1996). These findings suggest that if the round goby pheromones are steroids, they are likely to be conjugated. Conjugated steroids, released in urine and feces, are more soluble in water than free steroids and, therefore, potentially more likely to be utilized as pheromones (Scott and Vermeirssen 1994).

Fig. 19. Mean EOG responses of reproductive females (a) and non-reproductive females (b) to HPLC fractions of methanol eluate after C-18 solid-phase extraction of reproductive male water (solid circles) and non-reproductive male water (open circles) (adapted from Corkum et al. 2006 with kind permission of Springer Science and Business Media).





The EOG responses by non-reproductive females to reproductive male fractions differed when compared with non-reproductive male fractions (Hotelling's *t*-test, $T^2 = 21.5$, $P < 0.0001$), but not to the same extent as reproductive females (Fig. 19). Overall, the EOG responses by reproductive females were about 8-fold higher than non-reproductive females to reproductive male fractions.

Conclusions

Results from these two experiments illustrate that odors of mature male round goby induce behavioral and physiological responses in reproductive conspecific females. Specifically, a chemical signal (released in the washings of reproductive males) lures reproductive females to a specific location, presumably to the nest of the parental male in the field.

The control of invasive species, particularly round goby, will likely arise from multiple strategies. In the future, the impacts of invasive species may be reduced through the use of pheromones, resulting in more-sustainable harvests of commercial and sport species. Sorensen and Stacey (2004) suggest that pheromone traps used in concert with acoustic and light attractants would be an effective option to control invasive species, if directed at ripe fishes. Depending on the species, male or female odors could be used to attract and remove members of the opposite sex. Additionally, pheromones could be used to disrupt reproductive success, disrupt or divert migrations, promote the success of sterilized fishes, repel fishes (alarm cues), and assess population size and distribution (Sorensen and Stacey 2004). A challenge is to develop a mechanism to deploy and effectively disperse synthetic pheromones in the field. We suggest that reproductive male odors may be useful in developing a control strategy using natural pheromones to disrupt the reproductive behavior of the invasive round goby and to curtail its effects on native species.

THIAMINE STATUS OF TOP PREDATORS IN EASTERN LAKE ERIE, 1992-2004, AND ITS RELATION TO REPRODUCTION

John D. Fitzsimons[9], Scott Brown, Lisa Brown, Lenore Vandenbyllaardt, and Tom Johnson

Introduction

In the Great Lakes, thiamine deficiency in salmon and trout (Marcquenski and Brown 1997; Fitzsimons and Brown 1998) has been associated with a diet dominated by either alewives or rainbow smelt, species that contain relatively high amounts of thiaminase (Tillitt et al. 2005). For alewife, thiaminase activity has been shown to vary among stocks (Fitzsimons et al. 2005) and, within a given stock (Lake Michigan), shows variation related to year, season, and size (Tillitt et al. 2005). The dietary link occurs in fish because thiamine, a B vitamin (vitamin B1), can only be obtained through the diet of consumers.

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For most prey species, including alewife, thiamine levels in muscle tissue appear adequate to support trout and salmon (Fitzsimons et al. 1998). Thiaminase, in contrast, is an enzyme that destroys thiamine. Sources of thiaminase in prey fish like alewife include thiaminase-producing bacteria in the gut (Honeyfield et al. 2002) but likely also include dietary sources, although the relative contribution of each is unknown. Considerable variability in the thiaminase activity of different fish species exists, suggesting that development of thiamine deficiency in consumers will be highly dependent on diet composition (Table 2). Gizzard shad and spottail shiner had the highest average thiaminase activity and were followed by alewife and rainbow smelt. Thiaminase activity of deepwater sculpin, ninespine stickleback, bloater, round goby, and yellow perch were much lower.

Table 2. Mean thiaminase activity (pmol thiamine destroyed$\cdot g^{-1} \cdot min^{-1}$) in various species of Lake Michigan fish sampled in 1998-2000. Data from Tillitt et al. (2005).

Species	Activity
Spottail shiner	32,700
Gizzard shad	31,800
Alewife	4,280
Rainbow smelt	2,640
Deepwater sculpin	172
Ninespine stickleback	85
Bloater	35
Round goby	18
Yellow perch	12

Thiamine deficiency is of concern, because it results in a variety of lethal and sublethal effects, all of which may affect recruitment of salmonines (Brown et al. 2005a). Most prominent is the acute lethality or Early Mortality Syndrome (EMS) that occurs as trout and salmon fry emerge from their spawning habitat. Signs include loss of equilibrium, hyperexcitability, reduced yolk-sac utilization, and swimming in a spiral pattern. The syndrome ultimately results in death if affected fry are not treated with thiamine (Fitzsimons 1995; Fitzsimons et al. 2001; Brown et al. 2005b), which effectively reverses the deficiency effects. Thiamine immersion of eggs or fry is now routinely used by hatchery personnel to treat thiamine deficiency and counteract the effects of an alewife-dominated diet. This remedy is not available for fry hatched in the wild.

Less is known about the sublethal effects of thiamine deficiency that occur at higher egg-thiamine concentrations. Although these effects do not result in outright mortality, they can seriously compromise survival. The tentative egg-thiamine-concentration threshold for growth effects (i.e., specific growth rate) in larval lake trout of 4 nmol·g^{-1} is approximately 2.5-fold higher than the concentration predicted to result in 50% EMS mortality (Fitzsimons et al. 2007).

Lake Erie Thiamine Deficiency

Lake Erie lake trout have not been as closely monitored for thiamine-deficiency effects as those from Lakes Ontario and Michigan (Fitzsimons et al. 1999; Brown et al. 2005a; Fitzsimons et al. 2007); however, they may be at risk because rainbow smelt, a species containing relatively high thiaminase activity, is the dominant prey species (J.L. Markham, personal communication, 2004). Fisher et al. (1996) reported that EMS accounted for 25.2% of the mortality in lake trout eggs sampled from Lake Erie in 1992; however, only six fish were sampled. This level of EMS, although based on a small sample size, was considerably lower than the 67% reported for affected Lake Ontario lake trout during 1994 (Brown et al. 1998). The average egg-thiamine concentration (3.1 nmol·g^{-1}) for the six Lake Erie lake trout was close to the effective dose at which 20% (ED20) of the Lake Ontario lake trout tested by Fitzsimons et al. (2007) expressed EMS (2.63 nmol·g^{-1}) and was consistently higher than the mean annual egg-thiamine concentration over a ten-year period reported by these same authors for Lake

Ontario lake trout. In 1996, additional lake trout egg collections were made in Lake Erie, but no EMS was observed in the fry hatched from the eggs of 12 fish. The lack of EMS in 1996, as compared to 1992, was consistent with the mean egg-thiamine concentration (4.25 nmol·g^{-1}), which exceeded both the ED50 (1.57 nmol·g^{-1}) and the ED20 (2.63 nmol·g^{-1}) (Fitzsimons et al. 2007). Whether this change was the result of a declining proportion of rainbow smelt in the diet or other factors is not known. Nevertheless, despite showing annual variability, the mean thiamine concentration in Lake Erie lake trout that fed primarily on rainbow smelt was always higher than that for Lake Ontario lake trout that fed on alewife (Fitzsimons et al. 2007), suggesting that Lake Erie lake trout are at a lower risk of developing thiamine deficiency than Lake Ontario lake trout. Although resulting in a less-serious thiamine deficiency, the rainbow smelt diet could impact reproduction in some years, because average egg thiamine was below the tentative threshold for larval growth effects (e.g., 4 nmol·g^{-1}) in two of three years examined.

Lake Erie rainbow trout also appear to be affected by thiamine deficiency. The eggs of nine rainbow trout collected in 1996 developed EMS, with mortality that averaged 14.9% (range 1.4-31.6%). The thiamine concentration, measured in the eggs of five of the females, averaged 4.39 nmol/g. The relatively low occurrence of EMS in these samples was consistent with the threshold for rainbow trout that is in excess of 2 nmol·g^{-1} (Hornung et al. 1998) but below 12.9 nmol·g^{-1} (Marcquenski and Brown 1997). The occurrence of EMS in Lake Erie rainbow trout was lower than that reported for Lake Ontario (30%) during the period 1978-1984 (Skea et al. 1985) or for Lake Michigan (43%) during 1993 (Hornung et al. 1998) and may reflect the relative importance of alewife in the diet of rainbow trout from these lakes.

Walleye is also a top predator in Lake Erie's eastern basin, but the effects of a smelt diet on thiamine-deficiency-mediated-reproductive success are less clear for this species, as compared to lake and rainbow trout. In 2004, 12 walleye were sampled from the Grand River (Ontario) in Lake Erie's eastern basin (Fig. 1), and mean egg-thiamine concentration (3.70±0.36 nmol·g^{-1} (mean±SE)) was less than one-third the average for 24 walleye sampled during 2004 from southern Lake Winnipeg (13.31±0.37 nmol·g^{-1}). Johnson et al. (2005), however, was unable to relate variation in early-life-stage survival of Bay of Quinte (Lake Ontario) walleye to egg-thiamine concentration that averaged 4.58±2.08 nmol·g^{-1} (range 2.17-12.25 nmol·g^{-1}). Similarly Honeyfield et al. (2005) could not relate the reproductive status of walleye stocks in three southern U.S reservoirs to their mean egg thiamine concentrations that ranged from 2.13 to 3.14 nmol·g^{-1}. Although the thiamine concentration of Lake Erie walleye appears to be affected by its smelt-dominated diet, reproductive effects seem unlikely.

Conclusions

Lake Erie lake trout and rainbow trout are at risk for reduced reproductive success associated with thiamine deficiency in their eggs, although a more-complete analysis is not possible until an assessment of sublethal effects has been completed. However, the EMS-related impacts appear less severe in Lake Erie as compared to other Great Lakes (e.g., Lakes Ontario and Michigan) where alewife is the dominant prey fish. Although walleye in the eastern basin also consume rainbow smelt and appear to show declines in egg-thiamine concentration associated with this diet, comparisons with other systems where walleye consume alewives suggests that current egg-thiamine concentrations will unlikely affect reproductive success.

UPDATE ON BOTULISM IN LAKE ERIE

Helen M. Domske[10]

Botulism in Lake Erie

Avian botulism, a disease caused by *Clostridium botulinum*, has been recognized as a major cause of mortality in migratory birds since the 1900s. Although type C has caused the die-off of thousands of waterfowl (especially ducks) across the western United States, type E has been somewhat restricted to fish-eating birds in the Great Lakes. During 1999-2003, large die-offs of fish and waterfowl occurred in Lake Erie and Lake Ontario, and type E botulism was isolated with these outbreaks. The bacterium is classified into 7 types (A-G) by characteristics of the neurotoxins that are produced. The toxins produced by *Clostridium botulinum* are among the most-potent biological poisons, warranting human health and safety concerns. From 1960 to 1963, 11 cases of human type E botulism were reported in Lake Michigan and Lake Huron, from improperly prepared fish.

In birds, the neurotoxins bind to the receptors on nerve endings, impacting neuromuscular function, which results in a paralytic effect. Impacted waterfowl typically show signs of weakness, dizziness, inability to fly, muscular paralysis, and respiratory impairment. The necks of impaired birds may become so weak that the animal actually drowns. Often the inner eyelid or nictitating membrane becomes paralyzed, impairing the bird’s normal vision. Impacted fish typically show signs of disorientation, erratic swimming patterns, muscular paralysis, respiratory impairment, and complete ataxia (the inability to coordinate muscular activity).

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Although both type C and type E avian botulism outbreaks occurred in the Great Lakes in the past, there are some significant differences between the two types. Type C botulism primarily impacts dabbling ducks and bottom-feeding waterfowl, although shorebirds may also fall victim to this type of botulism. In type C botulism, the spores do not produce toxin until they are infected by a “phage” or virus. This relationship with a virus does not exist with type E. Type E botulism typically impacts fish-eating birds, such as loons and grebes. Several species of gulls that are common in the Great Lakes region have been impacted by both type C and type E botulism. Fish may also contain the type E toxin, and feeding on these fish can pass the disease to waterfowl. The type E toxin has been found in round goby and researchers are studying the role this invader may play in recent outbreaks of the disease in Lake Erie.

Spores of both type C and type E botulism are naturally found in anaerobic habitats such as soils, aquatic sediments, and intestinal tracts of animals. The spores can remain in the ecosystem for extended periods of time, even years, and are quite resistant to temperature variations and drying. In the absence of oxygen, with a suitable nutrient source, and under favorable temperatures and pH, vegetative growth of the spores can occur (Brand et al. 1988). Decaying fish and insect carcasses provide favorable conditions for *Clostridium* because the decay process uses up oxygen and creates anaerobic conditions (Friend et al. 1996). Not all spores contain the toxin, but those that do can impact wildlife that ingest this powerful neurotoxin.

Types C and E botulism are believed to perpetuate through a carcass-maggot cycle. Birds and fishes that have died from botulism decompose and become hosts for maggots. Maggots may contain the toxin, and, if fed upon by other birds, the cycle is continued. In many avian botulism outbreaks, healthy birds are often found in close proximity to sick and dying birds. This close proximity helps to spread the disease among the birds, often causing greater mortality.

Recent Botulism Outbreaks in Lake Erie

A number of recent botulism outbreaks have occurred in Lake Erie, including outbreaks in New York and Pennsylvania waters, Ohio waters (2002-2003), Ontario waters, and a recent outbreak in Michigan waters of Lake Michigan (2006). Species of fish involved in botulism outbreaks were primarily nearshore benthic species like sheepshead (freshwater drum), round goby, and sturgeon. Mortality has generally run in the tens of thousands of fish as a result of the outbreaks, and most fish die-offs occur from July through early October. Species of birds involved in botulism die-offs include: ring-billed gull, herring gull, Bonaparte's gull, greater black-backed gull, red-breasted merganser, common loon, coots, grebes, oldsquaw, and various small shorebirds.

Although fishes have been impacted by botulism outbreaks, other possible causes of fish die-offs in Lake Erie include temperature intolerances (upwellings), anoxia, toxic algal blooms (*Microcystis*), spawning stress, discarded bycatch, or synergistic effects of any or all of these factors. Fish die-offs of any magnitude concern biologists, but, in particular, from 2000-2003, 61 dead lake sturgeon were collected by the NYSDEC. The lake sturgeon is a threatened species in New York, so the potential loss of this valuable fish species is of great concern. During 2000, eight dead lake sturgeon were collected from Lake Erie, and, in 2001, 27 were collected, including one that measured 2 m (80 inches) in length. In 2002, biologists collected four dead lake sturgeon from Lake Erie, and, in 2003, another 22 were collected from Lake Ontario waters.

Potential Causes of Botulism Outbreaks

Recent botulism outbreaks in the Great Lakes may have a connection to abundances of the quagga mussel and the round goby. Quagga mussels first appeared in the eastern basin of Lake Erie in 1991 and are currently more abundant than zebra mussel. Quagga mussels are typically found in deeper, colder water and on softer sediments than zebra mussels. Quagga mussels also have different food habits and faster growth rates than zebra mussels. The round goby was first collected in the eastern basin of Lake Erie in 1998, and it is currently quite abundant. This invasive benthic fish feed heavily on dreissenid mussels and is fed upon heavily by many predators. A number of fish-eating diving waterfowl also feed on round goby. Diet studies at Pennsylvania State University indicate that goby 80 mm or larger feed primarily on dreissenid mussels.

Botulism Workshops

New York Sea Grant collaborated with Pennsylvania and Ohio Sea Grant to co-sponsor annual workshops on avian botulism in Lake Erie. These workshops brought together researchers, fishery and wildlife biologists, resource managers, and agency representatives with the goal of sharing findings from both the American and Canadian shores and developing a research agenda for future efforts. Organizers wanted to determine the extent of the botulism problem based on geography and the environmental conditions that existed during outbreaks. The following information is based on presentations made at those workshops. Proceedings of all the botulism workshops can be found at http://www.seagrant.sunysb.edu/botulism/. During the workshops, researchers summarized findings related to species-specific toxicity, botulism detection techniques, behavioral responses to botulism toxins in fishes, and possible mechanisms for transmission of the toxin.

Human Health Considerations

Human botulism is typically caused by eating improperly canned or stored foods and normally involves type A or type B botulism toxin. Illnesses were reported during the 1960s in the Great Lakes basin and were attributed to type E toxin, but outbreaks were caused by eating improperly smoked or cooked fish that contained the toxin. Humans, dogs, and cats are generally considered resistant to type C avian botulism (Friend, et al. 1996). To minimize the risk of impacts on humans from type E botulism the following steps should be taken:

- Properly cook fish and waterfowl.
- Use sufficient heat when canning or smoking fish or waterfowl to ensure that toxins are killed; do not eat raw or cold-smoked fish.
- Avoid harvesting any sick or dying fish or waterfowl or those demonstrating unusual behavior in areas where avian botulism has occurred.

- Do not handle dead birds or fish on shore with bare hands; always use gloves or a plastic bag to avoid risks. If a diseased or dead bird is touched directly, hands should be washed with hot soapy water or with an anti-bacterial cleaner.
- Contact local agencies responsible for fish and wildlife management to notify them of fish and bird die-offs. Record the location, type of fish or birds, and number of carcasses found.
- Follow agency recommendations in handling dead fish and wildlife. In certain areas, burying of carcasses is allowed and in other areas incineration may be recommended. If birds are to be collected, they should be placed in heavy plastic bags to avoid the spread of botulism-containing maggots.

PROGRESS ON FISH-COMMUNITY GOALS AND OBJECTIVES AND FUTURE CONSIDERATIONS

Jeffrey T. Tyson[11], Roy A. Stein, and John M. Dettmers

Lake Erie has experienced a degree of change—somewhat like the other Great Lakes, but in some ways even more profound—mediated by changes in water quality induced by new invasive species, by habitat modifications, and by ongoing land-use changes in the watershed. In response to these changes, its fish communities have changed through time (Ludsin et al. 2001). Percid abundance has increased (see Kayle, this volume), prey fish appear to be reasonably stable (see Johnson, this volume), steelhead stocking programs continue to be successful (see Markham, this volume), and efforts to rehabilitate lake trout continue (see Markham, this volume). However, a view of the entire ecosystem suggests that it is not completely in balance, with prey fish in high demand by predators, zooplankton showing signs of heavy predation pressure (see Johnson, this volume), and nutrient loading becoming more variable as water-quality improvements continue (see Ludsin et al., this volume). Key cold-water salmonines may be affected by thiamine deficiency from their predation on invasive alewife and rainbow smelt (see Fitzsimons et al., this volume). The flow of contaminants through the food web also has changed, with the movement of PCBs and heavy metals through a strong benthic component of the food web centered around dreissenid mussels and round goby (see Domske, this volume; Kim 2007; Southward-Hogan et al., 2007). As a shallow lake with low retention time, Lake Erie responds quickly to perturbation and also can recover quickly.

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Progress on Fish-Community Goals

> *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.*
>
> *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.*

The LEC has made measurable progress in achievement of the above two broad goals for the lake's fish community and ecosystem. As regards the first goal, walleye remains a key predator in the western, central, and nearshore waters of the eastern basin, despite recent variability in recruitment. The cool-water fish community continues to exhibit diversity, especially recently (Ludsin et al. 2001), with valuable fisheries for walleye, yellow perch, white bass, and smallmouth bass and with anecdotal evidence of increases in abundance of other nearshore species. However, the ongoing ecological instability, driven especially by invasive species, challenges continued progress. Less progress has been made on the second goal. Lake trout have not reproduced, likely a function of continued high sea lamprey predation (see Sullivan and Fodale, this volume) and possibly thiamine deficiency (see Fitzsimons et al., this volume). But, the dramatic recovery of burbot (see Stapanian, this volume) and a modest recovery of lake whitefish (see Markham, this volume) indicate some progress.

Progress on Fish-Community Objectives

> *Maintain mesotrophic conditions (10-20 ug/L phosphorus) that favor a dominance of cool-water organisms in the western, central, and nearshore waters of the eastern basin; summer water transparencies should range from 3-5 m (9.75-16.25 ft) in mesotrophic areas.*

In the above FCO, Ryan et al. (2003) made a case for mesotrophy and the possibility of achieving harmonic percid communities for Lake Erie. These authors believed that the species composition and yield from harmonic communities were predictable and relatively stable, and were particularly desirable traits for fisheries management as recommended earlier by Ryder and Kerr (1978). In spite of recent oligotrophication, areas of Lake Erie still have not met targeted mesotrophic conditions. Large tributary outwelling zones continue to be eutrophic, whereas some nearshore areas, particularly in the eastern basin, have become oligotrophic, likely associated with dreissenid grazing. Stochastic inputs of phosphorus from the tributaries seem to be driving ecosystem production, more so than average annual phosphorus. In fact, spring tributary discharge appears well correlated with yellow perch recruitment and walleye growth, suggesting that the phosphorus associated with tributary inputs may be regulating percid success (see Ludsin et al., this volume).

Lake Erie is a naturally dynamic system because it is shallow and has a relatively low water retention time. Management of nutrients and fish exploitation have largely moved Lake Erie's trophic status toward mesotrophy. Yet, instability associated with the impacts of invasive species is pervasive throughout the food web. The ongoing invasions, as well as limited progress toward restoring important coastal nearshore and tributary habitat, have hampered achievement of this objective. Although control of invasive species shows some promise (see Sullivan and Fodale, this volume; Corkum et al., this volume), complete mitigation of the impacts of invasive species in Lake Erie is unlikely.

Secure a potential annual sustainable harvest of 13.6-27.3 million kg (30-60 million lb) of highly valued fish

After fish harvests peaked in the mid-1980s (>70 million pounds), total commercial harvest has declined to about 40 million pounds but is still within the range of the above objective specified in Ryan et al. (2003). Declines in both commercial and recreational harvest may continue due primarily to lost productivity associated with invasive species and to habitat degradation (Koonce et al. 1996). Although strong fisheries were yet being maintained, changes in recruitment mechanisms (see Ludsin et al., this volume) and loss of habitat (see Tyson, this volume) will likely lead to further shifts in fish-community structure. Warm- and cool-water species in the western and central basins have recovered substantially, but reduced productivity influences percid populations and yields (see Kayle, this volume). Benthivorous species across Lake Erie are showing signs of recovery and, to some degree, of stability, and both signs are associated with the recovery of *Hexagenia* and the population expansion of the exotic round goby (see Johnson, this volume). In the eastern basin, lake whitefish made a modest recovery, and their harvest has increased (see Markham, this volume).

Basin Objectives

> *Provide sustainable harvests in the western basin "of walleye, yellow perch, smallmouth bass, and other desired fish."*
>
> *Provide sustainable harvests in the central basin "of walleye, yellow perch, smallmouth bass, rainbow smelt, rainbow trout, and other desired fishes.*
>
> *Provide sustainable harvests in the eastern part "of walleye, yellow perch, smallmouth bass, whitefish, rainbow smelt, lake trout, rainbow trout and other salmonids; restore a self-sustaining population of lake trout to historical levels of abundance."*

The above three objectives from Ryan et al. (2003) focused on maintenance of Lake Erie's major commodity fishes and as such are the objects of interagency assessments. In the western and central basins, walleye populations have declined recently, with highly variable recruitment continuing to persist (see Kayle, this volume). Yellow perch populations have recently increased and appear generally more stable, but recruitment has been variable. Although difficult to monitor, smallmouth bass populations may be experiencing new stressors, due possibly to egg predation by round goby (Steinhart et al. 2004), and to direct predaton by cormorants (Lantry et al. 2002). Both white bass and white perch (in the category above of "other desired fishes") continue to increase in abundance. Little information exists on other desired fishes (sunfishes, northern pike), but their abundance may improve owing to increased quality of some nearshore habitats (see Tyson, this volume).

In the eastern basin, the walleye population consists of older individuals that migrate from the western and central basins, as well as smaller resident fish and, as such, may recover more slowly than populations in the west and central basins. Yellow perch have recovered modestly in both abundance and biomass and appear relatively stable. Lake trout rehabilitation efforts have yet to produce sustainable natural recruitment (see Markham, this volume) in spite of reductions in the standing stock of sea lampreys (see Sullivan and Fodale, this volume). Additionally, thiamine deficiency in lake trout eggs, caused by a maternal diet dominated by rainbow smelt, may impact lake trout reproductive success (see Fitzsimons et al., this volume). Burbot have undergone a dramatic recovery attributed to sea lamprey control and improvements in water quality (see Stapanian, this volume). Lake whitefish have undergone a modest recovery and provide a sustainable harvest. The stocking of rainbow trout has been very successful and has created significant offshore and tributary fisheries (see Markham, this volume).

> *—maintain nearshore habitats that can support high quality fisheries for smallmouth bass, northern pike, muskellunge, yellow perch, and walleye.*
>
> *—protect and restore* [in riverine and estuarine areas] *self-sustaining, stream-spawning stocks of walleye, white bass, lake sturgeon, and rainbow trout.*
>
> *—protect, enhance, and restore fish habitat throughout the watershed to prevent degradation and foster restoration of the fish community.*

Habitat degradation in the Lake Erie basin continues to impact the fish community and the ability of the member agencies of the LEC to achieve the above objectives from Ryan et al. (2003). A thorough discussion of related initiatives advanced by the LEC was provided earlier (see Tyson, this volume) and will only be summarized here. The LEC released two position statements: the LaMP Rehabilitation of Nearshore Habitat and Lower Tributaries and the Water Level Position Statement. The LEC is also developing environmental objectives that will outline issues as well as the environmental/habitat conditions necessary for their achievement. The member agencies are also rehabilitating stream-spawning walleye stocks in two rivers and are monitoring the response of the nearshore fish community to re-establishment of submerged aquatics.

> *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.*

The lake's food-web structure remains fragile despite the advocacy inherent in the above objective from Ryan et al. (2003) and despite the progress made in managing nutrients and exploitation (see Johnson, this volume). Dreissenids have greatly modified phytoplankton and zooplankton production, forage fish are exerting high predatory pressure on zooplankton, and predators are exerting high pressure on forage fishes. Biomass of benthic organisms has greatly increased following the arrival of dreissenid mussels, although non-dreissenid biomass has remained relatively unchanged due to positive associations between dreissends and some benthic invertebrates. Dreissenid mussel densities have changed little since 1992, but their biomass has increased four-fold in recent years due to changes in dominance from *Dreissena polymorpha* to *D. bugensis* (Patterson et al. 2005). *Hexagenia* successfully re-colonized the western basin through the mid-1990s, and full recovery was predicted by 1998-2000 (Madenjian et al. 1998). The deepwater amphipod *Diporeia* comprised a substantial portion of the eastern basin benthic community in the 1970s, but it has not been recorded in Lake Erie since 1998 (Dermott and Kerec 1997). Round goby appears to be affecting the food-web structure by increasing the energy pool for many of the goby-reliant predators (see Johnson, this volume). Exotic introductions continue to affect the food web with consequences that are not predictable.

Maintain a diversity of forage fishes to support terminal predators and to sustain human use.

The diversity of forage fishes in Lake Erie has been maintained as called for in the above objective (Ryan et al. 2003), but their sustainability is questionable. Biomass of forage-sized fish in eastern Lake Erie has declined since 1987, with the dominant pelagic forage being the exotic rainbow smelt (see Johnson, this volume). In the central basin, the forage community is more diverse, comprised primarily of rainbow smelt, emerald shiner, alewife, and round goby. In the western basin, forage biomass has declined since its peak in 1990, but its composition is as diverse as it is in the central basin and more diverse than in the eastern basin. Rainbow smelt, clupeids, and emerald shiner dominate predator diets; however, many predators have switched to round goby as a primary diet item.

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.

As called for in the above objective (Ryan et al. 2003), contaminant levels in many Lake Erie fishes have declined dramatically over the past several decades due to pollution abatement. However, polychlorinated biphenyls (PCBs) and mercury continue to result in fish-consumption advisories for some species. Changes in the food web associated with introductions of dreissenids and round goby may be causing increases in PCB levels and higher than expected mercury levels in those species that consumed round goby, when the former dominant forage species declined in abundance (Kim 2007; Southward-Hogan et al. 2007). In addition, over the past several years, periodic outbreaks of botulism have killed waterfowl, wading birds, and nearshore benthic fishes. These outbreaks may be related to interactions between quagga mussels and round goby (see Domske, this volume).

Maintain and promote genetic diversity by identifying, rehabilitating, conserving, and/or protecting locally adapted stocks.

The above objective from Ryan et al. (2003) recognizes the stock concept as a guiding principle for conservation and management of the lake's fishery resources. Implicit here is the idea that harvest will have the greatest impact on the least productive stocks within a larger population. The LEC has a long history of supporting research on population structure, particularly for walleye (Merker and Woodruff 1996; Stepien and Faber 1998; Bartnik 2005; Strange and Stepien 2007), yellow perch (Ford and Stepien 2004), smallmouth bass (Borden and Stepien 2006), and white bass (Jeff Miner, personal communication, 2003). Although much has been accomplished through genetic studies, emerging techniques, such as otolith microchemistry, show promise in determining stock-specific recruitment (Bartnik 2005) to the fishery (Bigrigg 2004) and the contribution of stocked fish to population rehabilitation (Krausse 2002). Further work will be necessary before managers can effectively use this information to manage the lake's diverse populations (Johnson et al. 2005).

Prevent extinction by protecting rare, threatened, and endangered fish species (for example, lake sturgeon and lake herring) and their habitats.

In keeping with the above objective from Ryan et al. (2003), the member agencies of the LEC restrict harvest of rare, threatened, and endangered species, although bycatch mortality associated with recreational and commercial fisheries needs further investigation. Lake sturgeon have recovered modestly in the Lake St. Clair region, and juvenile and adult sturgeon are captured in Lake Erie with increasing frequency. Cisco continue to persist in Lake Erie but at a very low abundance. More research is needed regarding the status of rare, threatened, and endangered species in Lake Erie.

Future Considerations

The LEC has built a highly successful monitoring collaboration that has resulted in a number of interagency long-term data series, including the western-basin interagency trawl series for fish-community structure, collaborative lower trophic level sampling surveys, and joint lakewide hydroacoustic surveys to assess pelagic forage-fish abundance. These long-term data are immensely valuable for management of the two dominant commercial and recreational species, walleye and yellow perch. They also effectively characterize the prey-fish community and cold-water fishes; however, these data need to be more fully utilized by managers to inform management decisions. Similar approaches should be applied to species that are not now assessed well (e.g., smallmouth bass, northern pike), such that both managers and stakeholders can assess the trends in their populations. Of course, understanding the fish community is merely a first step, because many of these species consist of multiple stocks, each with a likely different productive capacity. Through time, the LEC should consider apportioning monitoring effort in such a way that stock structure can be evaluated. Ultimately, these long-term data will be used to document the impact of ongoing management strategies on the species of interest, as well as on the entire fish community.

Because Lake Erie continues to be a changing system, the LEC should continue to develop, through collaborative efforts or their own resources, spatially and temporally appropriate monitoring programs for other trophic levels, including benthos, zooplankton, algae, and nutrients (see Johnson, this volume). If such programs had been fully in place, managers would have had quantitative insights into the relationshop between the increases in soluble reactive phosphorus and blue-green algae blooms, and their associated pathogenic responses (e.g., botulism). With these ideas in mind, the LEC should consider committing to another ten-year stint of lower trophic-level monitoring (as it did in 1999). By continuing to monitor benthic communities, we gain insight into changes in dreissenid mussel densities through time and better document the resurgence of mayflies in the western basin. As other components are added to the existing Lake Erie monitoring databases, the LEC may want to consider moving to an internet-based system for easier access.

In conjunction with its cooperative monitoring of the fish community, the LEC has developed stock assessment models to forecast the appropriate rates of exploitation of percid populations. Although these models have become a primary tool for setting harvest limits for walleye and yellow perch, small changes in critical parameters can mean large changes in predicted population sizes and, hence, in the potential for exploitation. The LEC should continue to consider regular, rigorous, and critical evaluations of their quantitative population modeling. Results from these models must be derived from the best available science if the LEC is to effectively maintain its central role in partitioning of future harvests among member agencies.

The LEC has made substantial progress toward understanding the central role of suitable habitat to the success of Lake Erie fishes (see Tyson, this volume). Much of this progress has been related to understanding the importance of critical reproductive habitat for walleye. Yet, additional work remains to fully integrate an understanding of fish habitat into fishery management. We encourage the LEC to assess tributary habitat in the context of how much of what kind is needed for ecosystem function. The quality of tributary habitat serves the ecosystem at both ends of the food web. First, it regulates nutrient inputs to the lake and influences percid recruitment (see Ludsin et al., this volume). Maintaining in-lake nutrient conditions that reflect a mesotrophic state favorable for cool-water percids is a primary underlying concept of the current fish-community goals and objectives. Second, excellent tributary habitat will enhance the success of river-spawning fishes, including walleye, white bass, and lake sturgeon.

Similarly, the LEC should assess nearshore habitat to determine how much of what kind is needed to support historical fish populations, e.g., those of northern pike, centrarchids, and lake sturgeon. Importantly, if the LEC can agree on quantitative targets, such targets could serve to guide nearshore recovery, for instance, of benthos and macrophytes, ultimately leading to fish-community restoration, as envisioned. Finally, offshore habitat (e.g., offshore reefs) should be assessed in this same context, to determine how much of what kind is needed to support reef-spawning fishes, including walleye and coregonids; to support offshore spawning fishes, such as yellow perch in the central basin; and to enhance rehabilitation efforts for lake trout in the eastern basin.

Historically, Lake Erie supported large populations of ciscoes (Oldenburg et al. 2007). Recovery of lake whitefish, begun in 1984, has been limited and cisco (formerly lake herring) have not recovered to any extent. As one of the FCOs, restoration of these species should be an important goal for fishery managers. Maintaining walleye at high levels and restoring lake trout should enhance recovery of ciscoes because these predators will reduce populations of alewife and rainbow smelt, both of which compromise reproductive success of ciscoes (Oldenburg et al. 2007). Via walleye and lake trout management and coregonine stocking, perhaps in the eastern basin, these native species may return to a more-prominent place in the lake's fish community.

Rehabilitation of lake trout remains elusive in Lake Erie. The LEC needs to continue to support increases in lake trout stocking rates, in spite of no observed natural reproduction. Further, sea lamprey marking rates, although near target, appear to be too high. These high rates could curtail the adult stock that has been building over the last five years. As a result, it may be critical for the LEC to keep sea lamprey control on its list of management priorities, despite its primary focus on percid management in the lake. Control of sea lampreys is important, because they prey not only on lake trout, but also on lake sturgeon (Sutton et al. 2003) and burbot (see Stapanian, this volume).

Standardized monitoring and cutting-edge research work hand-in-hand to prepare managers for future perturbations, leading them to anticipate future change and to structure their response accordingly. Because ecosystem conditions change rapidly in Lake Erie, relatively conservative exploitation strategies may make sense to preserve sufficient adult stocks, in spite of the intense demand for percids by both recreational and commercial fishers. This demand also extends to other recreational and commercial species, such as smallmouth bass and lake whitefish, species that are indirectly affected (buffered) by exploitation diverted to percids. Stakeholders also must recognize that the ability of Lake Erie to produce desired species is certainly not limitless, nor is it immune to ongoing change. Hence, stakeholders must join with managers to support suitable exploitation rates structured to the current capacity of the lake to produce fish, in light of what has been learned about the function of this ecosystem.

Given the complexities associated with continued ecosystem changes, complex management needs, and continued threats from invasive species, we encourage the LEC to develop long-term strategies for cooperative, partnership-based research, similar to the successful cooperative monitoring programs already in place. With an agreed-upon cooperative research plan in place, the partnership among member agencies will be strengthened, because the agencies have come to a consensus about what is important to know about the Lake Erie fish community. Providing a vision for future research would be useful to universities and federal and private entities with research operations on Lake Erie. By having a long-term plan in place, the LEC allows these agencies to plan for future opportunities, which can increase the amount of research targeting LEC priorities. With this suggestion comes the understanding that individual agencies will still maintain research programs of their own where they now exist or are being developed.

Based on the past, ongoing, and likely future changes to Lake Erie, the following are important priority recommendations for the LEC to consider as it moves toward achieving its fish-community goals and objectives:

- Work cooperatively with state and federal governments, and private industry, to eliminate sources of invasive species, especially through ballast-water management
- Continue and expand successful collaborative monitoring, assessment, planning, and research efforts in support of management activities
- Ensure that stock assessment models are based on the best available science and that the process of establishing harvest limits is transparent
- Continue to pursue stock discrimination techniques for percids
- Achieve a better understanding of the relationship between suitable habitat and improved fish populations
- Judiciously employ position statements and follow through to make known to governments why these positions should be taken seriously

The state of the fish community in Lake Erie appears relatively robust. Nevertheless, substantial threats to a healthy Lake Erie fish community remain, primarily driven by much uncertainty about the trajectory of the percid community. In particular, invasive species continue to threaten sustainable management of walleye and yellow perch. Although the LEC has made progress toward its FCOs for cool-water fishes, much less progress has been made toward achieving its cold-water objectives. We encourage the LEC to continue its efforts to manage toward its stated objectives. Indeed, incorporating the recommendations made above will aid in these efforts.

Several emerging issues will likely influence the LEC's ability to achieve its fish-community goals and objectives into the future. The resurgence of the double crested cormorant has generated concern within the basin, for this species can compromise survival of inshore fishes, such as smallmouth bass and yellow perch, as has been suggested in a suite of papers summarized by Stapanian (2002). We encourage the LEC, through the GLFC, to partner with other lake committees to design and implement control strategies for double crested cormorants. Given that localized control, such as harassment, only leads to displacement of birds from one jurisdiction to another, agencies signatory to the Joint Plan (GLFC 2007) should coordinate their efforts, both to allow effective control and to reduce redundant efforts. Only through cooperation across lakes can the impact of this predator be moderated.

Additionally, the earth's climate will change into the future. With these changes will likely come changes in percid populations, for climate variables, such as spring warming rate, precipitation, and wind speed (Busch et al. 1975; Madenjian et al. 1996; Mion et al. 1998; Roseman et al. 1996) influence recruitment. Winter conditions, which influence gonadal maturation, may well change, leading perhaps to changes in relative success of different species (Hokanson 1977). These are just a few of the impacts that can occur with climate change, and we encourage the LEC to pursue research that allows it to anticipate how the Lake Erie fish community, and percids in particular, will respond. It would be prudent for managers to develop strategies that respond to the possibility of climate changes, which may alter population or ecosystem productivity, and to develop indicators to anticipate them. For example, research suggests that anticipated climate change (e.g., increasing frequency of spring storms) will likely lead to reduced recruitment in walleye populations. As a result, the LEC should consider developing management strategies that detect this problem as early as possible and take this event into account. In our view, being forewarned is being forearmed in the arena of climate change.

In our view, the state of Lake Erie, while not completely up to expectations, is improving in some areas. Substantial attention has been paid to issues such as habitat, managing for sustainable fisheries, and lake trout rehabilitation. The dynamic nature of Lake Erie, coupled with the ongoing changes to the ecosystem associated with invasive species, means that managers will continue their efforts in these arenas and will incorporate more ecosystem-based perspectives as the lake changes into the future.

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