THE STATE OF LAKE ONTARIO IN 2008

Great Lakes Fishery Commission

SPECIAL PUBLICATION 14-01

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August 2014

The STATE OF LAKE ONTARIO IN 2008

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Citation (entire volume): Adkinson, A.C., and Morrison, B.J. [EDS.]. 2014. The state of Lake Ontario in 2008. Gt. Lakes Fish. Comm. Spec. Publ. 14-01.

Citation (individual chapter): Lantry, J.R., Hoyle, J.A., Mathers, A., McCullough, R.D., Walsh, M.G., Johnson, J.H., LaPan, S.R., and Weseloh, D.V. 2014. Nearshore fish community. *In* The state of Lake Ontario in 2008. *Edited by* A.C. Adkinson and B.J. Morrison [EDS.]. Gt. Lakes Fish. Comm. Spec. Publ. 14-01, pp. 9-22.

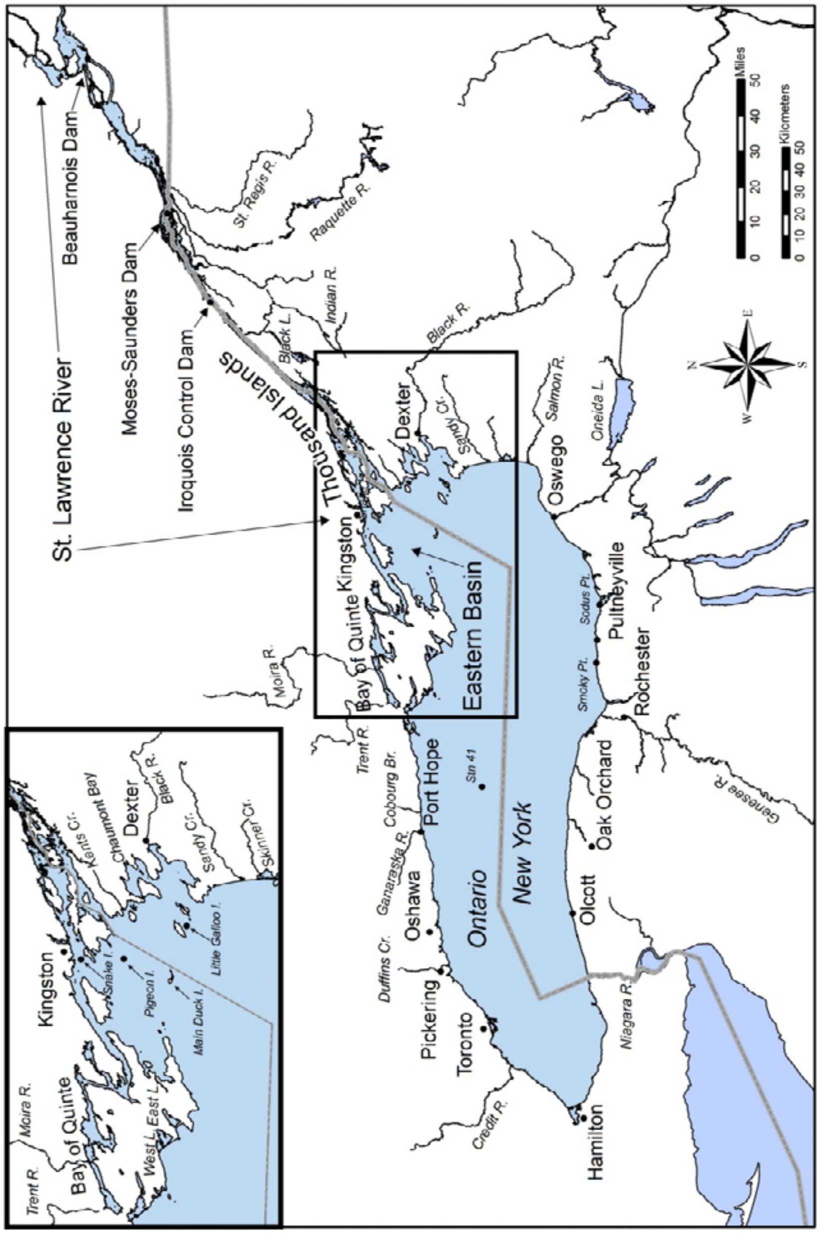
Great Lakes Fishery Commission
2100 Commonwealth Blvd., Suite 100
Ann Arbor, MI 48105-1563

August 2014

ISSN 1090-1051

Printed on recycled paper.

Frontispiece. Lake Ontario and the St. Lawrence River showing important geographic features.



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ABSTRACT[1]

During 2003-2007, Lake Ontario continued to provide a suitable environment for dynamic fish communities in nearshore and offshore waters. Since 2002, some progress towards achieving the fish-community objectives (FCOs) has occurred in the nearshore fish community and offshore pelagic fish community. Progress in the offshore benthic fish community, however, remains problematic. Even so, fish populations in all three zones are relatively stable and the trends of many indicators are positive. In the nearshore zone, walleye (*Sander vitreus*), smallmouth bass (*Micropterus dolomieu*), and yellow perch (*Perca flavescens*) all show lower yet relatively stable trends in abundance with some localized exceptions. Fisheries for these species are all meeting angler expectations. Walleye are recovering in the New York waters of eastern Lake Ontario. Some nearshore fishes that do not have indicator measures have shown improvement, and these include largemouth bass (*Micropterus salmoides*) and various species of sunfish (Centrarchidae). Fishes with some form of protective legislative status, such as lake sturgeon (*Acipenser fulvescens*) and American eel (*Anguilla rostrata*), are not meeting the indicators as described in 1999. Both species, however, are the focus of restoration initiatives. The population of non-native round goby (*Neogobius melanostomus*) has stabilized, and gobies are being eaten by many species of fish as well as by double-crested cormorants (*Phalacrocorax auritus*).

In the offshore benthic zone, measures of lake whitefish (*Coregonus clupeaformis*), lake trout (*Salvelinus*

[1]Full report with references is available at http://www.glfc.org/pubs/SpecialPubs/Sp14_01.pdf.

namaycush), burbot (*Lota lota*), and slimy sculpin (*Cottus cognatus*) suggest that the FCOs are not being met. Reasons for the lack of progress include the continued predation by sea lamprey (*Petromyzon marinus*) and a continuing change in the offshore food web. The non-native rainbow smelt (*Osmerus mordax*) is still present in this zone, albeit at lower levels of both abundance and size than in the other Great Lakes. Deepwater sculpins (*Myoxocephalus thompsonii*), once thought extirpated, were observed throughout 2003-2007. In the offshore pelagic zone, the current mix of stocked and wild fish is providing excellent fisheries. Chinook salmon (*Oncorhynchus tshawytscha*) is meeting indicator measures as is rainbow trout (*O. mykiss*). Coho salmon (*O. kisutch*) and brown trout (*Salmo trutta*) are supporting specialized fisheries. Naturally reproduced wild fish have been observed for all species save the Atlantic salmon (*Salmo salar*). The proportion of wild fish in the adult population is of interest from both an ecological and fisheries perspective. Atlantic salmon are the focus of a new restoration program that began during 2003-2007. Of concern in the offshore pelagic zone are the wide-ranging and rapid swings in alewife (*Alosa pseudoharengus*) abundance and condition that contribute uncertainty to assessment of predator-prey interactions.

Fish habitat, the lower food web, and environmental drivers are changing and not returning to the way they were prior to the introduction of zebra and quagga mussels (*Dreissena* spp.). These changes promulgate uncertainties that are difficult to understand, affect the lake zones differently, and are not easily related to fish production. These changes also make it difficult for the Lake Ontario Committee to determine where to focus management and research. Add to those uncertainties the influence of contaminants, diseases, and other species interactions, and the goal of meeting societal needs in the future certainly will be a challenge. As noted by the many authors of this report, the challenge will be recognizing these uncertainties while maintaining the relevant and achievable FCOs necessary for meeting commitments made in *A Joint Strategic Plan for Management of Great Lakes Fisheries* (GLFC 2007).

INTRODUCTION[2]

Bruce J. Morrison[3]

Goals and objectives for the Lake Ontario fish community (Stewart et al. 1999) were established as a result of the *A Joint Strategic Plan for Management of Great Lakes Fisheries* (Joint Plan) (GLFC 2007). The Joint Plan charged the Lake Ontario Committee (LOC) to define objectives for the lake's fish community and to develop means for measuring progress toward their accomplishment. The LOC is composed of fishery managers from the state of New York and the Province of Ontario. This state-of-the-lake report focuses on describing changes in Lake Ontario fish communities during 2003-2007 but, for perspective, also provides information on the community in earlier years. The report also compares community status in 2007 with indicators of progress specified in Stewart et al. (1999).

Description of Lake Ontario and Its Fish Community

Lake Ontario is the 17th largest lake in the world with a surface area of 18,960 km^2 (Beeton et al. 1999) and a maximum depth of 244 m. The lake receives 86% of its inflow from Lake Erie via the Niagara River. Major habitat zones in the lake are offshore (arbitrarily defined as a bottom depth greater than 15 m) and nearshore (bottom depth less than 15 m). The offshore is further subdivided into an on-or-near-the-bottom benthic zone and an off-bottom pelagic zone. Embayments are a minor habitat zone. The relatively shallow eastern basin (see Frontispiece for all place names) in northeastern Lake Ontario has numerous embayments and islands and

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[2]Full report with references is available at http://www.glfc.org/pubs/SpecialPubs/Sp14_01.pdf.

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includes more than 50% of the lake's shoreline. The major nutrient dynamic has been phosphorus concentration, which peaked in the late 1960s at around 28 $\mu g \bullet L^{-1}$ and then decreased to a target level of 10 $\mu g \bullet L^{-1}$ by the mid-1980s in response to phosphorus management mandated by the Great Lakes Water Quality Agreement of 1972 (Stevens and Neilson 1987; Millard et al. 2003).

In the early 1970s, the nearshore fish community was dominated by non-native species, and environmental conditions bordered on hyper-eutrophy (Christie 1973). Following two consecutive severe winters during 1976-1978, non-native alewife (see Table 1 for an alphabetical list of common fish names and their corresponding scientific names) and white perch populations declined (O'Gorman and Schneider 1986; Casselman and Scott 2003), and several native fishes in the nearshore zone, particularly walleye, rebounded, resulting in a shift from non-native to native species (Mills et al. 2003). By the mid-1970s, fish populations in the offshore zone of Lake Ontario, particularly native species, were in a dismal state, and even efforts to stock Pacific salmon were unsuccessful (Christie 1973; Owens et al. 2003). Through the 1980s, nearshore fish communities responded quite rapidly to improvements in water quality leading to periods of high abundance of many desirable species. Sea lamprey control, which began in 1971, eventually enhanced the survival of stocked salmon and trout (Pearce et al. 1980; Elrod et al. 1995). However, there was no measurable recovery of the burbot or deepwater sculpin (Owens et al. 2003; Mills et al. 2003). Predator-prey balance in the offshore pelagic zone was restored by the 1980s. During the early 1990s, however, managers became concerned that the balance could tip in favor of the predators, and they responded by reducing the number of fish stocked in the lake (Jones et al. 1993; O'Gorman and Stewart 1999). Non-native mussels, zooplankters, and round gobies established and became abundant through the 1980s and 1990s, resulting in major changes in the offshore food web in the early 2000s (Hoyle et al. 2008; Walsh et al. 2007, 2008a).

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

Common Name	Scientific Name
alewife	*Alosa pseudoharengus*
American eel	*Anguilla rostrata*
Atlantic salmon	*Salmo salar*
black crappie	*Pomoxis nigromaculatus*
bloater	*Coregonus hoyi*
bluegill	*Lepomis macrochirus*
brook trout	*Salvelinus fontinalis*
brown trout	*Salmo trutta*
burbot	*Lota lota*
Chinook salmon	*Oncorhynchus tshawytscha*
cisco	*Coregonus artedi*
coho salmon	*Oncorhynchus kisutch*
common carp	*Cyprinus carpio*
deepwater ciscoes	(*Coregonus* spp.)
deepwater sculpin	*Myoxocephalus thompsonii*
emerald shiner	*Notropis atherinoides*
freshwater drum	*Aplodinotus grunniens*
gizzard shad	*Dorosoma cepedianum*
kiyi	*Coregonus kiyi*
kokanee	*Oncorhynchus nerka*
lake sturgeon	*Acipenser fulvescens*
lake trout	*Salvelinus namaycush*
lake whitefish	*Coregonus clupeaformis*
largemouth bass	*Micropterus salmoides*
muskellunge	*Esox masquinongy*
northern pike	*Esox lucius*

Table 1, continued

Common Name	Scientific Name
Pacific salmon	*Oncorhynchus* spp.
pumpkinseed	*Lepomis gibbosus*
rainbow smelt	*Osmerus mordax*
rainbow trout (steelhead)	*Oncorhynchus mykiss*
round goby	*Neogobius melanostomus*
sea lamprey	*Petromyzon marinus*
shortnose cisco	*Coregonus reighardhi*
slimy sculpin	*Cottus cognatus*
smallmouth bass	*Micropterus dolomieu*
splake	*Salvelinus namaycush* x *Salvelinus fontinalis*
spottail shiner	*Notropis hudsonius*
sunfish	Centrarchidae
threespine stickleback	*Gasterosteus aculeatus*
walleye	*Sander vitreus*
white perch	*Morone americana*
yellow perch	*Perca flavescens*

Goals and Guiding Principles

The goal for the Lake Ontario fish community is the common goal in the Joint Plan (GLFC 2007; Stewart et al. 1999)

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

To achieve that goal, the LOC established 13 guiding principles and objectives for fish communities in the three major fish-habitat zones (Stewart et al. 1999). A special conference focusing on progress toward achieving the Lake Ontario fish-community objectives was held at Niagara Falls, Ontario, in March 2008. This report is a compilation of some of the papers presented at that special conference. The first three chapters address the objectives for the nearshore, offshore-benthic, and offshore-pelagic fish communities. The final chapter discusses lower food-web dynamics, physical and chemical aspects of habitat, and other environmental drivers in relation to the status of the fish communities. This state-of-the-lake report serves to focus attention on critical fisheries issues and to enhance communication and understanding among fishery agencies, environmental agencies, political bodies, and the public.

NEARSHORE FISH COMMUNITY[4]

Jana R. Lantry[5], James A. Hoyle, Alastair Mathers, Russell D. McCullough, Maureen G. Walsh, James H. Johnson, Steven R. LaPan, and D.V. Weseloh.

Background

The status of the nearshore fish community (≤15-m deep in warmest months) in 2003-2007 was the result of long-term and short-term perturbations that led to changes in nearshore productivity, habitat, and predator-prey interactions. The perturbations included a reduction in overall

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[4]Full report with references is available at http://www.glfc.org/pubs/SpecialPubs/Sp14_01.pdf.

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lake productivity (Munawar and Munawar 2003; Stewart et al. 2010a), changes in the plankton and prey-fish communities (Stewart et al. 2010a, 2010b), changes in double-crested cormorant (*Phalacrocorax auritus*) predation pressure (Farquhar et al. 2012), and establishment of numerous non-native species—zebra and quagga mussels (*Dreissena* spp., hereafter collectively, dreissenids), spiny water flea (*Bythotrephes longimanus*), fishhook water flea (*Cercopagis pengoi*), and round goby (Mills et al. 2003; Hoyle et al. 2012).

Objectives for the nearshore fish community are (Stewart et al. 1999)

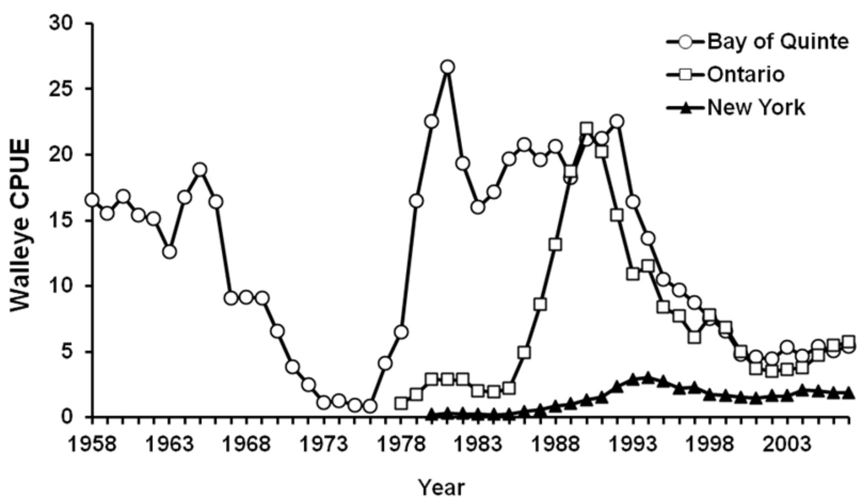
> *The nearshore fish community will be composed of a diversity of self-sustaining native fish species characterized by maintenance of existing walleye and yellow perch populations and expansion of walleye and yellow perch populations into favorable habitats; a population recovery of lake sturgeon sufficient for its removal from New York's list of threatened species; population levels of smallmouth bass, largemouth bass, and sunfish attractive to anglers; and increasing numbers of American eels consistent with global efforts for their rehabilitation.*

Walleye

In 2002, the year preceding this reporting period, walleye abundance and harvest in the Bay of Quinte and the Ontario waters of the eastern basin (see Frontispiece for all place names) were about 75% lower than the high levels observed in the early 1990s (Fig. 1; Hoyle et al. 2007). The population decline coincided with a decrease in production of young and no major change in adult mortality (Bowlby and Hoyle 2002). Walleye abundance in New York waters of the eastern basin in 2002 was somewhat lower than in the mid-1990s (Fig. 1). Walleye catch-per-unit effort (CPUE) and fishery harvest in the Bay of Quinte during 2003-2007 remained relatively stable, but catches in assessment gillnets were 73% lower, and angler harvest was 79% lower than in the early 1990s. The recreational harvest rate of walleye did not fall below the low harvest rate of 2000, and, in 2006, it was similar to the elevated harvest rates of the early 1990s. The walleye population in

New York waters of the eastern basin remained relatively stable during 2003-2007 with CPUEs in assessment gillnets similar to those of the early 1990s (Fig. 1). In contrast, walleye CPUE in Ontario waters of the eastern basin increased in 2006-2007, and, although CPUE was 47% higher than the low observed in 2002, it was 71% below early 1990s levels.

Fig. 1. Three-year running averages of catch-per-unit effort (CPUE) of walleye in standard gillnets set in Lake Ontario during summer in the Bay of Quinte (1958-2007, excluding 1966), Ontario waters of the eastern basin (1978-2007), and New York waters of the eastern basin (1976-2007).



Assessment data indicate that walleye may be undergoing a range expansion, which is a fish-community objective (FCO) (Stewart et al. 1999). Prior to 2003, the majority of walleyes in New York waters of the eastern basin were thought to have recruited from Ontario waters of the eastern basin and the Bay of Quinte. At that time, walleyes were thought to be spawning in two of New York's eastern basin tributaries (Kent's Creek and Black River), but there were no records of young fish. In 2004, however, age-1 walleyes were caught in New York waters of the eastern basin for the first time in 29 years, and, in 2005, walleye yolk-sac larvae were captured near the mouth of Kent's Creek (Farrell 2006). We take these observations to be evidence of a range expansion.

An increased occurrence of young-of-the-year (YOY) walleyes in bottom-trawl assessments of the Bay of Quinte and of age-1 walleyes in gillnet assessments of the eastern basin indicate improved walleye recruitment during this reporting period. The catch of YOY walleye in the Bay of Quinte was double that of the preceding five-year period. The 2003 year-class in the Bay of Quinte was reasonably strong and was also observed in New York waters of the eastern basin. In Ontario waters outside of the Bay of Quinte and the eastern basin, trapnet surveys of the nearshore fish community conducted in and around embayments indicated that healthy walleye populations existed in East Lake and West Lake and that much smaller populations of walleye occur in Hamilton Harbour and near the Toronto waterfront.

Progress and Outlook

During 2003-2007, walleye abundance stabilized at a level lower than in the 1980s and early 1990s, a level that is consistent with the current ecosystem (Fig. 1). Increased numbers of recruits suggest that abundance of the fishable stock may increase, although not to the levels of the early 1990s owing to unfavorable recent changes in the ecosystem. Dreissenids were implicated as the primary cause for declining walleye populations through 2002 (Bowlby et al. 2010). Also, alewife, an important prey item for adult walleye (Bowlby et al. 2010), was reduced in abundance by the early 1990s primarily in response to reduced lake productivity (Mills et al. 2003; Bowlby et al. 2007) and remains at this lower level (see Offshore Pelagic Fish Community chapter). In the future, newly established species, round goby (first record 1998) (Owens et al. 2003), bloody-red shrimp *Hemimysis anomala* (first record 2006) (Walsh et al. 2010), and viral hemorrhagic septicemia virus (VHSv) (first record 2005) (Lumsden et al. 2007) may affect walleye abundance. The present Lake Ontario ecosystem is very different from the ecosystem of the early 1990s in ways that detract from walleye productivity. A return in Canadian waters to the walleye catch rates seen in the 1980s and further range expansion of walleyes as specified in the indicator for the Nearshore Fish-Community Objective are unrealistic. Therefore, we suggest revision of the walleye objective and its indicators.

Yellow Perch

From the previous reporting period (1998-2002) to this reporting period (2003-2007), yellow perch abundance in the eastern basin increased 29% and 44% in Ontario and New York waters, respectively (Fig. 2). Yet, in the Bay of Quinte, yellow perch abundance declined in all three geographic areas (Fig. 3). The commercial harvest of yellow perch lakewide during 2003-2007 was 35% lower than during 1998-2002 (Fig. 4), but this reduction may owe to the economics of commercial fishing insomuch as yellow perch appear to be more abundant in the eastern basin where the commercial fishery operates. Prominent factors influencing yellow perch abundance include lake productivity, piscivore abundance, alewife predation on larval yellow perch (Brandt et al. 1987; Mason and Brandt 1996), and double-crested cormorant (*Phalacrocorax auritus*) predation (O'Gorman and Burnett 2001).

Fig. 2. Three-year running averages of catch-per-unit effort (CPUE) of yellow perch in standard gillnets set during summer in the eastern basin of Lake Ontario (Ontario waters, 1978-2007; New York waters, 1977-2007).

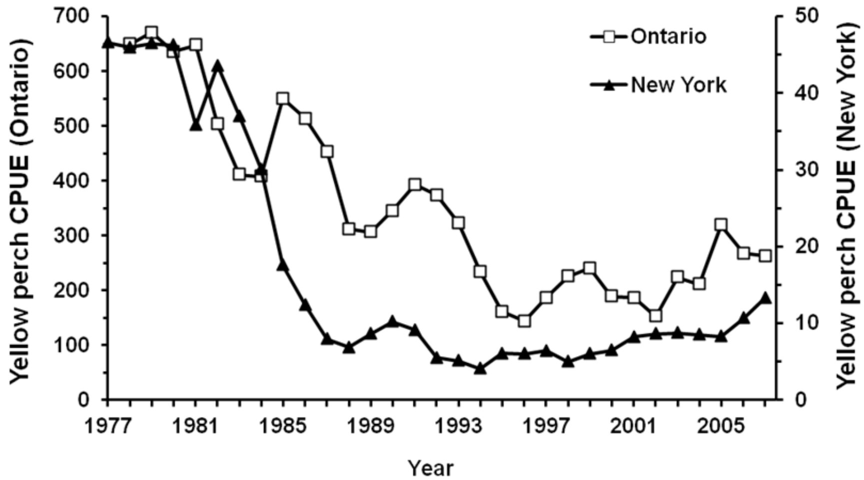


Fig. 3. Three-year running averages of catch-per-unit effort (CPUE) of yellow perch in standard gillnets set during summer in three geographic regions of the Bay of Quinte, 1972-2007.

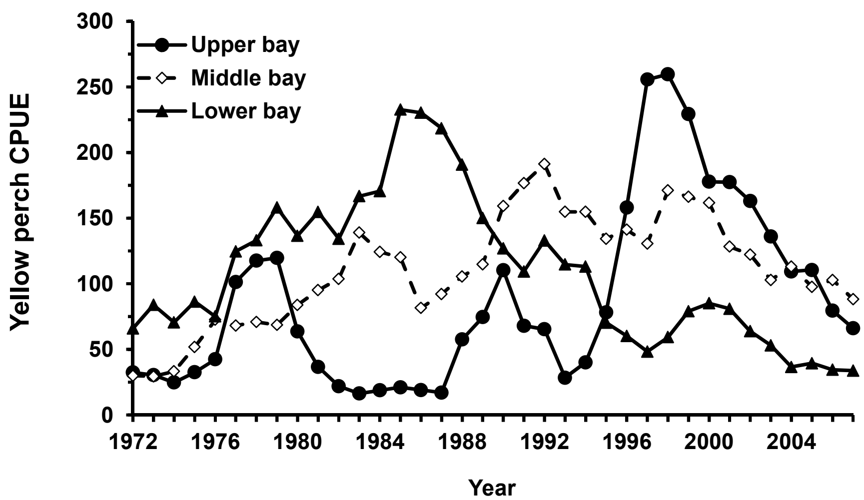
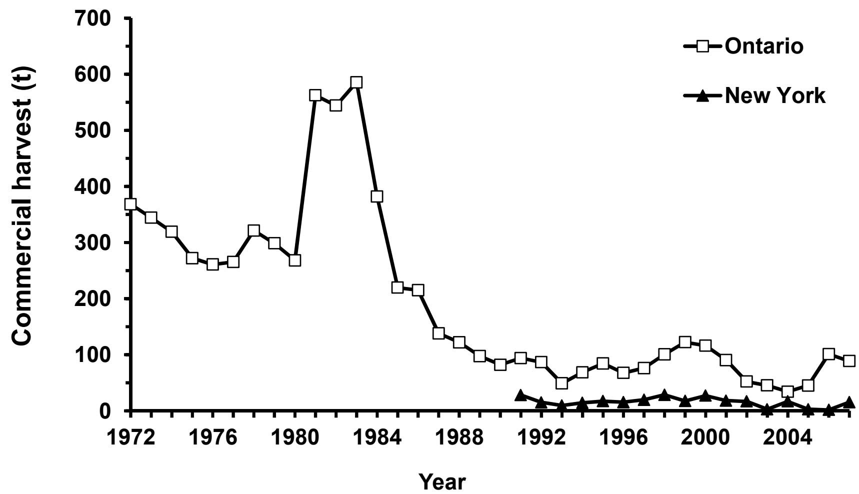


Fig. 4. Commercial harvest (t = metric tonnes) of yellow perch from Ontario and New York waters of Lake Ontario, 1972-2007.



In particular, reductions in alewife predation on larval perch owing to fewer alewives in this reporting period and reduced predation on age-1 and older yellow perch by double-crested cormorants could account for an increased abundance of yellow perch in the eastern basin. By 2005, round goby dominated the diet of double-crested cormorants at colonies on Snake and Pigeon Islands in Ontario's eastern basin and on Little Galloo Island in New York's eastern basin (Ross et al. 2005; Johnson et al. 2006). Thus, round goby appears to be "buffering" yellow perch from double-crested cormorant predation.

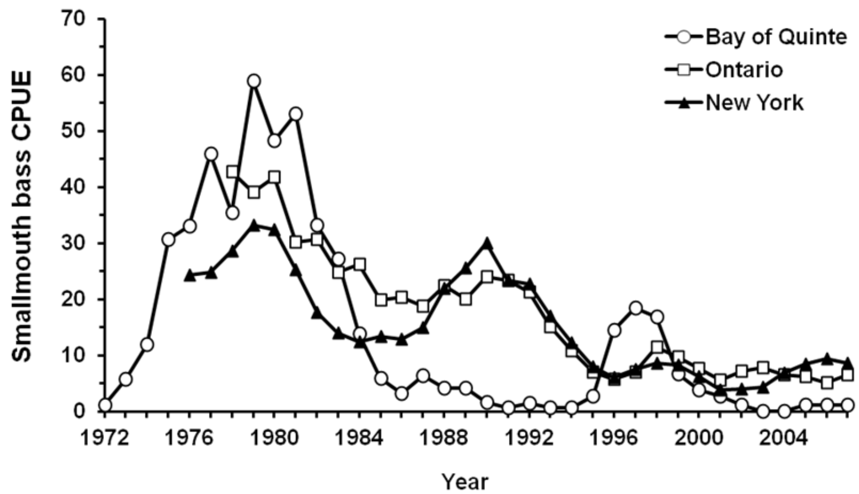
Progress and Outlook

Overall, the indicator for the fish-community objectives of increasing the abundance of yellow perch was positive during this reporting period. Maintaining this higher level of yellow perch abundance is a reasonable expectation, and it may provide for an improved commercial fishery if market conditions become more favorable. Looking ahead, over the short term, yellow perch abundance will likely not change markedly from current levels in the eastern basin of Lake Ontario. The decline in abundance of yellow perch in the Bay of Quinte remains unexplained and may require more attention in the future.

Smallmouth Bass and Other Centrarchids

During 2003-2007, the smallmouth bass population in the Bay of Quinte was relatively stable but at very low levels, similar to those of the early 1990s, but improved from 2002 (Fig. 5). In New York and Ontario waters of the eastern basin during the same period, population trends were similar with abundance relatively stable at levels lower than those during the late 1980s, the time period immediately prior to dreissenid establishment and to intense predation by double-crested cormorants (Fig. 5; Lantry et al. 2002). Although low, abundance indices in the New York portion of the eastern basin have improved slightly since the early 2000s. The increase is attributable to improved growth increasing the catchability of smallmouth bass (Lantry 2009) and to reduced predation by double-crested cormorants (Farquhar et al. 2012). In the eastern basin, angler catch rates of smallmouth bass in 2003, the first year of this reporting period, were even lower than the levels observed by McCullough and Einhouse (1999) in 1998. Nevertheless, the majority of smallmouth bass anglers in New York waters of the eastern basin now seem to be satisfied with the catch rates and sizes of bass. Similarly, in Ontario waters of the eastern basin, tournament bass anglers reported an increase in smallmouth bass weights consistent with the increased growth of bass. In the main basin, angler catch rates for smallmouth bass declined each year during 2003-2007, and, by 2007 they were the lowest recorded during the 23 years that angler surveys have been conducted (Lantry and Eckert 2008). In contrast, catch rates of round goby by anglers rose during 2003-2007 (Lantry and Eckert 2008). Round goby, which is increasing in abundance, may have contributed to record low smallmouth bass catch rates by interfering with fishing and by providing bass with an extremely abundant food supply, keeping them satiated. In the main basin of the lake near Pultneyville, New York, smallmouth bass appeared to be sufficiently abundant to provide a quality fishery (Sanderson 2008). Although the increase in water clarity and expansion of submerged aquatic vegetation that followed dreissenid colonization did not result in larger populations of smallmouth bass, the increase benefited other centrarchids, including largemouth bass, pumpkinseed, bluegill, and black crappie (Hoyle et al. 2007).

Fig. 5. Three-year running averages of catch-per-unit effort (CPUE) of smallmouth bass in standard gillnets set during summer in the Bay of Quinte (1972-2007) and the eastern basin of Lake Ontario (Ontario waters, 1978-2007; New York waters, 1977-2007).



Progress and Outlook

Catch rates of smallmouth bass in assessments and recreational fisheries were not maintained at levels of the late 1980s and, therefore, did not satisfy the Nearshore Fish-Community Objective for smallmouth bass established in 1999 (Stewart et al. 1999). Although abundance indices were stable in recent years, they were much lower than those recorded prior to the ecosystem changes of the 1990s. The smallmouth bass indicator requires a reevaluation that includes, in addition to current population parameters, ecosystem changes due to dreissenids, round goby as predator and prey, double-crested cormorant predation, and VHSv impacts. A quality smallmouth bass fishery that is attractive to anglers may be consistent with catch rates lower than those of the late 1980s.

Lake Sturgeon

During 2003-2007, small numbers of lake sturgeon were caught during surveys of the fish community in the eastern basin of Lake Ontario and the upper St. Lawrence River. The abundance of lake sturgeon, however, remained low relative to historical levels and did not change appreciably from that in 2002 (OMNR 2008; Lantry 2009). During the past decade, die-offs of lake sturgeon were occasionally reported in several areas of Lake Ontario as well as in Lake Erie. These die-offs were often in association with die-offs of other fish and wildlife, particularly of round gobies (Getchell 2004) and may have been due to type-E botulism (e.g., Klindt and Town 2005), although botulism was not confirmed and the role that VHSv or other fish pathogens may have played in the die-offs is unknown. Although the number of lake sturgeon that succumbed was not large (fewer than 27 fish reported per year; Klindt and Town 2005), this number may impair a population recovery.

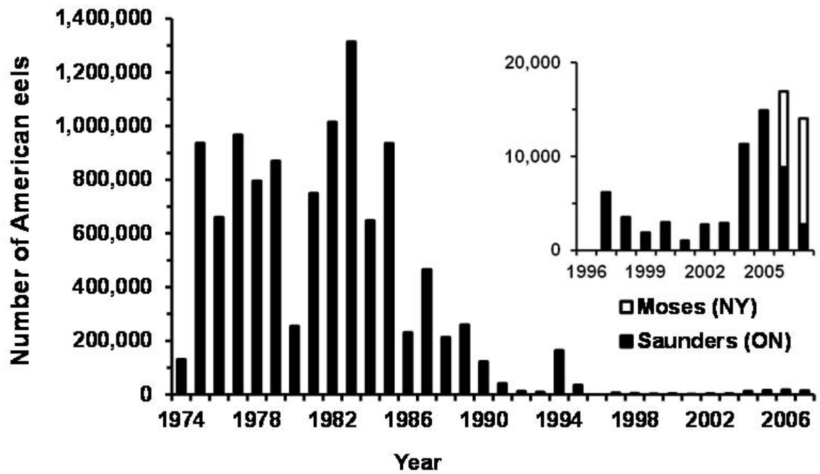
Progress and Outlook

Efforts are ongoing to create spawning shoals for lake sturgeon and to identify sources of sturgeon gametes for hatchery rearing and subsequent stocking in tributaries to Lake Ontario and the St. Lawrence River. The New York State Department of Environmental Conservation (DEC) stocked lake sturgeon (about 250-3,000 per site and year) in Oneida Lake in 2003-2004, the Genesee River in 2003-2004, Skinner Creek in 2006, the St. Lawrence River downstream of the Moses-Saunders Dam in 2003-2004, and in various tributaries to the St. Lawrence River (Black Lake/Indian River, 2003-2004; Raquette River, 2004; and St. Regis River, 2003-2004). Lake sturgeon stocked in the lower Genesee River survived and grew well suggesting that habitats such as this are highly suitable for sturgeon, and stocking has the potential to increase sturgeon abundance (Dittman and Zollweg 2006). Klindt and Adams (2006) and Klindt et al. (2007) identified a potential location for lake sturgeon gamete collection in the Black River at Dexter, New York. In October 2007, the New York Power Authority created lake sturgeon spawning shoals in the upper St. Lawrence River upstream and downstream of the Iroquois Control Dam as part of the relicensing agreement for the Moses Power Dam (Environnement Illimité inc. 2009). We suggest monitoring the man-made lake sturgeon spawning shoals for aggregations of adults, egg deposition, and larval emergence. Because lake sturgeon reach sexual maturity at an advanced age, a decade or more may be needed to observe responses to restoration efforts. The indicator of progress for the Lake Sturgeon Fish-Community Objective, which calls for increased sightings, is expected to be positive in the future. Likewise, we suggest that removal of lake sturgeon from New York's list of threatened species remains a valid, long-term goal.

American Eel

During 2003-2007, on average, 12,088 yellow (life stage) American eels navigated the eel ladder(s) at the Moses-Saunders Dam to continue their migration upstream (Fig. 6). This average was a modest increase over the previous five-year period, but the average was still less than 2% of the number of American eels navigating the ladder in the 1970s and 1980s.

Fig. 6. Total number of American eels migrating up the eel ladder(s) at the Moses-Saunders Dam in the upper St. Lawrence River, 1974-2007. Inset shows migrating American eel numbers in 1997-2007 in expanded scale. American eels were not counted in 1996. In 2006, a second eel ladder was opened.



Abundance of large yellow American eels continued to decline during 2003-2007. None were captured in 260 bottom trawls conducted in the Bay of Quinte. At Main Duck Island during 2003-2007, the number of yellow eels captured while electrofishing at night declined to less than 1% of the numbers captured in the 1980s. In addition, annual counts of out-migrating silver (life stage) American eels found dead below the St. Lawrence River Power Project (hereafter, power project) declined to 193 individuals in 2007, the lowest since record keeping began in 2000 (New York Power Authority 2008).

Progress and Outlook

In 2004, Ontario closed its dwindling commercial fishery for American eel and, in 2005, closed its recreational fishery. In 2006, as part of a hydropower relicensing agreement, the New York Power Authority, to facilitate upstream migration, opened a new ladder for the American eel on the New York side of the power project. During 2006 and 2007, a total of 576,340 glass (life stage) American eels obtained from commercial fisheries in New Brunswick and Nova Scotia were stocked in the upper St. Lawrence River as part of an action plan negotiated between Ontario Power Generation, the Ontario

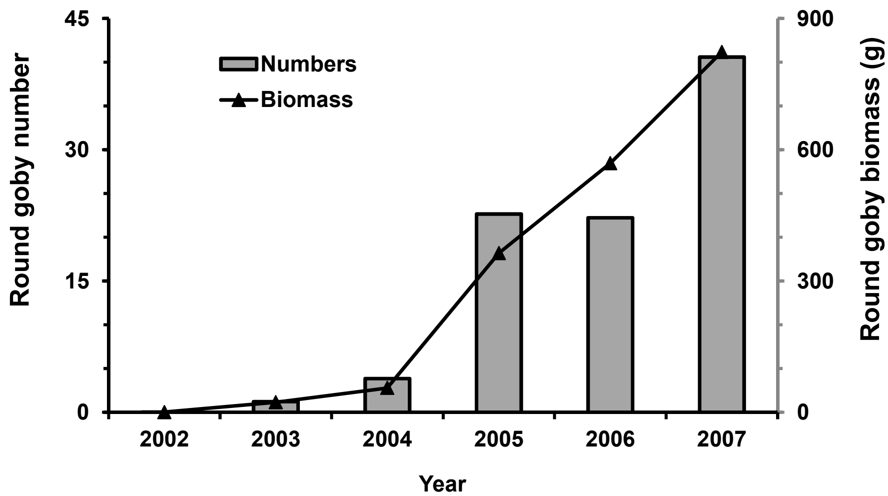
Ministry of Natural Resources (OMNR), and Fisheries and Oceans Canada. Another component of the action plan, still under development, is an assessment of transporting large yellow and/or silver eels caught upstream of dams to below the lowermost dam on the St. Lawrence River (Beauharnois Dam) in Quebec. In 2007, the American eel was designated as endangered in Ontario.

A recovery of the American eel in Lake Ontario will clearly require long-term research, management, and monitoring. Moreover, because American eels in Lake Ontario are part of a widespread, panmictic population, recovery will require conservation actions across numerous freshwater and marine jurisdictions. The draft Great Lakes Fishery Commission recovery plan for American eels established an interim goal of one million young eels migrating up the eel ladders, which is approximately 80 times the number migrating in 2003-2007 and five times the indicator of status for the American Eel FCO.

Round Goby

Lake Ontario's FCOs do not directly address the round goby, a non-native fish, even though it affects the nearshore fish community by acting as predator and prey. The round goby was first documented in Lake Ontario in 1998 (Owens et al. 2003), first reported in angler catches in 2001 (Eckert 2002), and first collected in bottom trawls in 2002 (Walsh et al. 2006). Abundance and biomass remained low initially but increased steadily during 2004-2007 (Fig. 7). Having reached high initial concentrations in the southwest and northeast corners of the lake, round goby in 2004-2007 colonized most areas of the lake's southern shore. By 2007, round goby had become important in the diet of virtually all nearshore fishes (Taraborelli et al. 2010; Hoyle et al. 2012; Lantry 2012). Increased abundance and biomass of round goby and their occurrence in diets may have contributed to the much improved condition and/or growth of smallmouth bass (Lantry 2012) and walleye (Bowlby et al. 2010; Hoyle et al. 2012). Double-crested cormorant diets at eastern basin colonies are now dominated by round gobies (Johnson et al. 2006), reducing cormorant consumption of more highly valued fishes, such as smallmouth bass and yellow perch. Conversely, round gobies are suspected of displacing native fishes from preferred habitat, preying on their eggs and fry, and contributing to botulism and VHSv outbreaks.

Fig. 7. Indices of the number and biomass (g) of round goby in the New York waters of Lake Ontario, 2003-2007. Indices are the sums of area-weighted means of catches in 10-min tows of bottom trawls conducted during April-May by the U.S. Geological Survey and the New York State Department of Environmental Conservation.



The round goby is a nearshore resident during summer but migrates to depths of 50-150 m during winter (Walsh et al. 2008b), so it is not a major part of the offshore benthic fish community for half of the year. The round goby eats dreissenids extensively, but its prey in offshore waters also includes invertebrates and the opossum shrimp (*Mysis diluviana*) (French and Jude 2001; Walsh et al. 2007). Because of its great abundance and extensive depth range, the round goby has become a major player in the lake's fish community.

OFFSHORE BENTHIC FISH COMMUNITY[6]

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Background

Lake Ontario's offshore benthic fish community includes primarily slimy sculpin, lake whitefish, rainbow smelt, lake trout, burbot, and sea lamprey. Of these, lake trout have been the focus of an international restoration effort for more than three decades (Elrod et al. 1995; Lantry and Lantry 2008). The

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[6]Full report with references is available at http://www.glfc.org/pubs/SpecialPubs/Sp14_01.pdf.

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deepwater sculpin and three species of deepwater ciscoes (*Coregonus* spp.) that were historically important in the offshore benthic zone became rare or were extirpated by the 1960s (Christie 1973; Owens et al. 2003; Lantry et al. 2007b; Roth et al. 2013). Ecosystem changes continue to influence the offshore benthic fish community, including the effects of dreissenid mussels, the near disappearance of burrowing amphipods (*Diporeia* spp.) (Dermott et al. 2005; Watkins et al. 2007), and the increased abundance and expanded geographic distribution of round goby (see Nearshore Fish Community chapter) (Lantry et al. 2007b). The fish-community objectives for the offshore benthic fish community, as described by Stewart et al. (1999), are

> *The offshore benthic fish community will be composed of self-sustaining native fishes characterized by lake trout as the top predator, a population expansion of lake whitefish from northeastern waters to other areas of the lake, and rehabilitated native prey fishes.*

Native Deepwater Prey Fishes

Deepwater Ciscoes

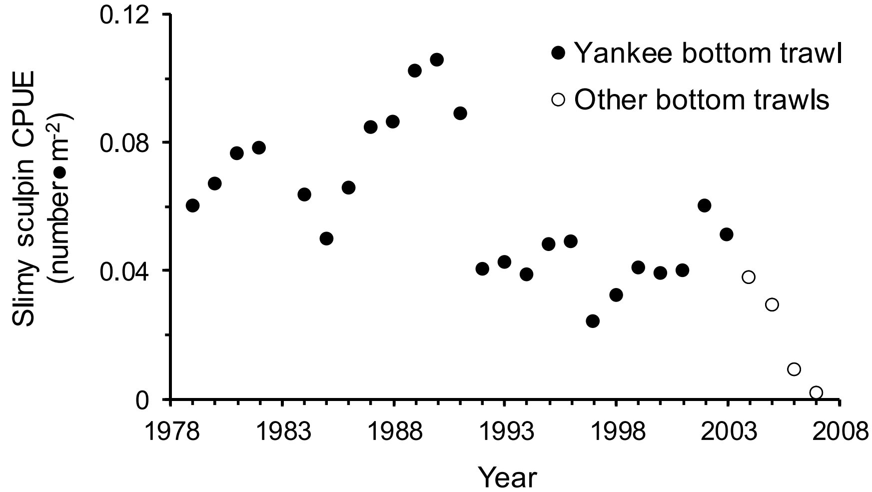
Historically, deepwater ciscoes (bloater, kiyi, and shortnose cisco, collectively deepwater ciscoes), were the dominant native planktivores in the offshore benthic zone of Lake Ontario (Roth et al. 2013). These three species are now gone (Mills et al. 2003; Owens et al. 2003). The dominant planktivore in Lake Ontario now, the non-native alewife, is restricted to the meta- and epilimnion during the period of thermal stratification. Therefore, the alewife did not fully replace the deepwater ciscoes. Alewives have an enzyme in their guts, thiaminase, that interferes with reproduction in some of the fishes that eat them, and the effect on reproduction is particularly severe among lake trout and Atlantic salmon (Honeyfield et al. 1998; Mills et al. 2003; Fitzsimons et al. 2007). Restoration of one or more deepwater ciscoes and rehabilitation of the cisco (see below) would diversify the offshore fish community and provide a source of low-thiaminase prey for salmon and trout. Re-establishment of deepwater ciscoes would also restore energetic pathways that formerly coupled deep offshore production with pelagic predators (Baldwin 1999).

Efforts to reintroduce deepwater ciscoes during 2003-2007 focused on assessing the genetic makeup of potential donor stocks (Fave and Turgeon 2008), obtaining fertilized eggs from pathogen-free sources in the upper Great Lakes (Stewart et al. 2002), and developing culture methods for producing fish for stocking (Dietrich et al. 2007). Fertilized eggs were successfully collected from Lake Superior in 2005, but the larvae hatched at smaller sizes than reported in the literature, and the underdeveloped larvae had difficulty feeding and died (Dietrich et al. 2007). A specific plan is needed for future efforts to restore deepwater ciscoes, one that includes identifying disease-free egg sources and experimenting with gamete collection and culture methods. Hatchery capacity to produce fish for stocking is also needed. Although efforts are underway to reintroduce deepwater ciscoes, thereby increasing the prospects for future sightings, as called for in the indicator of progress for these fishes, none have yet been stocked. We hope to be able to report sightings in the next reporting period.

Slimy Sculpin

Since the 1960s, the slimy sculpin has been the dominant bottom-dwelling prey fish in Lake Ontario (Wells 1969; Mills et al. 2003; Owens et al. 2003). This small (<130 mm) fish eats invertebrates, including *Diporeia* spp., *Mysis diluviana*, and midge (Chironomidae) larvae (Walsh et al. 2008a). Previous studies indicated that slimy sculpin comprised by weight about half of the diet of juvenile lake trout and were a critical component of the food web supporting the recovery of this native salmonid (Elrod and O'Gorman 1991). Since 1979, when annual October assessments began in southern Lake Ontario, slimy sculpin abundance has been on a downward trajectory. During 1979-1991, the average catch of slimy sculpins per square meter swept with a bottom trawl was 0.077, during 1992-2002 the average fell to 0.041, and, during 2003-2007, the average fell once again to 0.025 (Fig. 8). Changes in slimy sculpin abundance in the 1990s were attributed to the establishment of dreissenids and the subsequent reductions in the sculpin's preferred food, *Diporiea* spp. (Owens and Dittman 2003; Lantry et al. 2007b).

Fig. 8. Catch-per-unit-effort (CPUE) of slimy sculpin with bottom trawls towed in southern Lake Ontario by the U.S. Geological Survey during fall, 1979-2007. Bottom trawls other than the Yankee trawl were used after 2003 in an attempt to reduce the catch of dreissenids.

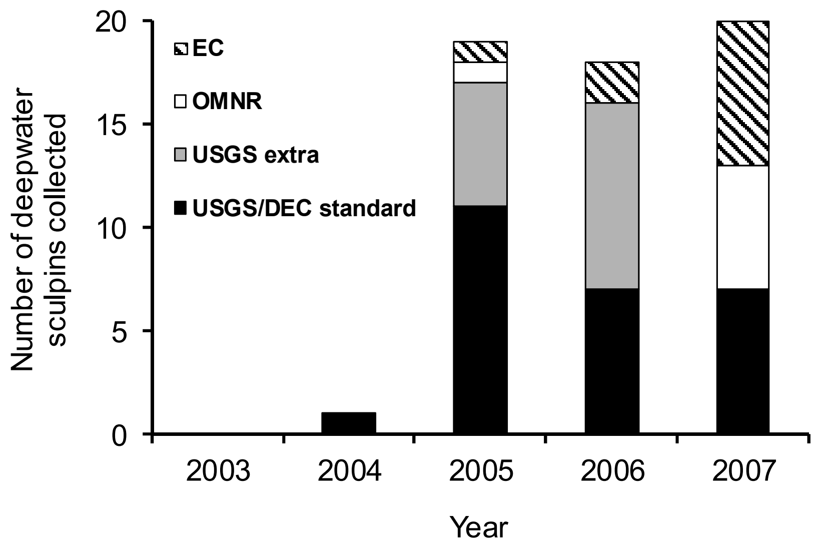


Deepwater Sculpin

The deepwater sculpin, thought to be abundant in Lake Ontario in the early 1900s, became very rare by the 1960s (Wells 1969; Christie 1973) and was not encountered during 1973-1995 (Owens et al. 2003; Lantry et al. 2007a). Three deepwater sculpins were collected in Ontario waters in 1996 and five in New York waters during 1998-2000 (Lantry et al. 2007b), marking the first signs of an incipient population recovery (Lantry et al. 2007a, 2007b). No deepwater sculpins were documented in 2001-2003, and only one was captured in 2004. The potential recovery of deepwater sculpins was thought limited by an abundance of predators on their pelagic larvae (alewife) and on the benthic adults (lake trout) and the near absence of one of the sculpin's important prey, *Diporeia* spp. (Kraft and Kitchell 1986; Hondorp et al. 2005). During 2005-2007, however, deepwater sculpins were caught consistently in standard assessments conducted by the U.S. Geological

Survey (USGS) and New York State Department of Environmental Conservation, in tests of trawling gear by the USGS, and in trawling conducted by the Ontario Ministry of Natural Resources and by Environment Canada (Fig. 9). Total lengths of the deepwater sculpin ranged from 45 to 193 mm, and small individuals were caught each year indicating that successful reproduction was occurring annually. Capture depths ranged from 75 to 175 m. By 2007, deepwater sculpins were being caught at widespread locations in New York and Ontario waters of Lake Ontario. The population recovery of deepwater sculpins does not appear to be limited by the decline in *Diporeia* spp., as was suggested by Lantry et al. (2007b).

Fig. 9. Number of deepwater sculpin caught in Lake Ontario with bottom trawls by Environment Canada (EC), Ontario Ministry of Natural Resources (OMNR), U.S. Geological Survey (USGS), and New York State Department of Environmental Conservation (DEC) during 2003-2007. No trawling was done by the OMNR in 2006.



Progress and Outlook

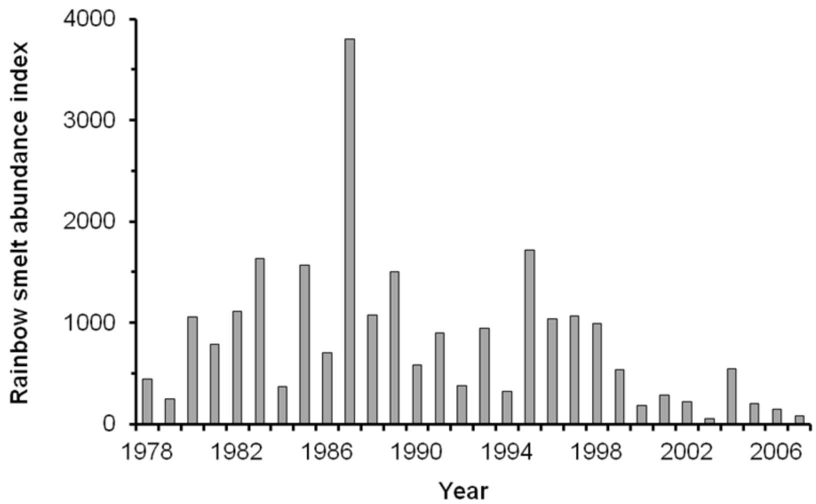
Increased sightings of deepwater sculpins over a larger geographical area, the indicator of progress for this uncommon species during 2003-2007, suggest that the status of this species is consistent with the Offshore Fish-Community Objective. The population increases may have been enhanced by the low abundance of alewives and lake trout (see Offshore Pelagic Fish Community chapter and Lake Trout subsection in this chapter).

Non-Native Deepwater Prey Fishes

Rainbow Smelt

Rainbow smelt were first found in Lake Ontario off Sodus Point, New York, (see Frontispiece for all place names) in 1929 (Bergstedt 1983). In Lake Ontario, rainbow smelt eat native invertebrates, including *Diporeia* spp. and *Mysis diluviana* as well as non-native invertebrates including the fishhook water flea (*Cercopagis pengoi*) and spiny water flea (*Bythotrephes longimanus*) (Walsh et al. 2008a). Rainbow smelt are an important prey for predatory fishes in Lake Ontario and are second only to alewife in salmon and trout diets (Lantry 2001). Rainbow smelt abundance fluctuated tenfold during 1978-2007 (Fig. 10). During this reporting period, 2003-2007, rainbow smelt abundance was lower than in any prior five-year period and will quite likely remain low into the immediate future.

Fig. 10. Abundance of rainbow smelt (age 1 and older) in the New York waters of Lake Ontario as indexed by the sum of area-weighted means of numbers caught per 10-min tow of a bottom trawl during June assessments conducted by the U.S. Geological Survey and New York State Department of Environmental Conservation, 1978-2007.

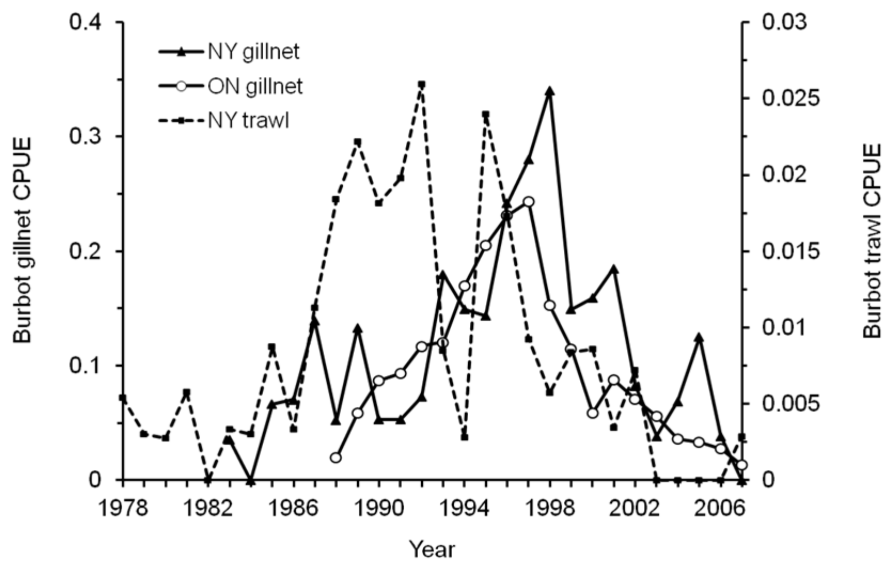


Burbot, Lake Whitefish, and Lake Trout

Burbot

Burbot catches in New York waters of Lake Ontario increased through the 1980s, declined in the 1990s, and remained low during 2003-2007 (Fig. 11). Increases in burbot abundance in the 1980s is attributed to reduced numbers of sea lamprey, buffering from sea lamprey predation by lake trout at a time when lake trout were abundant, and an easing of predation on pelagic burbot larvae owing to a reduction in the number of alewives (Stapanian et al. 2008). Subsequent declines in burbot abundance correspond with declines in lake trout abundance suggesting that predation by sea lamprey on burbot increased as the number of trout waned. Sea lamprey marking on other salmon and trout increased in 2007 (Lantry and Eckert 2008). The outlook for burbot remains uncertain; the continued low abundance of alewives during 2003-2007 (see Offshore Pelagic Fish Community chapter) should enhance recruitment of young burbot, but a relaxation in predation by sea lamprey may be necessary for those burbot young to survive to spawning ages. Until relaxation occurs, we do not expect to see increased catches of burbot as envisioned in the indicator for the fish-community objective for this species.

Fig. 11. Catch-per-unit effort (CPUE) of burbot with bottom trawls and gillnets, Lake Ontario, 1978-2007. For trawls, CPUE = number per 10-min tow. For gillnets set in New York (NY) waters, CPUE = number per 136.8 m of graded-mesh gillnet, and for gillnets set in eastern Ontario (ON) waters, CPUE = number per 152.4 m of graded-mesh gillnet.

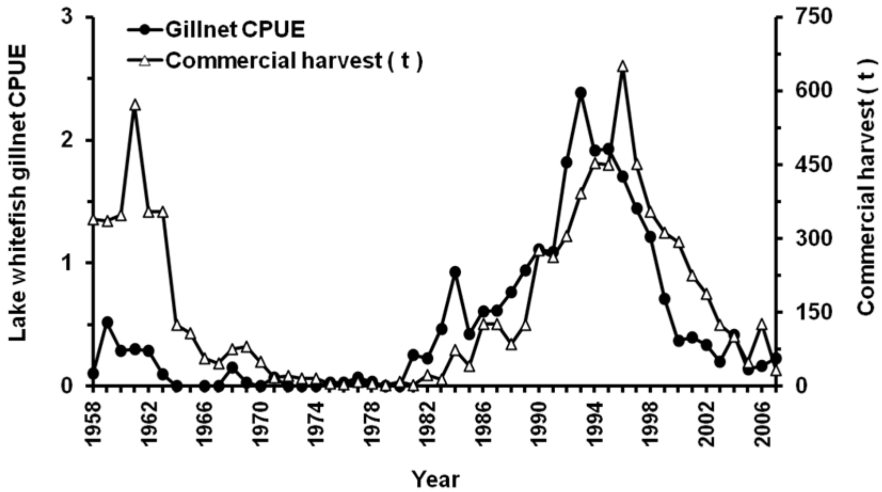


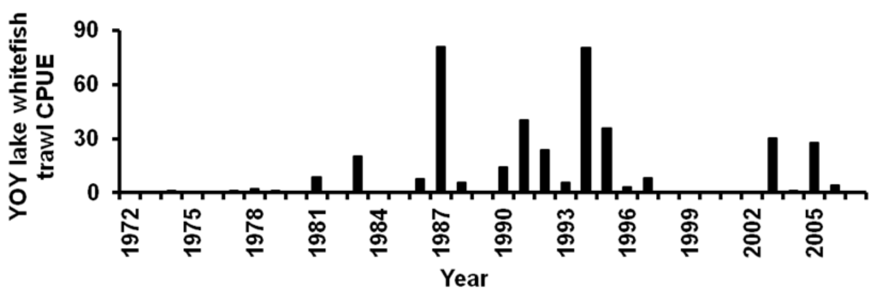
Lake Whitefish

Historically, the lake whitefish occurred throughout Lake Ontario, although, by the late 1900s, it was most abundant in the eastern basin (Hoyle et al. 2003; Owens et al. 2003). Commercial-fish-harvest statistics suggest that lake whitefish abundance fluctuated widely throughout the 1900s (Baldwin et al. 2009). Peak harvest occurred in the 1920s. Lake whitefish status was negatively affected by the severe food-web disruption and near loss of *Diporeia* spp. in the 1990s (Hoyle 2005; Owens et al. 2005; Lantry et al. 2007b). *Diporeia* spp. are an important food for sub-adult and adult lake whitefish (Hart 1931; Owens and Dittman 2003). Also, Hoyle et al. (2011) reported that the populations of zooplankton prey of larval lake whitefish, cyclopoid copepods and small-bodied cladocerans, had also collapsed between the mid-1990 and early 2000 and that the collapses coincided with a decline in larval whitefish growth and survival.

Lake whitefish year-class strength, as measured in eastern Ontario waters by the number of young-of-the-year lake whitefish caught with bottom trawls in August, appeared to improve in 2003 and 2005, but these increases did not translate into increased catches of older fish in index gillnets in subsequent years (Fig. 12). Lake whitefish abundance appears to be stabilizing at a low level, but one that is still higher than the remnant levels of the 1970s. Although recruitment is occurring, it is sporadic at best. Lake whitefish abundance and commercial harvest increased during the mid-1980s, declined after 1993, and remained low during 2003-2007 (Fig. 12).

Fig. 12. Catch-per-unit effort (CPUE) of (top panel) sub-adult and adult lake whitefish in graded-mesh gillnets set in Ontario waters of eastern Lake Ontario during 1958-2007 by the Ontario Ministry of Natural Resources (OMNR) and (bottom panel) young-of-the-year (YOY) lake whitefish in bottom trawls towed for 12-min in Ontario waters of eastern Lake Ontario and in the Bay of Quinte during August 1972-2007 by the OMNR. Also shown (top panel) is the commercial harvest (t = metric tonnes) of lake whitefish in Ontario waters of Lake Ontario during 1958-2007.





Progress and Outlook

During this reporting period, 2003-2007, the indicators for lake whitefish, maintenance of early-1990s catchs and range expansion, were negative. In fact, catch was far below the level of the 1990s owing to large changes in the food web that have reduced carrying capacity for this species, likely indefinitely. Accordingly, we suggest revision of the lake whitefish objective and its indicators to reflect a more-uncertain future for this species.

Lake Trout

Lake trout was a major native piscivore in the offshore benthic and pelagic zones of Lake Ontario until its extirpation in the early 1950s (Christie 1973; Elrod et al. 1995). Rehabilitation efforts, ongoing since the 1950s (Elrod et al. 1995), have been guided by successive documents. The first was Schneider et al. (1983): A Joint Plan for Rehabilitation of Lake Trout in Lake Ontario. The key objective in this document was to establish a stocked population large enough to produce 100,000 yearlings annually. By the mid-1980s, a large population of adult lake trout was established due to increased stocking in the late 1970s and to enhanced sea lamprey control in the early 1980s (Elrod et al. 1995). Population goals established in Schneider et al. (1983) were met by the mid-1990s, necessitating the drafting of a new plan, which was presented to the Lake Ontario Committee in 1998. The 1998 plan though viewed informally as an operational guide was never adopted and published. Subsequently, however, Stewart et al. (1999) endorsed the (three) measures of progress in the unpublished 1998 plan, thereby making them the “indicators” by which progress in lake trout rehabilitation would be evaluated. Here we present the three measures excerpted from the the 1998 plan, recognizing them as the “indicators” endorsed in Stewart et al. (1999) and report progress in their achievement:

1. Maintain the density of mature females heavier than 4,000 g (>4,000 g) at 2.0 and 1.1 fish per standard assessment gillnet set in New York and Ontario waters, respectively.
2. Sustain the density of wild lake trout in New York waters at a total catch of 26 age-2 fish in standard bottom-trawl surveys conducted during July and increase the abundance of wild age-2 lake trout in Ontario waters above current levels.
3. Establish a population of naturally produced mature fish and increase the density of naturally produced mature females (>4,000 g) to 0.20 and 0.11 fish per standard assessment gillnet in New York and Ontario waters, respectively.

Abundance of lake trout was high in the early 1990s but declined substantially lakewide during the late 1990s (Elrod et al. 1995; Lantry et al. 2007b). For lake trout stocked at age 1, survival indices (the number caught at age 2 per 0.5 million stocked) declined sharply in New York waters starting with the 1990 year-class and remained low for the 2001-2005 year-classes (Fig. 13). Similar declines in survival of stocked lake trout were seen in Ontario waters where a large drop in survival from age 1 to age 3 occurred for the 1991-1994 year-classes and where lowered survival has persisted through 2007 (Fig. 14). In New York waters, declines in survival of stocked fish reduced recruitment and led to a 31% reduction in adult abundance from 1998 to 1999 (Fig. 14). Reduced adult abundance persisted through 2004. In 2005, adult abundance declined by an additional 54%. Declining abundance of adult lake trout during the 1990s was due to diminished survival of stocked fish and a 50% reduction in the number of fish stocked during 1992-1993. In New York waters, the abrupt decline in adult abundance during 2004-2005 was across all sizes and ages of adult lake trout indicating that it was not due simply to lower recruitment. More likely, the 2004-2005 decline was due to an uptick in mortality from sea lamprey attacks because it corresponded closely to an increase in the number of fresh sea lamprey marks on lake trout and other salmon and trout (Lantry and Eckert 2008; Lantry and Lantry 2008; see Offshore Pelagic Fish Community chapter). After 2005, lake trout abundance declined slowly through 2007 when the catch-per-unit effort (CPUE) of adults in gillnets reached its lowest point since 1983 (Fig. 14).

Fig. 13. First-year survival of the 1980-2005 year-classes of lake trout stocked as yearlings in Lake Ontario during 1981-2006. Survival is indexed in New York (NY) waters as the total catch of age-2 fish in July bottom trawling per 0.5 million yearlings stocked one year earlier in New York and is indexed in Ontario (ON) waters as the average catch of age-3 fish in graded-mesh gillnets set during summer in Ontario waters of eastern Lake Ontario per 0.5-million yearlings stocked two years earlier in the same area.

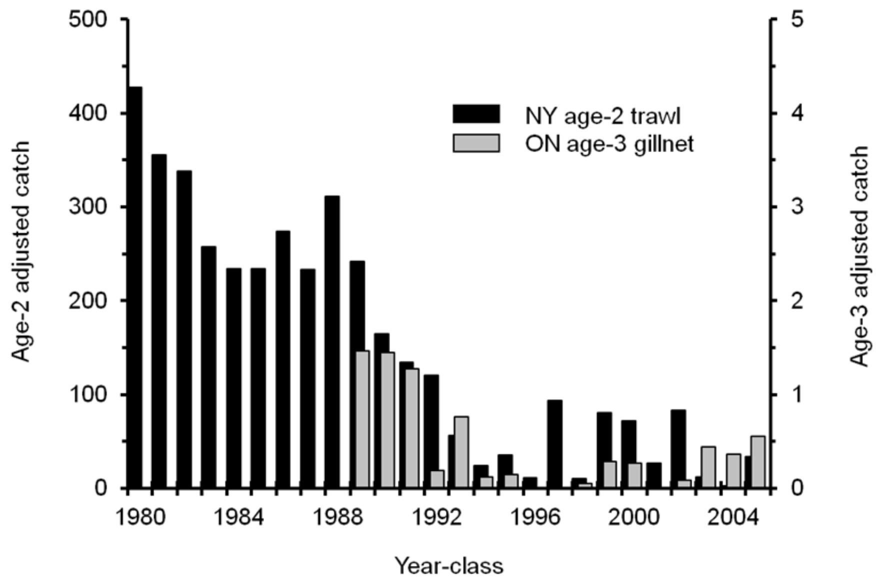
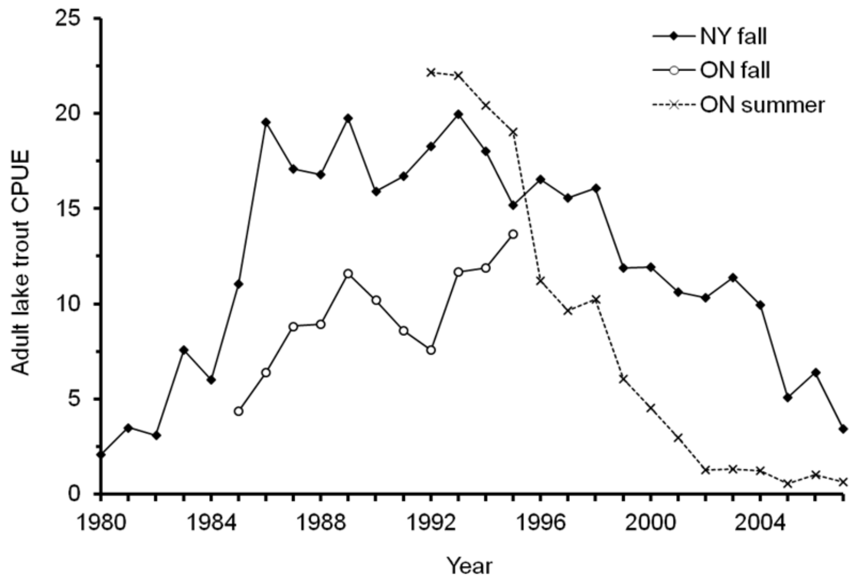
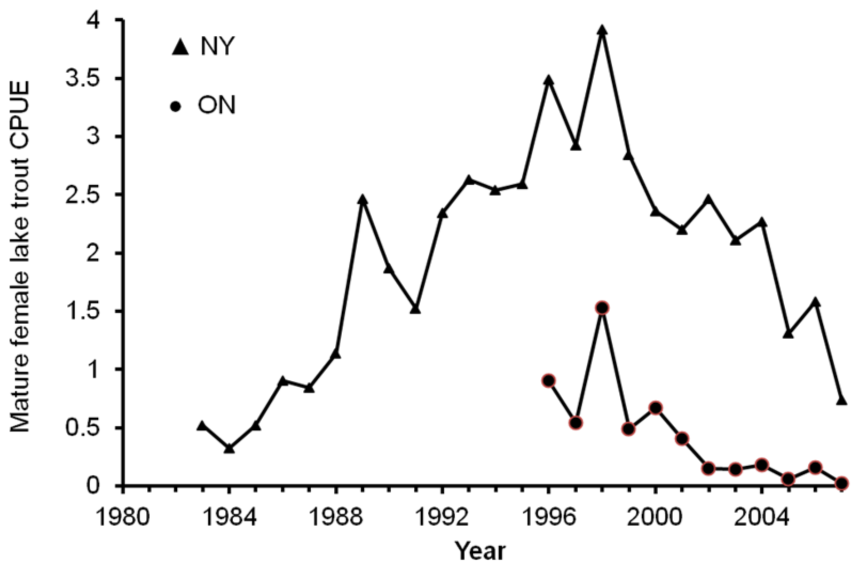


Fig. 14. Catch-per-unit effort (CPUE) of adult lake trout in graded-mesh gillnets set in Lake Ontario during 1980-2007. Fall CPUEs are for all New York (NY) waters and all Ontario (ON) waters, whereas the summer CPUE is for eastern Ontario waters only.



During 1992-2004, the CPUE of mature females heavier than 4,000 g exceeded the target of 2.0 for New York waters (Fig. 15). During this period of high population fecundity (Lantry and Lantry 2008), naturally produced yearling lake trout appeared in survey catches for the first time (Owens et al. 2003). The appearance of naturally produced fish also coincided with an abrupt increase in the springtime depth distribution of alewives (O'Gorman et al. 1998; O'Gorman et al. 2000). Each year during 1994-2007, small numbers of naturally produced age 0-3 lake trout from the 1993-2005 year-classes appeared in assessment catches (Lantry and Lantry 2008). Similarly, in Ontario waters, the proportion of adult lake trout that bore no evidence of being stocked (i.e., fish without a fin clip or a coded wire tag) began to increase in the late 1990s and reached an average of 13.5% during 2003-2007 (TS, unpublished data). Analysis of stable isotopes in the otoliths of unclipped and untagged fish indicated that about 90% of them were naturally produced (TS, unpublished data) suggesting that more than 10% of adult lake trout in the lake were wild.

Fig. 15. Catch-per-unit effort (CPUE) of mature female lake trout >4,000 g in graded-mesh gillnets set in Lake Ontario during September in New York (NY) waters and during summer in Ontario (ON) waters, 1983-2007.



Predation by sea lamprey continues to be an important determinant of lake trout survival, and thus abundance, as well as that of other fishes like burbot (Lantry et al. 2007b). Sea lamprey control, first implemented in Lake Ontario in 1971 (Elrod et al. 1995), suppresses the lamprey population by the application of lampricides in larval-lamprey-infested streams, by installing barriers to block the upstream spawning migration of adult lampreys, and by trapping and removing mature adults (Larson et al. 2003). The effectiveness of sea lamprey control is evaluated chiefly through two metrics: marking rates on lake trout (≤2.0 marks per 100 lake trout; Stewart et al. 1999) and the number of adult sea lampreys (≤30,000). During 2003-2007, Type A, Stage I, marks (Ebener et al. 2006) exceeded target levels in four of the five years, averaging 3.2 marks per 100 lake trout longer than 432 mm (Fig. 16). This rate was substantially above the 1998-2002 average of 2.2 marks per 100 lake trout. The upward trend is also reflected in the number of adult sea lampreys, which was above target levels in four of the five years (Fig. 17). The 2003-2007 average of 48,500 adult sea lampreys was about 50% more than the 1998-2002 average of 32,700. The cause of this increase is unknown but may owe partially to increasing production from the Moira and Trent Rivers in Ontario or from Sandy Creek in New York, which was found to be a new producer of sea lampreys in 2007.

Fig. 16. Frequency of Type A, Stage I, (A-I; Ebener et al. 2006) marks on lake trout >432 mm in Lake Ontario plotted by year in which the sea lampreys that inflicted the marks spawned, 1975-2007. The horizontal line shows the target of 2.0 marks per 100 lake trout >432 mm.

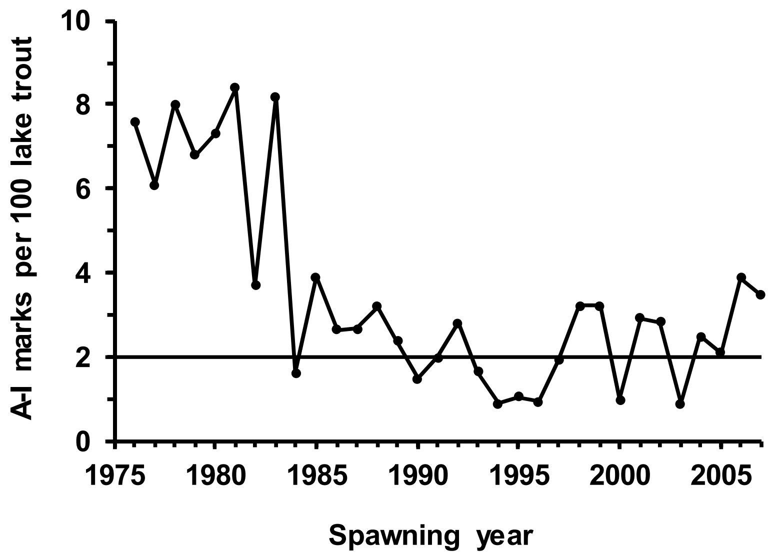
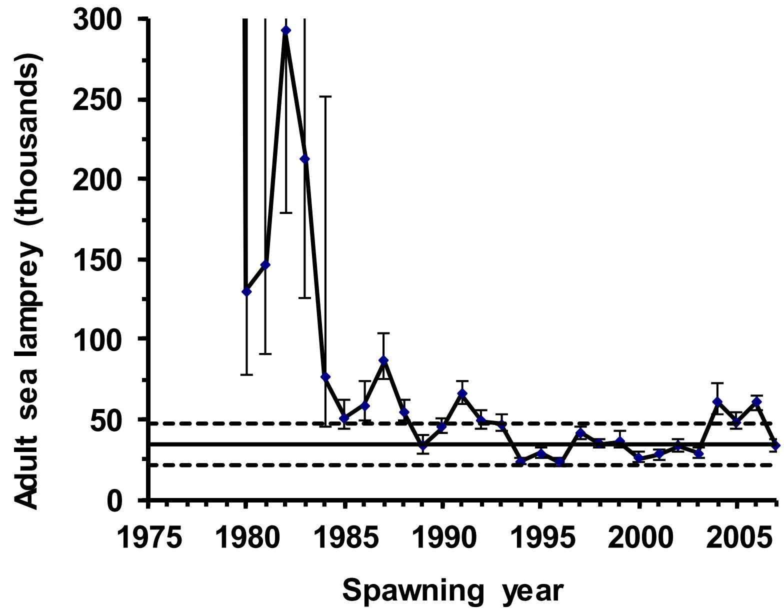


Fig. 17. Number (±95% CI) of adult sea lampreys in Lake Ontario, 1980-2007. Population estimates were generated by a model described in Mullet et al. (2003). The horizontal line shows the target of 30,000 ± 7,000 for adult sea lampreys.



Progress and Outlook

Measure 1, which seeks a high abundance of adult female lake trout, was not met during this reporting period (2003-2007) even though it was being met at the start of the period. Because Measures 2 and 3 depend on achievement of Measure 1, the prospects for their achievement remain dim. The original objective of producing a population of mature lake trout comprising 0.5-1.0 million individuals (Schneider et al. 1983) was met by 1992. Although this population dwindled thereafter, it was still large enough through 2004 to meet the levels of population abundance specified in Measure 1 (CPUE ≥ 2.0 in New York and 1.1 in Ontario; Fig. 15). A sharp decline in adult abundance after 2004 drove the mature female CPUE below the Measure-1 targets in 2005 for the first time in 14 years and CPUE continued to decline through 2007.

Sea lamprey predation and poor recruitment were implicated in the adult population declines. Sea lamprey abundance increased during 2004-2007 (Fig. 17), and steps are underway to address this increase. Lake trout recruitment declines were likely related to several factors, including cannibalism by an increasingly abundant population of large lake trout (at least through 1998), declines in prey-fish abundance, ecosystem changes associated with the proliferation of dreissenids and water fleas, and cuts in stocking (Elrod et al. 1993; Brendon et al. 2011; Lantry et al. 2011). Although Elrod et al. (1993) suspected that recruitment declines during 1980-1992 were the result of cannibalism, substantial declines in the numbers of large adult lake trout during 1998-2005 did not result in increased survival of stocked yearlings.

The continued appearance of naturally produced lake trout in survey catches is encouraging, but their abundance is low. Experience gained in over 40 years of restoration efforts indicates that achieving the long-term goal of a self-sustaining lake trout population will require establishing a population of adults large enough to overcome impediments to natural reproduction and supplying adequate amounts of low-thiaminase prey fish to increase thiamine levels in adult lake trout (Elrod et al. 1995; Fitzsimons et al. 2003; Lantry et al. 2007b). Declines in prey-fish abundance and ecosystem changes caused by non-native species are not readily susceptible to management control. Therefore, we suggest restoring native prey fishes, in particular deepwater sculpin and deepwater ciscoes. Lake trout stocking is under management control and studies just completed or underway are providing updated information on stocking methods, strain composition, and stocking rate (Lantry et al. 2011). This information is being considered in a rewrite of the unpublished 2008 rehabilitation plan.

OFFSHORE PELAGIC FISH COMMUNITY[8]

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Background

The offshore pelagic fish community consists of fishes that occupy the warm upper and cool middle layers of water during June-October, when the lake is thermally stratified. Stewart et al. (1999) called this zone the offshore

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[8]Full report with references is available at http://www.glfc.org/pubs/SpecialPubs/Sp14_01.pdf.

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pelagic habitat zone, and they included in it, for illustrative purposes, all waters where the bottom depth was greater than 15 m, except those in embayments. Offshore pelagic predators include Chinook salmon, coho salmon, rainbow trout, and brown trout (all non-native) and the reintroduced (native) Atlantic salmon. Although salmon and trout abundance is maintained mainly by stocking, some natural reproduction also occurs (Bowlby et al. 2007; Connerton et al. 2009). The prey-fish community in the offshore pelagic zone is dominated by the alewife (non-native) and includes much smaller populations of four native planktivores—threespine stickleback, emerald shiner, spottail shiner, and cisco. Only remnant populations of the formerly abundant cisco persist in Lake Ontario (Casselman and Scott 2003; Owens et al. 2003).

The diverse mix of salmon and trout in the offshore pelagic zone is maintained to provide quality fishing opportunities, rehabilitate indigenous species, and contribute to the ecological function of the fish community (Stewart et al. 1999). Relative abundance of the various fishes in the mix is determined not only by stocking but also by natural reproduction, fishing regulations, and environmental factors (e.g., weather, habitat changes, and predator-prey interactions). In addition to factors affecting the abundance of salmon and trout, angler catch and harvest may be influenced by angler preferences, fishing effort, prey-fish distribution and abundance, and technological improvements, and may vary by season and region.

The fish-community objectives (FCOs) for the offshore pelagic fish community, as described by Stewart et al. (1999), are

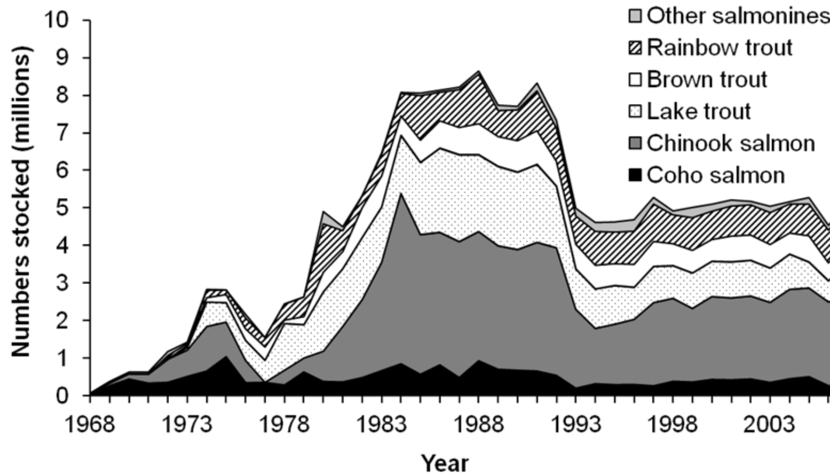
> *The offshore pelagic fish community will be characterized by a diversity of salmon and trout; Chinook salmon as the top predator; abundant populations of rainbow trout (steelhead); fishable populations of coho salmon and brown trout; populations of stocked Atlantic salmon at levels consistent with investigating the feasibility of restoring self-sustaining populations; amounts of naturally produced (wild) salmon and trout, especially rainbow trout, that are consistent with fishery and watershed plans; and a diverse prey-fish community with the alewife as an important species.*

Salmon and Trout

Stocked Salmon and Trout

The stocking of hatchery-reared trout and salmon shaped the diversity of the offshore predator community in Lake Ontario during 1968-2002 (Bowlby et al. 2007) and continues to be an integral part of the management of the lake. Compared to years prior to 2003, the number of trout and salmon stocked during 2003-2007 was stable (Fig. 18), averaging five-million fish per year (46% Chinook salmon, 17% rainbow trout, 16% lake trout, 12% brown trout, 7% coho salmon, and 3% Atlantic salmon). In 2006, stocking declined by 14% because of an outbreak of infectious pancreatic necrosis among lake trout being reared at a U.S. Fish and Wildlife Service hatchery, a poor egg-take in fall 2005 that reduced the number of Chinook salmon released in Ontario waters (OMNR 2006), and a discontinuation of coho salmon stocking by the Ontario Ministry of Natural Resources (OMNR) (resumed in 2008). Stocking targets were met for most species in 2007, and the mix of salmon and trout stocked has remained relatively consistent since 1999.

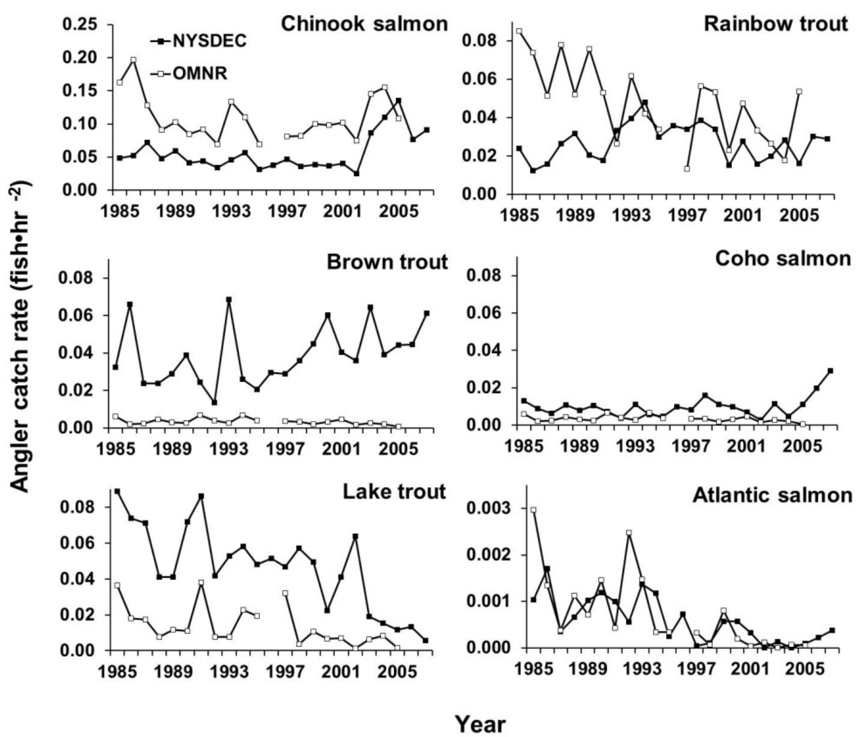
Fig. 18. Number of salmon and trout stocked annually in Lake Ontario, 1968-2007 (includes only fish >3 g). Other salmonines and years stocked include splake (1968-1976), kokanee (1968-1972), brook trout (1980-1981), and Atlantic salmon (1983-2007).



Chinook salmon was an important component of the recreational fishery in Lake Ontario during 1985-2002, averaging 27% of the angler catch in New York waters and 57% in Ontario waters (Bowlby et al. 2007). Since 2003, the proportion of Chinook salmon in the angler catch has increased, averaging 51% in New York waters during 2003-2007 and 75% in Ontario waters during 2003-2005 (angler surveys were not conducted in Ontario during 2006-2007). Chinook salmon is now the most-commonly caught species in both jurisdictions (OMNR 2006; Lantry and Eckert 2008). Chinook salmon catch rates have also increased. In New York, where fishing quality is indexed by catch rates on charterboats, the numbers of Chinook salmon caught per angler hour during 2003-2007 were the highest recorded in 23 years of angler surveys (Fig. 19), averaging 2.2 times higher than charterboat catch rates during the early 1990s (Lantry and Eckert 2008). Similarly, in Ontario, where fishing quality is indexed by catch rates on all fishing boats, Chinook salmon catch rates during 2003-2005 averaged 37% higher than in the early 1990s (OMNR 2006). Increased catch rates of

Chinook salmon may be attributable to increased numbers of salmon due to improved survival of stocked fish and increased levels of natural reproduction. As well, new technology (e.g., Internet-informed anglers) or the quantity, quality, or distribution of prey fish may be enhancing the vulnerability of Chinook salmon to anglers.

Fig. 19. Catch rates (number of fish caught per angler hour) of Chinook salmon, rainbow trout, brown trout, coho salmon, lake trout, and Atlantic salmon in the open waters of Lake Ontario during April-September, 1985-2007. The Ontario Ministry of Natural Resources creel survey is conducted in western Lake Ontario and catch rates include all fishing boats (OMNR 2006). The New York State Department of Environmental Conservation creel survey is conducted in southern and eastern Lake Ontario (Lantry and Eckert 2008), and the catch rate shown is for charterboats only. Note that scales of the Chinook salmon and Atlantic salmon panels differ from those in the other panels and from each other.



Rainbow trout was the second most-commonly caught fish in the sport fishery in Ontario waters during 1992-2005 (OMNR 2006). In New York waters, rainbow trout was a smaller component of the sport fishery and was the third or fourth most-commonly caught species each year during 1992-2007 (with the exception of 1998 when it was first). Compared to the early 1990s, rainbow trout catch rates in Ontario during 2003-2005 were 37% lower, and in New York during 2003-2007 were 22% lower (Fig. 20) (OMNR 2006; Lantry and Eckert 2008). Lower catch rates may be due partly to anglers shifting their effort toward Chinook salmon (JRL, personal observation). Other data, however, suggest a reduced population of rainbow trout in 2003-2007 compared to earlier years. Returns of rainbow trout to the fishway in the Ganaraska River, Ontario (see Frontispiece for all place names) lower in 2003-2007 (OMNR 2008), and a creel survey conducted on the Salmon River, New York, found that angler catch rates in 2006 were lower than those in the 1990s (Prindle and Bishop 2008).

Brown trout always has been a minor component of the fishery in Ontario waters, averaging only 2% of total angler catch (OMNR 2006). During 2003-2005, brown trout catch rates among all fishing boats in Ontario were 61% lower than catch rates in the early 1990s (Fig. 19). In New York waters, however, angling for brown trout near shore in the spring always has been an important component of the fishery. Prior to 2003, 21% of the angler catch was brown trout, and, each year since then, brown trout was the second most-commonly caught species, comprising 23% of the angler catch in New York. Among New York charterboats, brown trout catch rates during 2003-2007 were 48% higher than those in the early 1990s (Lantry and Eckert 2008).

Coho salmon has been a consistently minor component of Lake Ontario's trout and salmon fishery, comprising only 3% and 6% of total angler catch in Ontario and New York, respectively, during 1985-2002 (OMNR 2006; Lantry and Eckert 2008). Coho salmon catch rates among all fishing boats in Ontario waters during 2003-2005 were, on average, 57% lower than catch rates in the early 1990s (Fig. 19). In New York waters, coho salmon catch rates among charterboats during 2003-2005 were similar to catch rates in previous years. In 2006 and 2007, however, catch rates were the highest of the 23-year period of record, averaging about two times higher than coho salmon catch rates during the early 1990s (Lantry and Eckert 2008). A fall creel survey conducted on the Salmon River, New York, also documented a relatively high coho salmon catch in 2006 and 2007 (Prindle and Bishop 2008), and, in those years increased spawning runs of coho salmon were observed in Ontario tributaries as well (JNB, personal observation). In summary, Lake Ontario continues to provide a small and fishable population of coho salmon.

Although the lake trout is considered to belong to the offshore benthic community (see Offshore Benthic Fish Community chapter), it is a component of the offshore fishery and is discussed here to provide a more-complete overview. In both Ontario and New York waters during 2003-2007, lake trout catch rates, unlike those for other offshore salmon and trout, were substantially lower than they were during the early 1990s. Two important causes of the decline are (1) above-average fishing quality for other species of trout and salmon, particularly Chinook salmon, which likely reduced the amount of angling effort directed at lake trout and (2) a lakewide reduction in lake trout abundance (Lantry and Lantry 2008; OMNR 2008).

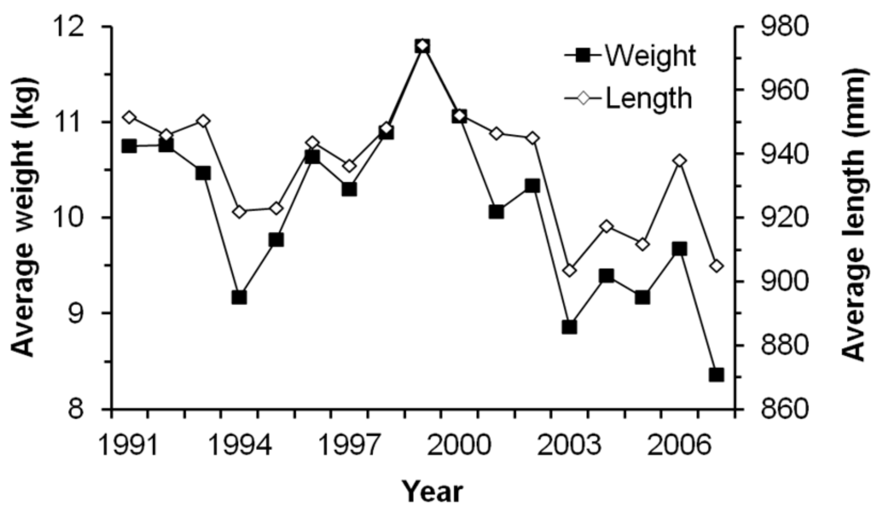
The Atlantic salmon, like the lake trout, is under rehabilitation, but, unlike lake trout, it is a minor component of the sport fishery, accounting for less than 1% of angler catch in each of the 23 years New York anglers were surveyed (Lantry and Eckert 2008).

Progress and Outlook

Two indicators of whether the objectives for the offshore pelagic fish community (Stewart et al. 1999) were met entail maintaining the preferred mix of salmon and trout in the fishery and the catch rates of the 1990s—both were positive during 2003-2007. Overall, the quality of trout and salmon fishing in Lake Ontario during 2003-2007 was better than in the early 1990s even though catch rates of rainbow trout and lake trout were lower. In 1999, when the FCOs for Lake Ontario were last updated, angler catch rates in the early 1990s seemed a reasonable indicator. Since that time, however, the Lake Ontario ecosystem has changed substantially making angler catch rates in the early 1990s a questionable benchmark. Alternatively, the catch rates for both lake and tributary anglers in the current (five-year) reporting period could be compared with those of the preceding five-year reporting period. More research and fishery-independent surveys are needed to understand how creel survey results relate to trout and salmon survival and abundance and whether natural reproduction makes a meaningful contribution to the catch.

Measures of size or condition of Chinook salmon should be considered as indicators of the health of the pelagic fish community and provided in future state-of-the-lake reports. Large fish are desired by the fishery and are an indicator of predator-prey balance. During 2003-2006, the average lengths and weights of adult Chinook salmon were mostly low, and by 2007 they were at or near record lows (Fig. 20; Bishop and Prindle 2008; Lantry and Eckert 2008; OMNR 2008). Despite these declines, the average weight of age-3 Chinook salmon caught in Lake Ontario (about 9.1 kg) was greater than that of age-3 salmon caught in Lake Huron (about 4.3 kg; J.E. Johnson, Michigan DNR, unpublished data) and Lake Michigan (5.5 kg; Claramunt et al. 2008).

Fig. 20. Average total length (mm) and weight (kg) of age-3 Chinook salmon caught in New York waters of Lake Ontario by anglers fishing from boats during August 1991-2007 (Lantry and Eckert 2008).



Wild Salmon and Trout

Chinook salmon spawn in at least 24 New York tributaries to Lake Ontario (Prindle and Bishop 2008). However, only six tributaries produce substantial amounts of wild fish (Wildridge 1990). Among these tributaries, the Salmon River, New York, is likely the largest single source of wild fish due to its size and high density of spawners (Bishop and Johnson 2008), producing an estimated 5.2-million Chinook salmon fingerlings in 2005 compared with annual stockings of 350,000 fingerlings in the Salmon River and 2.3-million fingerlings lakewide (Everitt 2006). Stream surveys conducted in Ontario from 1993-2005 documented increased catches of wild Chinook salmon fingerlings beginning in 1997 (Bowlby et al. 2007). Although the contribution of these wild fingerlings to the adult population in the lake remains uncertain, scale-pattern analysis indicated that an average of 42% of the Chinook salmon in four year-classes (1992, 1996, 2000, and 2002) were wild (Connerton et al. 2009).

Wild rainbow trout made up 18-33% of the Lake Ontario population from 1979 to 1995 (Rand et al. 1993; Bowlby and Stanfield 2001). The proportion of wild rainbow trout in the in-lake population was not estimated after 1995. Annual surveys of Ontario tributaries to Lake Ontario during 1993-2005 indicated no meaningful trends in densities of young-of-the-year (YOY) rainbow trout in 2003-2005, as compared with the long-term average (OMNR 2006).

Coho salmon and brown trout also reproduce in Lake Ontario tributaries, although production of young is lower than that of rainbow trout (OMNR 2006) and Chinook salmon. Coho salmon YOY in tributaries have become more numerous since 1998 (Bowlby et al. 2007). No information exists on the current proportions of wild adult coho salmon and brown trout in the lakewide populations. Despite suitable habitat (McKenna and Johnson 2005; Coghlan et al. 2007), the number of Atlantic salmon spawning in tributaries is low, and there is no recent evidence of successful reproduction.

Progress and Outlook

Whether the indicator of progress for the FCO for wild salmon and trout—increased catches in assessment and recreational fisheries—has been positive in this reporting period as compared to the previous reporting period is conjectural. Although salmon and trout in Lake Ontario are successfully reproducing in tributaries (Johnson and Ringler 1981; Wildridge 1990; Everitt 2006; Stanfield et al. 2006; Bishop and Johnson 2008), the contribution of their progeny to the sport fishery in 2003-2007 was not quantified. For most salmonids, tributary assessments of young fish provided the only measures of wild recruits to Lake Ontario. As compared to the previous reporting period, average densities of coho salmon YOY in Ontario tributaries were about two times higher, and catches of wild rainbow trout YOY were unchanged (OMNR 2006; Bishop and Johnson 2008). The proportions of wild rainbow trout, coho salmon, brown trout, or Atlantic salmon adults in recreational fisheries are not currently being studied. Anglers value catching wild fish and an understanding of the contribution of wild fish to in-lake populations is critical for managing salmon and trout in Lake Ontario. In 2008, the New York State Department of Environmental Conservation (DEC) purchased an automated fish-marking trailer to clip the adipose fins from all Chinook salmon stocked into Lake Ontario and to insert a coded wire tag in a subset of these salmon. Clipping and tagging studies of other species are also planned. The marking program will facilitate estimation of the proportion of wild salmon and trout in the lake and their contribution to open-lake and tributary fisheries.

Atlantic Salmon

Studies conducted since 2002 have demonstrated that nursery habitat in many streams is suitable for production of juvenile Atlantic salmon (Stanfield and Jones 2003; McKenna and Johnson 2005), but competitive interactions with rainbow trout may reduce Atlantic salmon production in some streams (Stanfield and Jones 2003; Coghlan et al. 2007). In streams stocked with fry and parr, densities of fingerlings in the fall at over half of the sites surveyed exceeded the benchmark of 5 fish•100 m^{-2} (Stanfield and Jones 2003). Moreover, stocked juveniles are surviving well and growing fast in target streams (OMNR 2008). The OMNR and DEC continue to stock

Atlantic salmon every year (Fig. 18), focusing on a few, high-quality cold-water streams, such as New York's Salmon River and Ontario's Credit River, Duffins Creek, and Cobourg Brook. Very few Atlantic salmon are caught by boat anglers in Lake Ontario, and catch rates have declined over the past two decades, with some of the lowest values occurring during 2003-2007 (Fig. 19). In contrast, stream anglers are catching more fish during summer and fall on the Salmon River (F. Verdoliva, New York State DEC, personal communication, 2012).

Progress and Outlook

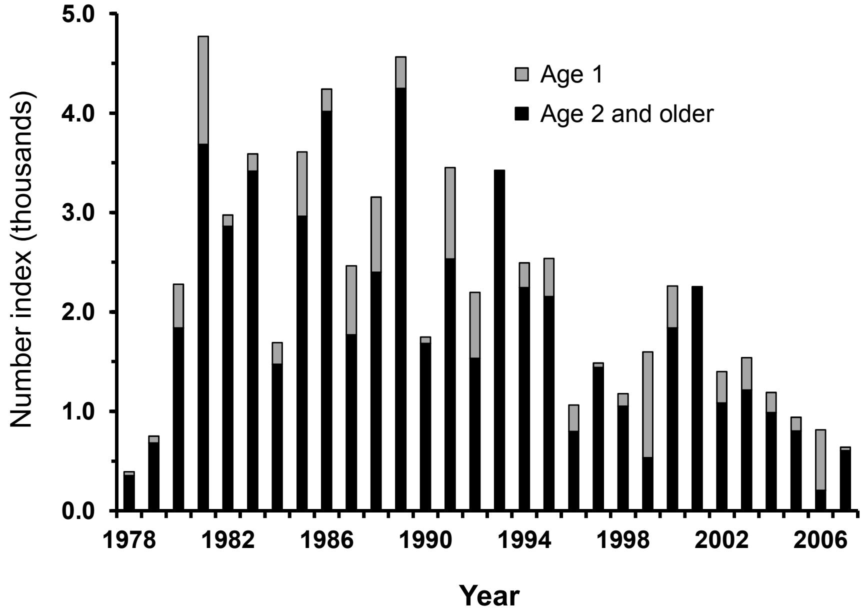
The indicator of progress for achieving the FCO for Atlantic salmon—achievement of growth and survival benchmarks in streams and increased catches in assessment and recreational fisheries—was mixed owing to the reduced catch rates. Efforts are underway or planned to improve performance. In 2006, the OMNR and the Ontario Federation of Anglers and Hunters established and led the Lake Ontario Atlantic Salmon Restoration Program (www.bringbackthesalmon.ca) with support from a network of partners and sponsors. The program includes building fish-culture capacity, rehabilitating habitat, addressing restoration challenges through directed research, and engaging local communities. In addition, the OMNR and U.S. Geological Survey (USGS) are planning to evaluate the performance of several strains of Atlantic salmon. The USGS intends to develop a Lake Ontario strain of Atlantic salmon by establishing spawning runs on the Salmon River, New York, a tributary where adult salmon can be readily captured and spawned. Their progeny will be reared in a hatchery and then released into tributaries. The OMNR plans to complement existing hatchery brood stock, which originated from a sea-run population in Nova Scotia (LaHave River), with two new brood stocks from landlocked populations in Maine (Sebago Lake) and Québec (Lac St-Jean). Genetic profiles have been developed for each individual brood fish in Ontario hatcheries as a means of tracking their progeny in the wild. Some of the salmon stocked in New York will be marked with external elastomer tags and fin clips. Access to spawning and nursery habitats also is being improved. Lastly, we suggest that thiamine deficiency, an impediment to Atlantic salmon reproduction (Fisher et al. 1996), be researched further to determine the extent that Lake Ontario Atlantic salmon are affected.

Prey Fish

Alewife

Bowlby et al. (2007) noted that, by 2003, alewife abundance had declined from levels seen in the 1980s and early 1990s and hypothesized that the decline was due mostly to reductions in lake productivity. Alewife continued the same pattern of decline during 2003-2007, with the total population fluctuating due to one strong year-class in 2005 and one weak year-class in 2006 (Fig. 21). A steady decline in the adult portion of the population occurred during 2003-2006, and, by 2006, adult abundance was the lowest on record. Adult numbers increased between 2006 and 2007 due to recruitment of fish from the strong 2005 year-class. The condition of individual alewife (weight per unit length) improved during 2003-2007. The alewife is a key component in the diets of native and introduced predators (Brandt 1986; Lantry 2001; Bowlby et al. 2010), but a large alewife population can also have direct and indirect negative effects on native fishes (Madenjian et al. 2008). Alewife year-class strength is influenced by several factors, including the number of adult alewives in the spawning stock and summer and winter water temperatures, all of which affect growth and survival of YOY alewife (O'Gorman et al. 2004).

Fig. 21. Abundance of age-1 and age-2-and-older alewife in the New York waters of Lake Ontario as indexed by the sum of area-weighted means of numbers caught per 10-min tow of a bottom trawl during spring assessments conducted by the U.S. Geological Survey and New York State Department of Environmental Conservation, 1978-2007. Note that year-class strength is indexed at age 1 and that age-1 fish in a given year belong to the year-class produced the previous year (e.g., the large number of age-1 alewife caught in 2006 indicates a strong 2005 year-class).



Progress and Outlook

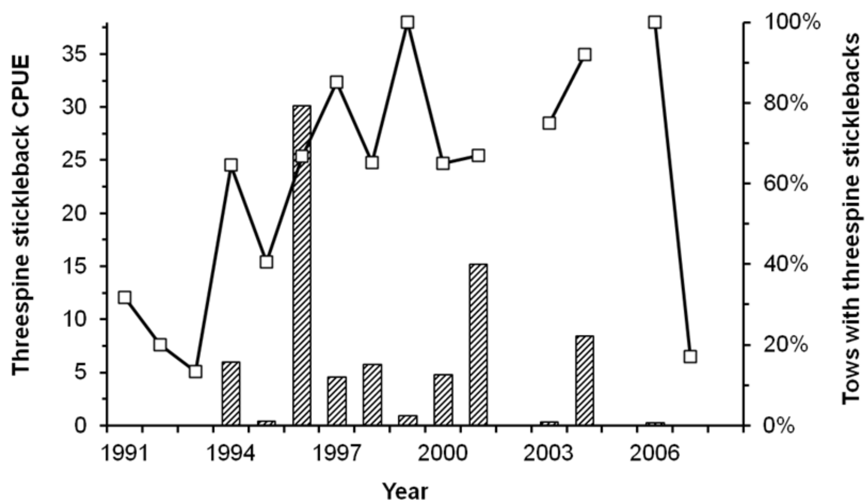
The FCO for the alewife—a pelagic community wherein it is an important species—was met during 2003-2007, but the indicator for the objective—a population above the 1994 level—was negative. In fact, by 2007, the population was about one-third of the 1994 level. Persistence of the alewife population within the range in abundance of even recent years will continue to depend on periodic production of strong year-classes and would be jeopardized if low adult numbers coincide with repeated weak year-classes due to reduced spawning stock and/or harsh environmental conditions. Monitoring the alewife population in Lake Ontario should be continued, and management actions, including changing the numbers of salmon and trout stocked, should be taken to maintain predator-prey balance (Stewart et al. 1999). For example, a reduction in stocking may be warranted if there are successive weak alewife year-classes, persistently low adult alewife abundances, and low proportions of spawning-sized alewife coincident with declining predator growth and condition. An increase in stocking may be warranted if there are successive strong alewife year-classes, high adult abundances, and declines in alewife condition coincident with increased predator growth and condition. Research is needed to understand the factors that led to the higher condition of alewife in this reporting period and how improved condition may change the stock-recruitment relationship of alewife either through higher fecundity of females or better survival of YOY.

Emerald Shiner, Threespine Stickleback, and Cisco

The emerald shiner population experienced a resurgence in the late 1990s. At that time, the species appeared more regularly in survey catches, and unusually large numbers (500 to 2,000 fish per 100 trawl tows) were caught in 1997-1998 (Owens et al. 2003). During 2003-2007, however, the catch per 100 tows ranged from 0 to about 12. Emerald shiners are an important bait fish used by anglers, and large schools are often observed in early summer near shore, in creek mouths, and in large rivers. Although they are captured during trawling surveys in offshore waters, the current surveys are not designed to effectively sample them. They are caught most frequently in April-May while bottom trawling at depths of 35 to 130 m (Owens et al. 2003).

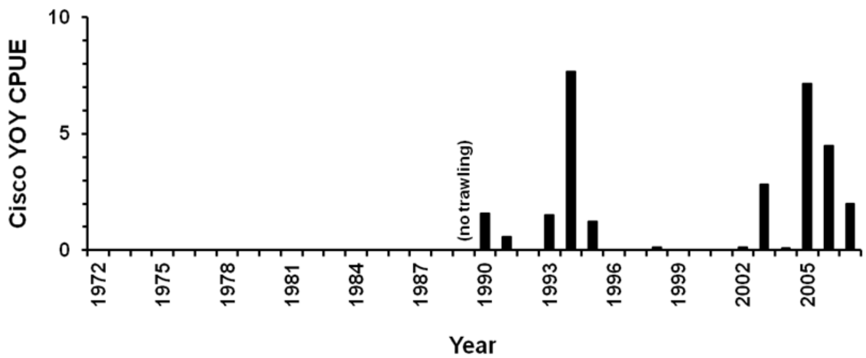
The threespine stickleback, essentially absent from survey catches during most of the 1980s, experienced a rebound in numbers in the mid- and late 1990s (Owens et al. 2003; OMNR 2008). The species was common in the spring diets of brown trout and rainbow trout in the late 1990s (Lantry 2001). More recently, however, threespine stickleback catches have declined. The total catch of threespine sticklebacks in all bottom trawling conducted in New York waters was 50 in 2007 compared to an annual average of 4,466 during 2003-2006. In Ontario waters of the eastern basin, catches of threespine sticklebacks declined to 0 in 2007 after averaging 33 sticklebacks per trawl tow from 1998 to 2002 (OMNR 2008). Similarly, in 2007, the catch of threespine sticklebacks in midwater trawling during a summer hydroacoustic survey was a record low 0.007 fish per 100-m towed compared to the long-term mean of 5.6 fish per 100-m towed (Fig. 22) (Connerton and Schaner 2008).

Fig. 22. Catches of threespine sticklebacks in midwater trawl tows conducted in Lake Ontario during summer hydroacoustic surveys, 1991-2007. Bars show the catch-per-unit effort (CPUE) of threespine sticklebacks in trawl tows (unit of effort is 100-m towed), and lines show the proportion of tows containing sticklebacks. Midwater trawl tows were not made in 2002 or 2005.



Cisco, historically an abundant pelagic planktivore in Lake Ontairo, has persisted only at remnant levels for the last half-century. Catches of ciscoes in routine assessments were common but low during 1980-2002, averaging from 5 to 45 fish per 350 trawl tows per year (Bowlby et al. 2007; Owens et al. 2003). During 2003-2007, only two ciscoes were caught in bottom-trawl surveys in New York waters (MGW, unpublished data), and catches in assessment netting in Ontario waters were sporadic (OMNR 2008). Although pelagic in offshore waters of the open lake, the cisco spawns near shore in embayments. Currently only the Bay of Quinte and Chaumont Bay in eastern Lake Ontario have persistent spawning populations. A commercial fishery in the Bay of Quinte harvests about 454 kg of spawning cisco each fall. During 2003-2007, catches of YOY cisco increased in bottom-trawl surveys conducted in Ontario waters of the eastern basin suggesting improved reproductive success of ciscoes spawning in the Bay of Quinte (Fig. 23).

Fig. 23. Catch-per-unit effort (CPUE) of young-of-the-year (YOY) cisco in bottom trawls towed for 6 min in the lower Bay of Quinte during 1972-2007.



Progress and Outlook

The indicator for the emerald shiner, threespine stickleback, and cisco FCO—continued population increases—was negative during this reporting period. Emerald shiner and threespine stickleback populations rebounded in the 1990s and early 2000s but have since declined despite the lower abundance of alewife and rainbow smelt, two non-native species thought to suppress shiners and sticklebacks through predation. More research is needed to understand the factors controlling emerald shiner and threespine stickleback abundance and to determine whether current surveys accurately measure their abundance. Future improvements in the status of the two native species may depend on a lower abundance of non-native competitors and predators. Cisco populations were showing signs of improvement during 1983-1992 but declined thereafter (Owens et al. 2003) and now cisco are rarely caught in offshore assessments. Recent evidence of improved reproductive success in the Bay of Quinte is encouraging. Research is needed to determine the key factors currently limiting cisco abundance and the feasibility of re-establishing spawning populations in historically used embayments.

ECOLOGICAL DRIVERS OF LAKE ONTARIO FISH ABUNDANCE AND DISTRIBUTION[10]

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In the preceding chapters, changes in the status of fish communities and fisheries in the nearshore and two offshore zones have been summarized. In some cases, there have been brief descriptions of the management activities and ecological factors influencing fish-community states and trends. In this chapter, we synthesize and generalize our developing understanding of the

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[10]Full report with references is available at http://www.glfc.org/pubs/SpecialPubs/Sp14_01.pdf.

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dominant ecological influences (other than direct fisheries-management activities) on fish abundance and distribution in Lake Ontario and refer to observations and ideas in the proceding chapters. We group the dominant ecological influences into the following five categories and discuss them in turn—Habitat, Chemicals and Nutrients, Invasive Species, Other Species Interactions, and Fish Diseases.

Habitat

Relating habitat characteristics to production by a fish species is difficult because of the complexity of the relationship between fish habitat and productivity, the difficulty of characterizing and quantifying fish habitat supply, and the paucity of species-specific habitat inventories (Rosenfeld 2003; Minns and Moore 2003; Minns and Wichert 2005; Rosenfeld and Hatfield 2006; Hayes et al. 2009). Major habitat influences include water levels artificially maintained by regulating the flow of the St. Lawrence River (see Frontispiece for all place names), physical barriers to fish passage, and climate change. Regulated water levels may be limiting the production of northern pike (Casselman and Lewis 1996; International Lake Ontario-St. Lawrence River Study Board 2006) and affecting the abundance of desirable wetland fishes (Jude and Papas 1992; Wei et al. 2004). Tributary characteristics, including barriers preventing access to productive habitat, are limiting reproduction and population growth of various species of trout and salmon and lake sturgeon (Meixler et al. 2005; Velez-Espino and Koops 2010).

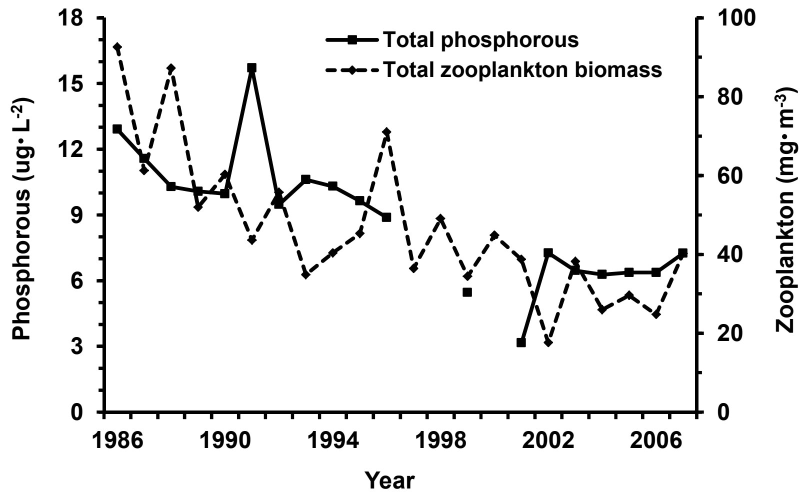
Increased temperature associated with global climate change will favor warm-water fishes and may impair reproduction of cold-water fishes (Casselman 2002; Shuter et al. 2002). Weather-induced changes to water temperature have been shown to influence recruitment of the alewife (O'Gorman et al. 2004) and smallmouth bass (Casselman 2002) and are likely influencing other fishes as well. Recent higher temperatures may be responsible for lower northern pike abundance and growth in Lake Ontario (Casselman 2002). However, the decline of the northern pike population began in the early 1990s and was most likely due to the effect of water-level controls on spawning habitat in wetlands. Degraded wetland quality is also an important influence on northern pike numbers (Farrell et al. 2006). The effects of temperature and the potential for weather patterns to deviate from conventional norms will continue to influence fish communities.

During the 1990s, the Lake Ontario ecosystem underwent substantial biotic changes that continue to influenced fish habitat (Mills et al. 2003). Expansion of populations of dreissenid mussels and increased nutrient controls were associated with increased water clarity (Millard et al. 1996; Watkins et al. 2007; Holeck et al. 2008b). In offshore Lake Ontario, the depths occupied by alewives, rainbow smelt, and juvenile lake trout increased after the 1990s (O'Gorman et al. 2000; Owens et al. 2003). At the same time, the lake whitefish expanded its geographic distribution (Owens et al. 2003). Nuisance levels of benthic algae developed in shallow nearshore areas, and protected bays experienced increases in the abundance and distribution of submerged aquatic plants (Makarewicz and Howell 2012 and references therein; Leisti et al. 2012). Increased submerged aquatic vegetation in the Bay of Quinte was associated with decreased survival of young walleye (Hoyle et al. 2008; Bowlby et al. 2010; Hoyle et al. 2012) increased sunfish and largemouth bass populations (Hoyle et. al 2007; Randall et al. 2012; Hoyle et al. 2012) and likely benefited northern pike (Casselman and Lewis 1996).

Chemicals and Nutrients

By far the dominant nutrient influencing fish communities is phosphorus and, of the total phosphorus entering Lake Ontario, 21-44% comes from the upper Great Lakes and Lake Erie via the Niagara River (Dolan and Chapra 2012). The rest comes from other tributaries and nonpoint sources. Declines in Lake Ontario primary productivity through the 1980s have been associated with planned reductions in phosphorus loads (Millard et al. 1996). The coincident decline in phosphorus and epilimnetic zooplankton biomass (Fig. 24) is consistent with strong food-web linkages between nutrients and zooplankton production. Lower zooplankton production can result in a reduced food supply for planktivorous fish, including the larval stages of many fish species (Stewart et al. 2010b; Stewart and Sprules 2011). Reduced productivity, in addition to other factors, was associated with declines in the abundance of alewife (Stewart et al. 2010b; Stewart and Sprules 2011). Nutrient declines in the Bay of Quinte were associated with declines in walleye and yellow perch abundance (Hoyle et al. 2012). General declines in productivity along with the collapse of the *Diporeia* spp. population may have been a contributing factor in the decline of the slimy sculpin population (Owens et al. 2003).

Fig. 24. Total phosphorous (µg•L^{-2}) in April-May and epilimnetic zooplankton biomass (mg•m^{-3}) in April-October, Lake Ontario, 1986-2007 (compiled from Holeck et al. 2013).



Synthetic contaminants, largely derived from industrial effluent and atmospheric deposition, may have played a role in the historical decline of native fishes (Cook et al. 2003), but evidence is limited for direct negative effects on the life history of contemporary fishes in Lake Ontario (Zint et al. 1995). However, the presence of synthetic toxic chemicals in fish tissue remains a human health issue (Schneider et al. 1998; French et al. 2006;

Carlson et al. 2010) that requires fish-consumption advisories for some sizes and species of fish (Ontario Ministry of the Environment 2008).

Invasive Species

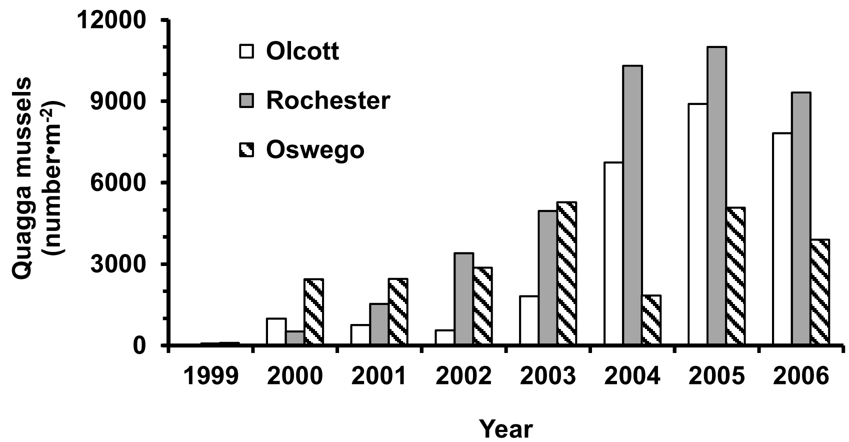
During the 1990s, the spiny water flea (*Bythotrephes longimanus*), fishhook water flea (*Cercopagis pengoi*), bloody-red shrimp (*Hemimysis anomala*), round goby, and dreissenid mussels established and became invasive (reached abundance) in Lake Ontario. The spiny water flea was first observed in Lake Ontario during the early 1980s, but, up to 2005, its abundance has remained low and variable (Makarewicz and Jones 1990; Johannsson and O'Gorman 1991; Holeck et al. 2008a; Stewart et al. 2010a). The fishhook water flea invaded and became abundant in 1998 (MacIsaac et al. 1999), but, up to 2005, it also was relatively low in abundance (Stewart et al. 2010a). Considering the low abundance of the two non-native predatory water fleas in Lake Ontario, the influence of their consumption on zooplankton populations may be low. One study suggested that a disproportionate decline in copepods in Lake Ontario was due to increased predation from non-native water fleas (Warner et al. 2006). Recent studies, however, suggest that alewife predation likely had a larger influence on zooplankton composition than water flea predation (Stewart et al. 2009; Stewart et al 2010b; Stewart and Sprules 2011). Unlike other Great Lakes and inland lakes, the invasion of Lake Ontario by the predatory water fleas has not been associated with any change in zooplankton species richness or diversity up to 2005 (Stewart et al 2010a). However, other studies suggest that water fleas may have had indirect effects on zooplankton by changing the depth distribution, growth, and behavior of other species (Pangle and Peacor 2006; Pangle et al. 2007).

The round goby is now a ubiquitous member of the Lake Ontario fish community and is eaten by all major nearshore fish predators (Somers et al. 2003; Dietrich et al. 2006; Johnson and McCullough 2008; DED, unpublished data). Improved growth and condition of some nearshore fishes have been attributed to round goby consumption (DED, unpublished data). Double-crested cormorants (*Phalacrocorax auritus*) (see next section) have increased their consumption of round goby reducing their predation on more-valued fish species, such as yellow perch and smallmouth bass

(Johnson and McCullough 2008). Various negative effects of round goby have been hypothesized—displacement, predation on eggs or fry, interference with fishing success, and links to botulism and fish viruses—but, to date, there has been no confirmation of negative effects of round goby on fish-community trends in Lake Ontario. The major diet item of round gobies is dreissenids (Walsh et al. 2007; Taraborelli et al. 2010) such that the subsequent consumption of round gobies by predators transfers dreissenid biomass up the food chain. However, when round gobies continue to expand into deeper water in winter, they could negatively affect slimy and deepwater sculpins or change the benthic community by selective predation on amphipods, chironomids, and smaller dreissenids as has occurred in Lake Erie (Barton et al. 2005).

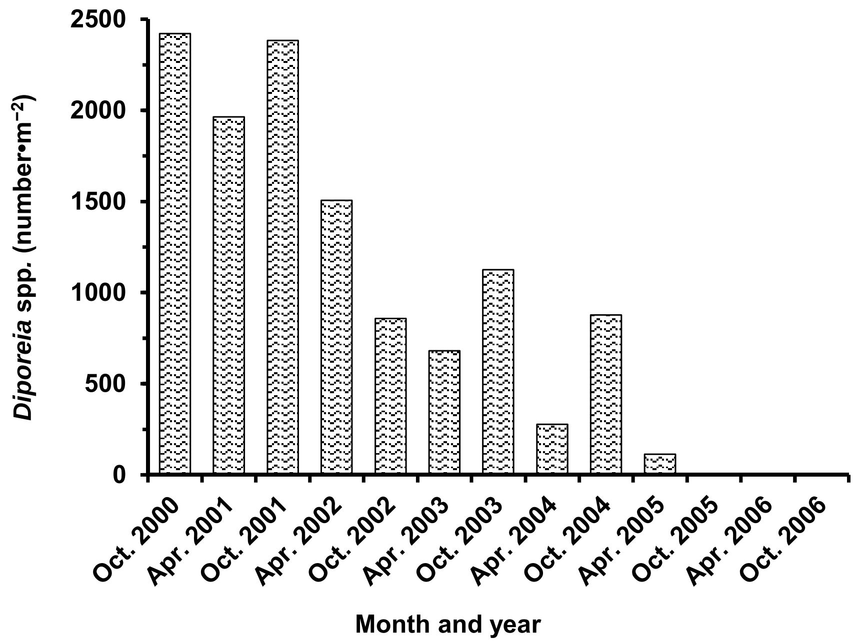
Since 2000, dreissenids have spread progressively deeper in Lake Ontario as documented by standardized sampling along the 95-m bottom contour at three widely separated locations off the south shore (Fig. 25). Dreissenid density increased at depths greater than 95 m as well, although, at some locations, decreases in dreissenid density have occurred at 55 m since 2002. The dreissenid population at a 130-m-deep site off Olcott, New York, remained above 3,000•m^{-2} between 2004 and 2006 (Dittman and Walsh 2007). Watkins et al. (2007) calculated that, during 2003, the most-common dreissenid, the quagga, averaged 8,000•m^{-2} at all sites less than 90-m deep in Lake Ontario.

Fig. 25. The average density (number•m^{-2}) of quagga mussels (*Dreissena bugensis*) at three locations in southern Lake Ontario at a depth of 95 m during October, 1999-2006 (from Dittman and Walsh 2007).



Declines in *Diporeia* spp. in Lakes Huron, Erie, and Ontario have coincided with dreissenid invasions. Hypotheses for the declines include dreissenid-induced food limitations and dressenid-associated toxins or pathogens (Dermott and Kerec 1977; Dermott et al. 2005; McNickle et al. 2006; Nalepa et al. 2009; Watkins et al. 2007). In Lake Ontario, coincident with the increasing numbers of dreissenids, *Diporeia* spp. declined from 3,000 to 145•m^{-2} between 1994 and 1997 (Lozano et al. 2001). By 2003, *Diporeia* spp. density in areas less than 90-m deep had declined to 63•m^{-2} (Watkins et al. 2007). Since 2003, the decline of *Diporeia* spp. has continued at depths greater than 90 m in Lake Ontario. Dittman and Walsh (2007) found that, at a depth of 130 m, *Diporeia* spp. density decreased from 2,800•m^{-2} during 2000 to 0•m^{-2} in 2005 and 2006 (Fig. 26).

Fig. 26. Average density (number•m^{-2}) of *Diporeia* spp. at a bottom depth of 130 m in southern Lake Ontario near Olcott, New York, in October 2000 and in April and October 2001-2006 (from Dittman and Walsh 2007).



Despite considerable research, evidence of the causal mechanism for the *Diporeia* spp. decline has been difficult to identify (Nalepa et al. 2009) other than a modest increase in mortality of *Diporeia* spp. exposed directly to dreissenid pseudofeces under laboratory conditions (Dermott et al. 2005). *Diporeia* spp. populations in Lake Ontario waters deeper than 90 m declined before dreissenids colonized those depths (O'Gorman and Owens 2003; Owens et al. 2003; Watkins et al. 2007). This sequence occurred also in Lake Michigan and in both lakes was attributed to remote effects possibly associated with the transport of an unknown agent in the biodeposits of nearshore dreissenids to offshore waters (Watkins et al. 2007; Nalepa et al.

2009). However, the asynchrony in the spatial and temporal decline in *Diporeia* spp. and the increase in dreissenid density suggests that perhaps there may be other causative agents coincident with the dreissenid invasions but without a direct link to them. Stewart and Sprules (2011) hypothesized that increased predation by *Mysis diluviana*, perhaps associated with water-clarity induced changes in *M. diluviana* distributions, played a role in the decline of *Diporeia* spp.

Regardless of the mechanism, the decline in *Diporeia* spp. populations did affect lake whitefish and slimy sculpin negatively in Lake Ontario (Hoyle et al. 2003; O'Gorman and Owens 2003; Owens and Dittman 2003). *Diporeia* spp. was also important in the diet of juvenile lake trout (Elrod and O'Gorman 1991) and could be important to the recovering population of deepwater sculpin (Kraft and Kitchell 1986). Whether *Diporeia* spp. declines in Lake Ontario have been associated with detrimental effects on these two fishes is not clear but an interaction seems likely. Slimy sculpins increased their reliance on *M. diluviana* following the decline of *Diporeia* spp. (Owens and Dittman 2003), and *M. diluviana* continues to be an important part of their diet (Stewart and Sprules 2011). The alewife ate very little *Diporeia* spp. (Mills et al. 1992; Stewart et al. 2009), and it likely has not been affected by *Diporeia* spp. declines.

Other Species Interactions

The ecological role of *M. diluviana* in Lake Ontario is not well understood, and the magnitude of its interaction with prey and predators, as well as its potential influence on the fish community, may have been underestimated (Stewart and Sprules 2011). *M. diluviana* exerts the same predation intensity on zooplankton as does the alewife, but it is also a major grazer of phytoplankton and likely a major predator of *Diporeia* spp. in the Great Lakes (Parker 1980; Sierszen et al. 2006; Stewart and Sprules 2011). Reduced availability of zooplankton for alewife near shore was coincident with the alewife shifting its distribution further offshore and increasing its consumption of *M. diluviana* (O'Gorman et al. 2000; Stewart et al. 2009; Stewart et al. 2010b). In 2004-2005, as compared to just before the 1990s, slimy sculpin and rainbow smelt consumed more *M. diluviana* (Stewart and Sprules 2011). Declines in *M. diluviana* biomass were consistent with increased predation pressure on *M. diluviana* aggravated by a decline in their food supply (Johannsson et al. 2011). Poor reproductive success of *M. diluviana* during 2002-2005 suggests that it may not be a stable food resource for fish (Johannsson et al. 2011).

The alewife is the dominant prey fish in Lake Ontario (Owens et al. 2003), and its response to ecosystem change has the potential to change the structure and function of the entire food web. The alewife exerts high predatory demand on lower trophic-level production (Rand et al. 1995), its feeding influences the size and species composition of the zooplankton community (Johannsson and O'Gorman 1991; O'Gorman et al. 1991; Johannsson 2003; Stewart and Sprules 2011), and it is the preferred prey of salmon and trout (Lantry 2001; Stewart and Sprules 2011). The alewife also feeds on the non-native fishhook and spiny water fleas (Stewart et al. 2009) and is likely preventing these two species from becoming over-abundant. The alewife eats the recently hatched young of native lake trout (Krueger et al. 1995) and yellow perch (Brandt et al. 1987; Mason and Brandt 1996). It also competes with, and may prey directly upon, the young of threespine stickleback and cisco. The alewife likely is hindering restoration of lake trout not only through predation on its young but also by being a source of thiaminase. Thiaminase is present in the digestive tracts of alewives and can cause a thiamine (vitamin B) deficiency in fishes that eat them, thus hindering their reproduction (Fitzsimons et al. 2007).

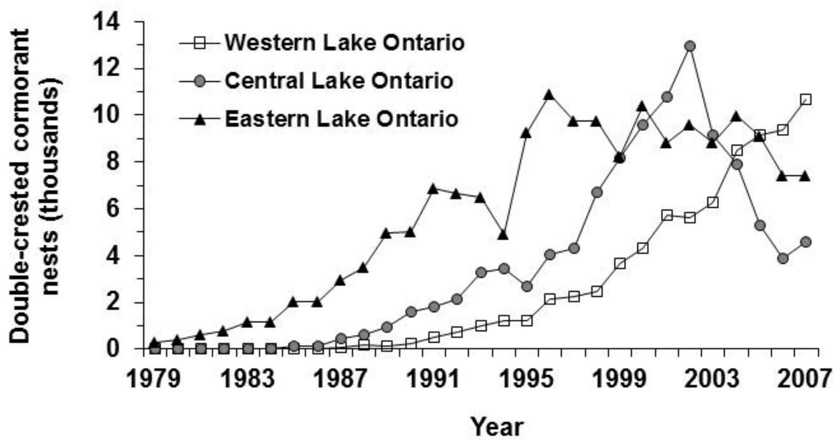
Alewife biomass and production declined by about half after the 1990s (Stewart et al 2010b), matching the observed decline in zooplankton production over the same time period (Stewart et al. 2010a) and reaffirming the strong influence of lower trophic-level productivity on alewife production (Stewart and Sprules 2011). Alewives are also prone to mass die-offs and rapid changes in abundance (O'Gorman and Stewart 1999). In Lake Michigan (Madenjian et al. 2002) and Lake Huron (Barbiero et al. 2011), alewife abundance declined abruptly to very low levels. The prey-fish communities of Lakes Michigan and Huron are more diverse than that of Lake Ontario (Madenjian et al. 2002; Dobiesz et al. 2005), yet the reduction of alewife biomass in these ecosystems was very disruptive. In Lake Michigan, alewife-dependent fishes like Chinook salmon declined in abundance, whereas fishes with a more-diverse diet, like rainbow trout, increased (Hansen and Holey 2002). In Lake Huron, Chinook salmon abundance also declined, and natural reproduction and abundance of lake trout, walleye, and cisco, which apparently had been negatively affected by an abundance of alewife, increased (Fitzsimons et al. 2010; JEJ, Michigan DNR, personal communication, 2012; Barbiero et al. 2011).

The Chinook salmon is the top predator on alewife in Lake Ontario (Stewart and Sprules 2011), but all trout and salmon feed on the alewife (Brandt 1986; Lantry 2001). Consumption of alewife by trout and salmon in combination with that by other fish-eating predators could cause a severe decline in alewife abundance (Jones et al. 1993). However, up to 2005, the production of alewife was in balance with the predatory demand by trout and salmon (Murry et al. 2010; Stewart and Sprules 2011). Murry et al. (2010) estimated that Chinook salmon consumed 7-29% of the total annual production of alewife in Lake Ontario with an average consumption of 14% during 1989-2005. In an independent study, Stewart and Sprules (2011) estimated that all salmon and trout combined consumed 19-23% of the total annual alewife production during 2001-2005. These estimates agree and are consistent with the high growth rates of trout and salmon in Lake Ontario (New York State DEC 2010). Although conservative levels of stocking have resulted in a predator-prey balance, other factors outside the control of fisheries managers could influence alewife abundance in future years and disrupt the Lake Ontario fish community.

In the eastern basin of Lake Ontario, analysis of data from bottom-trawl and gillnet assessments, combined with data on diets of double-crested cormorants, implicated cormorant predation as a cause of population declines of some nearshore fishes, particularly smallmouth bass and yellow perch (Johnson et al. 2000; O'Gorman and Burnett 2001; Lantry et al. 2002). Double-crested cormorants are managed by oiling eggs to prevent hatching, by nest removal, and by culling, but the intensity of management varies among lake regions. In Lake Ontario, double-crested cormorant numbers increased from two birds at one colony in 1970 to 28,166 nests at 23 colonies in 2002 (Fig. 27) (McCullough and Weseloh 2007). In central Lake Ontario during 2003-2007, there was an overall decline in numbers of double-crested cormorant nests reaching a low of about 3,900 in 2006 followed by an increase to 4,600 in 2007. In contrast, in western Lake

Ontario, double-crested cormorant nest numbers increased steadily during 2003-2007 and, by 2007, reached 10,650 nests (Fig. 27). In eastern Lake Ontario, the number of double-crested cormorant nests in 2006-2007 fell to 7,400, the lowest nest count since 1994. As recently as 2000, there were over 10,400 nesting pairs of double-crested cormorants in eastern Lake Ontario on five active Ontario sites in Ontario waters and one active site in New York waters (Weseloh et al. 2002).

Fig. 27. Number of double-crested cormorant nests in western, central, and eastern Lake Ontario, 1979-2007.



In 2002, diets of double-crested cormorants on Little Galloo Island, New York, located in the eastern basin, were dominated by alewife (40%) and yellow perch and other pan fish (39%). Game fish comprised 3% of the double-crested cormorant diet and most were smallmouth bass (Johnson et al. 2003). By 2007, however, double-crested cormorant diet was dominated by round goby (72%), and there was a sharp decline in the consumption of alewife (8%), yellow perch and other pan fish (17%), and game fish (1%) (Johnson and McCullough 2008). Recent increases in smallmouth bass and yellow perch abundance in the eastern basin are likely related to reduction in double-crested cormorant numbers and diet shifts.

Fish Diseases

Viral hemorrhagic septicemia virus (VHSv) was first documented in Lake Ontario in the Bay of Quinte in 2005 where it was linked to a large-scale die-off of freshwater drum (Lumsden et al. 2007). Vulnerability to VHSv appears to be highly variable among fish species with some unaffected but acting as carriers (Iowa State University 2007). Other noteworthy VHSv mortalities include those of muskellunge in the Thousand Island region of the St. Lawrence River. first documented in 2005 (OMNR 2006), and round goby in Lake Ontario in 2006 and 2007 (Groocock et al. 2007). Although large-scale die-offs of sport fish in Lake Ontario have not been documented, they may have gone undetected. In addition, VHSv-related mortality in a fish population could be triggered by physiological stressors (temperature, poor condition, spawning stress, and other pathogens).

The Type-E botulism toxin is produced by bacteria that occur naturally in sediments. The bacteria produce a toxin when oxygen concentrations are low, a protein source is available, and the temperature is appropriate (OMNR 2011). If fish or other animals eat foods that contain the botulism toxin, they may die. Small-scale die-offs of fish and birds associated with botulism occur regularly in the Great Lakes (Riley et al. 2008), and a large-scale die-off of waterfowl linked to botulism occurred in Lake Ontario in 2007 (OMNR 2011). Round goby and dreissenids may contribute to the increased occurrence of botulism mortalities by creating the right conditions for the bacteria to produce toxin, but this link is not firmly established. Widespread negative effects on fish abundance and distribution associated with botulism have not been documented in Lake Ontario.

ACKNOWLEDGEMENTS

We thank Colin Lake for drafting the frontispiece.

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