THE STATE OF LAKE ONTARIO IN 2014

Great Lakes Fishery Commission

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THE STATE OF LAKE ONTARIO IN 2014

Edited by

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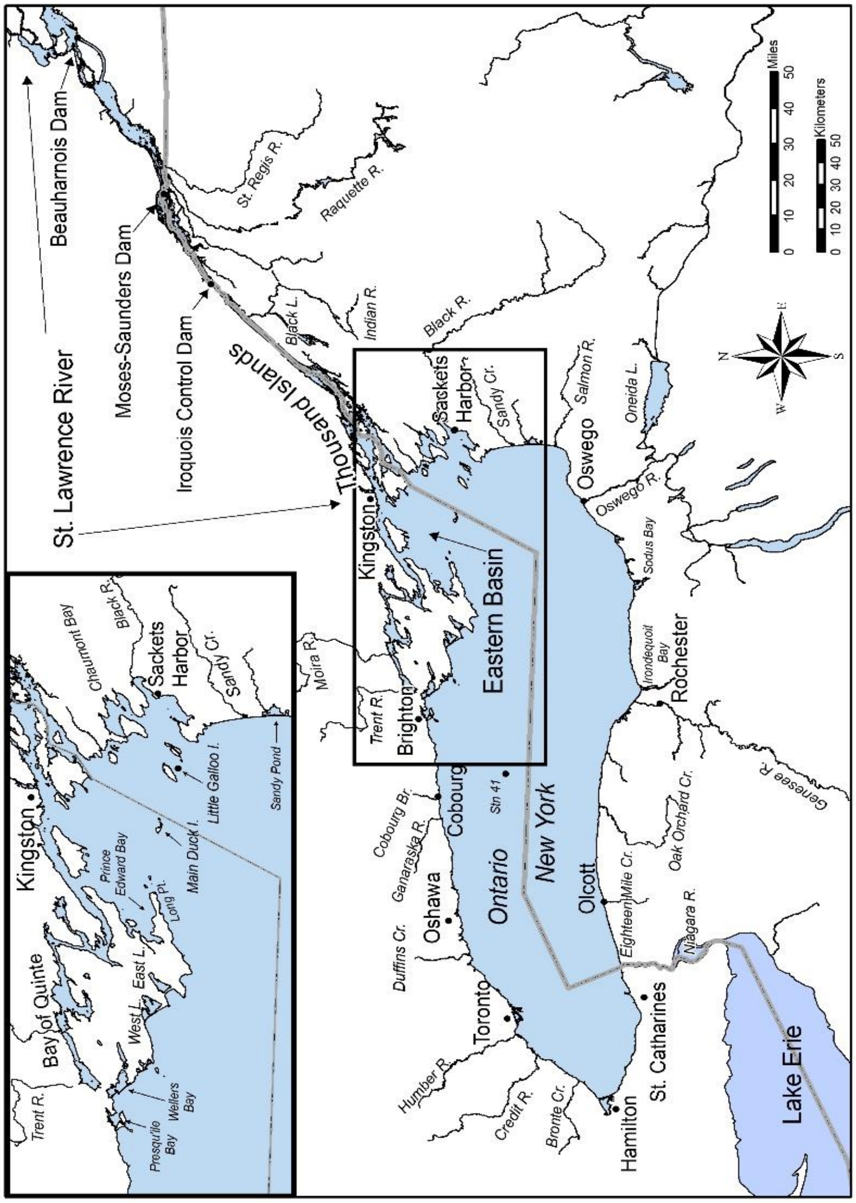
Frontispiece. Lake Ontario and the St. Lawrence River showing important geographic features.



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ABSTRACT[2]

This report is the third in a series that describes the status of the Lake Ontario ecosystem, typically for a five-year period and, in this case, from 2008 to 2013. Phosphorus concentrations (<10 $\mu g \cdot L^{-1}$) indicate that oligotrophic conditions have been maintained since 1995. Phytoplankton biomass and epilimnetic chlorophyll did not trend during the reporting period following steep declines in the mid-1990s. Water clarity increased as compared to the previous reporting period (2002-2007). Zooplankton biomass in the whole water column was no different than that in the previous reporting period owing to a community shift from bosminids and cyclopoid copepods to larger calanoid copepods associated with the deep chlorophyll layer. The density of quagga mussels (*Dreissena rostriformis bugensis*) appeared to be declining while *Diporeia* spp., previously abundant, are now almost absent from the lake. The abundance of *Mysis diluviana* has not changed during the two most-recent reporting periods. During this reporting period, Walleye (*Sander vitreus*) abundance increased in the Bay of Quinte and eastern Lake Ontario, Yellow Perch (*Perca flavescens*) and Smallmouth Bass (*Micropterus dolomieu*) population abundance varied depending on location, Northern Pike (*Esox lucius*) abundance remained low relative to historical levels, and abundance of the non-native Round Goby (*Neogobius melanostomus*) stabilized. Restoration efforts on Lake Sturgeon (*Acipenser fulvescens*) and American Eel (*Anguilla rostrata*) continued. In the offshore pelagic zone during 2008-2013, catch rates of salmon and trout were

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[2]Complete publication including map of place names, other chapters, scientific fish names, and references is available at http://www.glfc.org/pubs/SpecialPubs/Sp17_02.pdf.

maintained or increased as compared to the previous reporting period. In addition, the Alewife (*Alosa pseudoharengus*) population was maintained, abundance of Rainbow Smelt (*Osmerus mordax*) remained low and stable, and Cisco (*Coregonus artedi*) numbers increased. Restoration efforts on Atlantic Salmon (*Salmo salar*) resulted in good growth and survival of parr in tributaries, increased catch rates of adults in the open lake, and a sufficient number of adults returning to the Salmon River, New York, to support a small fishery. Reproduction in the Salmon River and in a second surveyed stream, the Credit River, Ontario, was likely not enough to maintain either population. In the offshore pelagic zone during 2008-2013, prey-fish diversity was stable; however, diversity has generally declined over the last thirty years due to the increasing dominance of Alewife and declining numbers of Rainbow Smelt, Emerald Shiner (*Notropis atherinoides*), Cisco, and Threespine Stickleback (*Gasterosteus aculeatus*). Progress indicators for stocked Lake Trout (*Salvelinus namaycush*) were met whereas those for in-lake production of wild young were not met. Collection of Bloater (*Coregonus hoyi*) eggs from Lake Michigan, rearing of young in hatcheries, and stocking of juveniles represented substantial progress towards restoration of the deepwater cisco (*Coregonus* spp.) community and, as well, towards improved prey-fish diversity. Lake Whitefish (*Coregonus clupeaformis*) and Slimy Sculpin (*Cottus cognatus*) persisted at below historical levels, Deepwater Sculpin (*Myoxocephalus thompsonii*) abundance trended higher, while Burbot (*Lota lota*) abundance was far below historical levels and lower than in the previous reporting period. Suppression of the Sea Lamprey (*Petromyzon marinus*) limited their numbers to target levels, suggesting that this non-native species did not impede native fish recovery or cause substantial losses to the salmonid sport fishery during the current reporting period.

INTRODUCTION TO THE STATE OF LAKE ONTARIO IN 2014[3]

Alastair Mathers[4] and Jana R. Lantry

Goals and Guiding Principles

A Joint Strategic Plan for Management of Great Lakes Fisheries (Joint Strategic Plan) (GLFC 2007) provides a common goal statement for all Great Lakes fishery-management agencies:

> *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*
> - *a healthy aquatic environment*

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[3]Complete publication including map of place names, other chapters, and references is available at http://www.glfc.org/pubs/SpecialPubs/Sp17_02.pdf.

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The responsibility for fisheries management in Lake Ontario is shared by the Ontario Ministry of Natural Resources and Forestry (OMNRF) and the New York State Department of Environmental Conservation (DEC). The two agencies cooperatively develop fish community objectives (FCOs) for Lake Ontario to guide management actions by the Lake Ontario Committee (LOC) of the Great Lakes Fishery Commission, which is composed of fishery managers from the DEC and OMNRF. The FCOs are developed and updated periodically in accordance with the Joint Strategic Plan. The most-recent FCOs for Lake Ontario are described by Stewart et al. (2013). The Joint Strategic Plan also charges the LOC to measure progress towards achievement of the FCOs—a charge that is met by producing a report on the state of the lake every five or six years. This state-of-the-lake report describes the status of the Lake Ontario fish community at the end of the 2013 field year, compares trends in the fish community during 2008-2013 (current reporting period) with those during 2003-2007 (previous reporting period; Adkinson and Morrison 2014), and uses the indicators specified in Stewart et al. (2013) to evaluate progress towards the FCOs made since the previous reporting period. This report also serves to focus attention on issues critical to Lake Ontario's fish community and to enhance communication and understanding among fishery agencies, environmental agencies, political bodies, and the public.

A special conference focusing on progress toward achieving the Lake Ontario FCOs was held at Windsor, Ontario, in March 2014. This five-chapter report is a compilation of some of the information presented at that conference. The first chapter relates trends in nutrients, phytoplankton, zooplankton, and macrobenthos; all four play a major role in defining the lake's productive capacity and can influence fish community composition. Subsequent chapters focus on the fish communities in the three lake zones—the nearshore, the offshore pelagic, and the deep pelagic and offshore benthic. A final chapter provides a management perspective.

The nearshore zone was defined by Stewart et al. (2013) as including the shallower (approximately <15-m water depth) exposed coastal areas and sheltered embayments. Nearly all fish species in the lake use this zone for spawning and to support their early life stages. Various prey fish, percids, centrarchids, and native fish species of concern are the key groups of fish discussed in the nearshore chapter. Two offshore zones are located in the main body of the lake, and they contain most of the water and living components of the Lake Ontario ecosystem. An important ecological feature of the offshore zone is its summertime organization into a warm upper layer (epilimnion) and a cool deeper layer (metalimnion); together they form the offshore pelagic zone. Prey fish, Cisco (see Table 1 for common and scientific names of fish), and salmonines are the key groups of fish that are discussed in the offshore pelagic chapter. The coldest, deepest layer of water, below the metalimnion, is called the hypolimnion, and this area, including the lake bottom, is the deep pelagic and offshore benthic zone. The chapter on this zone discusses the status of sculpins, deepwater ciscoes, Lake Whitefish, Sea Lamprey, Lake Trout, and Burbot.

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*
Bloater	*Coregonus hoyi*
Brook Trout	*Salvelinus fontinalis*
Brown Trout	*Salmo trutta*
Burbot	*Lota lota*
Chain Pickerel	*Esox niger*
Chinook Salmon	*Oncorhynchus tshawytscha*
Cisco (formerly Lake Herring)	*Coregonus artedi*
Coho Salmon	*Oncorhynchus kisutch*
deepwater ciscoes	*Coregonus* spp.
Deepwater Sculpin	*Myoxocephalus thompsonii*
Emerald Shiner	*Notropis atherinoides*
Johnny Darter	*Etheostoma nigrum*
Kiyi	*Coregonus kiyi*
Kokanee	*Oncorhynchus nerka*

Table 1, continued

Common Name	Scientific Name
Lake Sturgeon	*Acipenser fulvescens*
Lake Trout	*Salvelinus namaycush*
Lake Whitefish	*Coregonus clupeaformis*
Largemouth Bass	*Micropterus salmoides*
Muskellunge	*Esox masquinongy*
Northern Pike	*Esox lucius*
Rainbow Smelt	*Osmerus mordax*
Rainbow Trout (steelhead)	*Oncorhynchus mykiss*
Round Goby	*Neogobius melanostomus*
Round Whitefish	*Prosopium cylindraceum*
Sea Lamprey	*Petromyzon marinus*
Shortnose Cisco	*Coregonus reighardi*
Slimy Sculpin	*Cottus cognatus*
Smallmouth Bass	*Micropterus dolomieu*
Splake	*Salvelinus namaycush* x *Salvelinus fontinalis*
Spottail Shiner	*Notropis hudsonius*
Threespine Stickleback	*Gasterosteus aculeatus*
Trout-perch	*Percopsis omiscomaycus*
Walleye	*Sander vitreus*
White Perch	*Morone americana*
Yellow Perch	*Perca flavescens*

Description of Lake Ontario and Its Fish Communities

Lake Ontario's volume (1,640 cubic km or 393 cubic miles) is the twelfth largest of all freshwater lakes in the world, but it is the second smallest of the Laurentian Great Lakes. The lake has an average depth of 86 m (283 ft) and a maximum depth of 244 m (802 ft). It has a surface area of 18,960 square km (7,340 square mi) and a drainage area of 64,030 square km (24,720 square mi). Lake Ontario receives 86% of its water from the upper Great Lakes and Lake Erie via the Niagara River, drains to the St. Lawrence River, and has a water retention time of six years (www.epa.gov/glnpo/atlas).

Phosphorus, an important nutrient driving biological productivity in freshwater systems, peaked in Lake Ontario in the late 1960s at around 28 $\mu g \cdot L^{-1}$ and then decreased to a target level of 10 $\mu g \cdot L^{-1}$ in the offshore zone by the mid-1980s. This change was in response to phosphorus management mandated by the Great Lakes Water Quality Agreement of 1972 (Stevens and Neilson 1987; Millard et al. 2003), and the decline played an integral role in shaping Lake Ontario's fish communities. Phosphorus concentrations declined further and remained stable below the 10 $\mu g \cdot L^{-1}$ target from the late 1990s to the mid-2000s (Dove 2009).

In the early 1970s, the nearshore fish community was dominated by non-native species, and environmental conditions bordered on hyper-eutrophic (Christie 1973; O'Gorman et al. 1989). Following two consecutive severe winters during 1976-1978, non-native Alewife and White Perch declined (O'Gorman and Schneider 1986; Casselman and Scott 2003), and several native fish in the nearshore zone rebounded, particularly Walleye, resulting in a shift from non-native to native species (Mills et al. 2003). Through the 1980s, nearshore fish communities responded quite rapidly to improvements in water quality leading to periods of high abundance of some desirable species. The 1990s saw explosive growth of dreissenid populations (*Dreissena* spp.) and increases in water clarity due to the mussels' filtering activities; submerged macrophytes expanded in bays and other sheltered areas of the nearshore creating additional habitat for various centrarchids (Hoyle et al. 2007). Double-crested Cormorant (*Phalacrocorax auritus*) numbers increased rapidly, and cormorant predation was implicated in population declines of Yellow Perch and Smallmouth Bass in the eastern basin (O'Gorman and Burnett 2001; Lantry et al. 2002). Walleye and American Eel declined.

In the last reporting period, the nearshore fish community continued to change in response to numerous influential factors, some old (reduced lake productivity and Double-crested Cormorants) and some new (Round Goby, Viral Hemorrhagic Septicemia virus, and botulism) (Lantry et al. 2014b; Stewart et al. 2014b). Populations of Walleye and Smallmouth Bass were generally stable but at levels lower than during the 1980s and 1990s. American Eel migrating to Lake Ontario registered a modest increase as did the populations of Yellow Perch and Lake Sturgeon. Round Goby was becoming abundant throughout Lake Ontario as managers grappled with understanding its effect on fish communities as a predator and as a prey, not only in the nearshore but also in the offshore to where goby migrates in fall and remains until spring (Walsh et al. 2007, 2008a; Stewart et al. 2014b). Lake Ontario's offshore fish communities also changed markedly over the years not only in response to ecosystem changes but also in response to management actions. By the early 1970s, native fish populations in the two offshore zones were in a dismal state while the populations of non-native Alewife and Rainbow Smelt were left uncontrolled due to a lack of predators (Christie et al. 1989; O'Gorman et al. 1989). Initial efforts to reintroduce Lake Trout were unsuccessful, due in large part to excessive Sea Lamprey predation (Christie 1973, 1974; Owens et al. 2003). Sea Lamprey control began in 1971 and eventually resulted in enhanced survival of stocked salmon and trout (Pearce et al. 1980; Elrod et al. 1995). However, there was no measurable recovery of Burbot or Deepwater Sculpin (Owens et al. 2003; Mills et al. 2003). In the 1980s, large-scale stocking of salmon and trout restored the balance between the lake's predators and Alewife, the dominant prey fish in the offshore pelagic zone. During the 1990s, however, managers became concerned that the abundant hatchery-reared predators could collapse the Alewife population, and they responded by reducing the number of fish stocked (Jones et al. 1993; Rudstam 1996; O'Gorman and Stewart 1999). Burbot, Lake Whitefish, and Lake Trout populations expanded, and, although first-year survival of stocked Lake Trout declined precipitously, young, naturally produced Lake Trout were present in assessment catches for the first time, albeit in low numbers (Lantry et al. 2014a).

During the last reporting period, Burbot, Lake Whitefish, and Lake Trout declined to the lowest levels since the mid-1980s (Lantry et al. 2014a). Natural production of young Lake Trout continued at a low level. Deepwater Sculpin, once thought extirpated, was increasingly common, although the formerly abundant Slimy Sculpin was greatly reduced (Lantry et al. 2007; Walsh et al. 2008a). Lake Whitefish and Slimy Sculpin were heavily affected by the near disappearance of the mainstay of their diets, *Diporeia* spp., which coincided with the proliferation of dreissenids (Hoyle et al. 1999; Hoyle et al. 2003, 2008; O'Gorman and Owens 2003; Owens and Dittman 2003). Nevertheless, angler catch rates in the offshore waters were much improved for Chinook Salmon, Coho Salmon, Brown Trout, and Atlantic Salmon and remained stable for Rainbow Trout (Connerton et al. 2014b).

NUTRIENTS, PHYTOPLANKTON, ZOOPLANKTON, AND MACROBENTHOS[5]

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Lower trophic levels support the prey fish on which most sport fish depend. Therefore, understanding the production potential of lower trophic levels is integral to the management of Lake Ontario's fishery resources. Lower

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[5]Complete publication including map of place names, other chapters, scientific fish names, and references is available at http://www.glfc.org/pubs/SpecialPubs/Sp17_02.pdf.

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trophic-level productivity differs among offshore and nearshore waters. In the offshore, there is concern about the ability of the lake to support Alewife (Table 1) production due to a perceived decline in productivity of phytoplankton and zooplankton whereas, in the nearshore, there is a concern about excessive attached algal production (e.g., *Cladophora*) associated with higher nutrient concentrations—the oligotrophication of the offshore and the eutrophication of the nearshore (Mills et al. 2003; Holeck et al. 2008; Dove 2009; Koops et al. 2015; Stewart et al. 2016). Even though the collapse of the Alewife population in Lake Huron in 2003 (and the associated decline in the Chinook Salmon fishery) may have been precipitated by a cold winter (Dunlop and Riley 2013), Alewife had not returned to high abundances in Lake Huron as of 2014 (Roseman et al. 2015). Failure of the Alewife population to recover from collapse has been attributed to declines in lower trophic-level production (Barbiero et al. 2011; Bunnell et al. 2014; but see He et al. 2015). In Lake Michigan, concerns of a similar Alewife collapse led to a decrease in the number of Chinook Salmon stocked. If lower trophic-level production declines in Lake Ontario, a similar management action could be considered. On the other hand, in Lake Erie, which supplies most of the water in Lake Ontario, eutrophication is increasing and so are harmful algal blooms. Thus, there is also a concern that nutrient levels and algal blooms could increase in Lake Ontario, especially in the nearshore. Solutions to the two processes of concern—eutrophication in the nearshore and oligotrophication in the offshore—may be mutually exclusive. In either circumstance, fisheries management needs information on the productivity of lower trophic levels in Lake Ontario.

In this chapter, we review the status of lower trophic levels in Lake Ontario with special attention to the current (2008-2013) and previous (2003-2007) reporting periods. During the two reporting periods, three whole-lake surveys of lower trophic levels were conducted: the Lower Trophic Level Assessment (LOLA) in 2003 and 2008 (Makarewicz and Howell 2012; Munawar et al. 2015b) and the Cooperative Science and Management Initiative (CSMI) in 2013. Analyses of the CSMI data are ongoing. In addition to the three one-year sources of information on lower trophic levels, several multi-year sources of information are available, including data from the surveillance program conducted since 1965 by Environment Canada (EC) (Dove 2009), monitoring conducted since 1980 by the U.S.

Environmental Protection Agency's (EPA) Great Lakes National Program Office (GLNPO) (Barbiero et al. 2014; Reavie et al. 2014), sampling for a Bioindex Program at two stations, one offshore and one in the Eastern Basin, assessments of *Mysis diluviana* (formerly *Mysis relicta*) conducted since 1980 by Fisheries and Oceans Canada (Johannsson et al. 1998, 2011) and the Ontario Ministry of Natural Resources and Forestry (OMNRF), and monitoring conducted since 1995 by the Biomonitoring Program (BMP) on the New York side of the lake (Holeck et al. 2015b). The BMP is a collaboration of the New York State Department of Environmental Conservation (DEC), U.S. Fish and Wildlife Service, U.S. Geological Survey (USGS), and Cornell University.

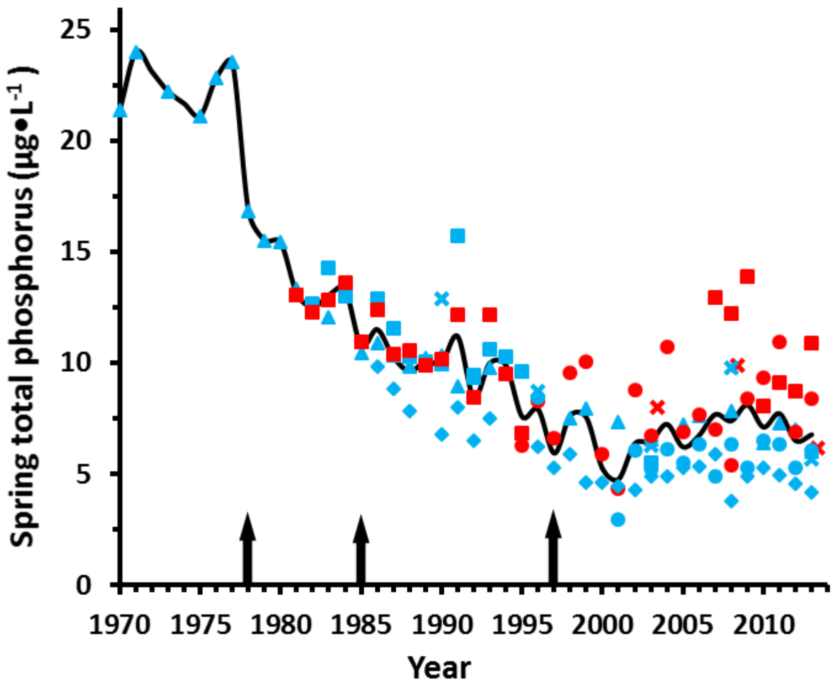
Nutrients, Phytoplankton, and Water Clarity

Primary production in lakes is limited by nutrients, such as phosphorus and nitrogen, and diatom production is limited by silica. In Lake Ontario, inorganic nitrogen (NO^2 and NO^3) concentrations have increased over time, which has resulted in an increase in the nitrogen-to-phosphorus ratios from values close to the Redfield ratio of 7.2 gN:gP in the 1970s to about 60.0 in the 2000s (surface values; Dove and Chapra 2015). Even higher ratios were present in the EPA's Great Lakes Environmental Database (GLENDA), which shows an average ratio of 83 gN:gP (range 73-101) for 2008-2011. The current high N:P ratio and the trend over time indicate that Lake Ontario's primary production is limited by phosphorus rather than nitrogen. Therefore, the current concentrations of phosphorus and the changes in phosphorus over time are of most interest.

In southern Lake Ontario, total phosphorus (TP) concentrations in April-May were relatively stable in the two most-recent reporting periods with offshore and nearshore average values during the 2008-2013 reporting period (offshore: 5.6 $\mu g \bullet L^{-1}$, range 3.8-7.3; nearshore: 8.2 $\mu g \bullet L^{-1}$, range 6.8-11.0; BMP data) similar to those in the 2003-2007 reporting period (offshore: 6.5 $\mu g \bullet L^{-1}$, range 6.3-7.3; nearshore: 8.7 $\mu g \bullet L^{-1}$, range 7.7-10.8) (Fig. 1; Holeck et al. 2015b). In both reporting periods, TP concentrations were mostly <10 $\mu g \bullet L^{-1}$, the concentration suggested by Thomas et al. (1980) as a goal for achieving the objectives of the Great Lakes Water Quality Agreement of 1972 and were considerably lower than the 20-25

$\mu g \bullet L^{-1}$ of TP recorded in the 1970s (Fig. 1). The long-term data averaged across the different programs show significant ($P < 0.001$) changes in concentrations in 1978, 1985, and 1995 (change points identified by change-point analysis; Taylor 2000). There has been no significant change in phosphorus levels in the lake since 1995 (lakewide: $r^2 = 0.04$, $P = 0.39$; offshore: $r^2 = 0.02$, $P = 0.57$; nearshore and eastern basin: $r^2 = 0.08$, $P = 0.27$), although the trend in the nearshore is towards an increase whereas the trend in EC's primarily offshore surveillance program is towards a decline ($r^2 = 0.30$, $P = 0.08$). The TP concentration in spring is a good indicator of summer phytoplankton production (Dillon and Rigler 1974), and, therefore, it is often used as an indicator of lake trophic state (Carlson 1977; Wetzel 2001). Average values for spring TP suggest similar levels of phytoplankton production since 1997. From 1997 to 2013, TP concentrations in offshore waters were within the 1-10 $\mu g \bullet L^{-1}$ range for oligotrophic systems (Wetzel 2001).

Fig. 1. Total phosphorus (TP) concentrations ($\mu g \bullet L^{-1}$) in the top 20 m of the water column in Lake Ontario during April-May, 1970-2013. Concentrations in the nearshore and eastern basin are shown in red, and concentrations in the offshore are shown in blue. Triangles are data from Environment Canada's Surveillance Program, squares are data from the Fisheries and Oceans Canada Bioindex Program in cooperation with the Ontario Ministry of Natural Resources and Forestry, circles are data from the Biomonitoring Program (New York waters only), diamonds are data from the EPA's Great Lakes National Program Office, and crosses are from the Lake Ontario Trophic Transfer Program (1991 and 1997), the Lake Ontario Lower Trophic Level Assessment (2003 and 2008), and the Cooperative Science and Management Initiative (2013). The line is the average of the TP concentrations measured by the different sampling programs. Arrows mark significant ($P < 0.001$) change points in the average concentration in 1978, 1985, and 1997. Modified from Holeck et al. (2015a, b).

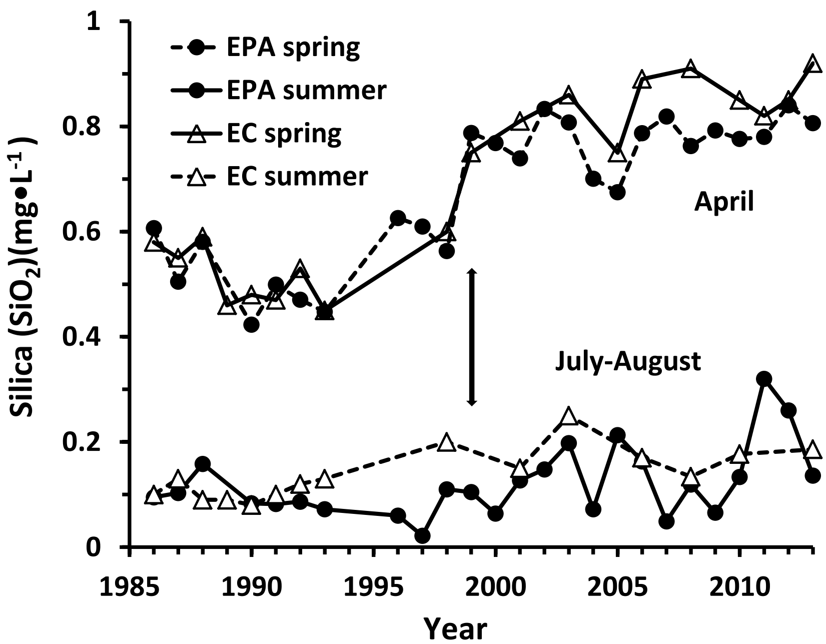


The TP levels in Lake Ontario have not declined in recent years even though TP in Lakes Michigan and Huron declined during the same time period (Dolan and Chapra 2012; Dove and Chapra 2015). Lake Ontario, however, is immediately downstream from Lake Erie where TP levels have either increased (Scavia et al. 2014) or remained stable (Dove and Chapra 2015) since the mid-1990s. Holeck et al. (2015b) reported that TP concentrations were elevated at stations around the mouth of the Niagara River and nearby Olcott compared to nearshore stations farther east, indicative of loading from the Niagara River. Dolan and Chapra (2012) estimated that around 30% of the TP loading into Lake Ontario was from Lake Erie during 1994-2008, and loading may have increased since 2008. In addition, the same processes leading to increased phosphorus loading to Lake Erie from its tributaries (e.g., changes in agricultural practices) likely also operate in the Lake Ontario watershed. Increased local phosphorus input is consistent with the increase in *Cladophora* in some nearshore areas (Makarewicz et al. 2012; Howell et al. 2012).

In shoreside areas (wadeable depths), TP concentrations can be substantially higher than in nearshore or offshore areas, and concentrations can reach eutrophic conditions (often over 50 $\mu g \bullet L^{-1}$) on both the south and north shores (Howell et al. 2012; Makarewicz et al. 2012). Makarewicz et al. (2012) showed that nutrient levels decreased with distance from shore and declined to <10 $\mu g \bullet L^{-1}$ at 1-4 km from shore (depending on season and location). There are no historical data to determine if shoreside phosphorus concentrations have increased—potentially due to zebra mussels (*Dreissena polymorpha*; Hecky et al. 2004) or changes in agricultural practices—or if shoreside concentrations have declined in proportion to the long-term decline in the offshore since the 1970s. Even so, high nutrient levels in the shoreside area coupled with increased light penetration due to grazing by dreissenid mussels are the likely causes of nuisance *Cladophora* growth and beach fouling (Auer et al. 2010; Higgins et al. 2012).

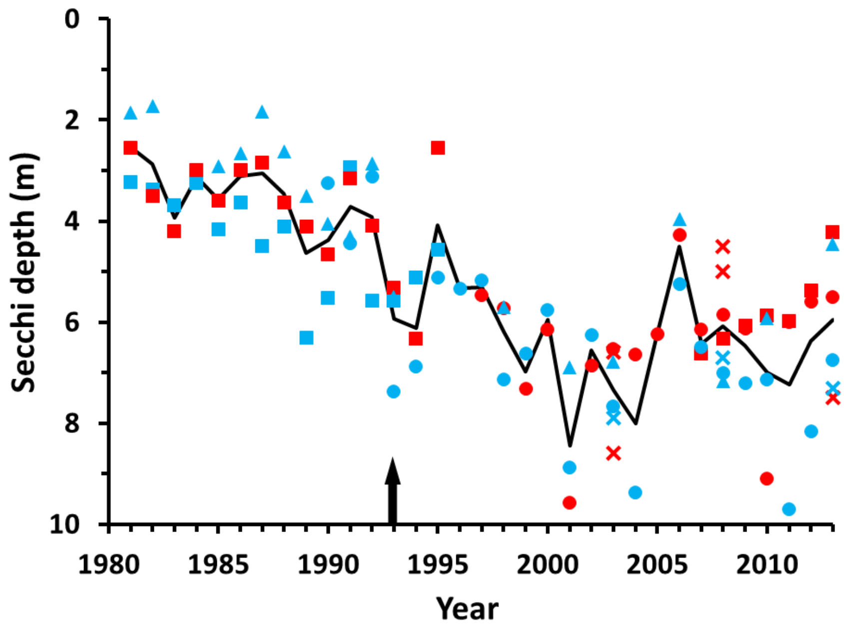
Offshore, spring silica concentrations increased significantly between 1986 and 2013 (r^2 = 0.69, P < 0.0001) (data from GLENDA and EC; see also Watkins et al. 2013; Holeck et al. 2015a); however, the average concentration during the current reporting period (0.80 mg $SiO^2 \bullet L^{-1}$) was similar to that in the previous reporting period (0.76 mg $SiO^2 \bullet L^{-1}$; GLENDA). Silica concentrations reported in GLENDA were similar to those reported in EC's surveillance data (Dove 2009). Dissolved silica concentrations typically decrease from spring through summer as silica is incorporated into diatom frustules that later sink to the lake bottom thereby transporting silica below the thermocline and out of the photic zone. The difference between spring and summer silica concentrations is a proxy for silica utilization by diatoms that has been used as an indicator of diatom production in the Great Lakes (Schelske et al. 1986; Mida et al. 2010; Watkins et al. 2013). In Lake Ontario, the average summer silica concentration during 2008-2013 (0.16 mg $SiO^2 \bullet L^{-1}$) was similar to the average concentration in 2003-2007 (0.14 mg $SiO^2 \bullet L^{-1}$). Silica utilization in the current reporting period was not much different from that in the previous reporting period, although it has increased significantly over the last 25 years ($r^2 = 0.45$, $P < 0.0002$; Fig. 2).

Fig. 2. Mean silica (SiO^2) concentrations ($mg{\bullet}L^{-1}$) in Lake Ontario during spring (April) and summer (July-August), 1986-2013. Data are from the Environmental Protection Agency's (EPA) Great Lakes National Program Office and Environment Canada's (EC) Surveillance Program. The arrows indicate a significant change point for silica utilization in 1999 ($P < 0.001$, 95% CL 1997-2001). Modified from Holeck et al. (2015a).



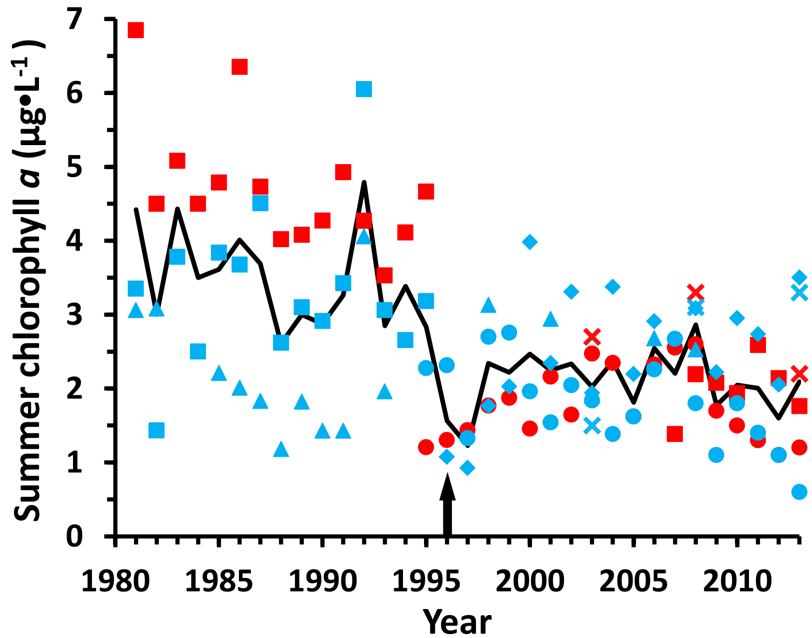
Water clarity in offshore waters during April-May, indexed as Secchi depth, averaged 11.7 m (range 8.9-15.0 m) in this reporting period compared to 11.2 m (range 10.0-13.5 m) in the previous reporting period (USGS, Lake Ontario Biological Station, unpublished data). Secchi depth was >13 m in 2006, 2011, and 2013. Spring water clarity in the offshore has increased greatly since the early 1990s but only marginally since 1994 (Holeck et al. 2015a). Summer Secchi depth in the offshore averaged 7.7 m during 2008-2013, similar to the 2003-2007 average of 7.2 m (USGS, Lake Ontario Biological Station, unpublished data). Summer Secchi depths have increased over time, from around 4 m in the 1980s to around 7 m in the 2010s (Fig. 3). Water clarity is affected by the amount of chlorophyll, inorganic and organic particles, and dissolved matter in the water. In Lake Ontario, late summer precipitation of calcium carbonate (whiting events) typically decrease water clarity. Water clarity affects primary production rates and predator-prey interactions in lakes (Kirk 1994; Boscarino et al. 2010) and is an indicator of trophic state (Carlson 1977; Wetzel 2001).

Fig. 3. Mean Secchi depth (m) in various areas of Lake Ontario during July-August, 1981-2013. Depths in the nearshore and eastern basin are shown in red and in the offshore in blue. Symbols identify the sampling program that collected the data and are defined in the caption of Fig. 1. The line shows the average of mean depths across programs, and the arrow marks a significant change point in 1993 ($P < 0.02$, 95% CL 1993-1995).



In Lake Ontario's offshore waters during July and August, the chlorophyll *a* concentration in the epilimnion during 2008-2013 (BMP data) averaged 1.3 $\mu g \cdot L^{-1}$ (range 0.6-1.8), which was lower (P = 0.053) than the average of 2.0 $\mu g \cdot L^{-1}$ (range 1.4-2.7) during 2003-2007 (Fig. 4). Nearshore, the BMP values for chlorophyll *a* concentration were significantly lower (P = 0.039) in 2008-2013 (1.6 $\mu g \cdot L^{-1}$, range 1.2-2.6) than in 2003-2007 (2.3 $\mu g \cdot L^{-1}$, range: 1.6-2.6). Chlorophyll *a* concentration is an index of phytoplankton biomass, and decreases in average values indicate lower productivity in recent years. However, whole-lake sampling (LOLA data) reported higher chlorophyll *a* concentrations and summer phytoplankton biomass in 2008 compared to 2003 (Holeck et al. 2015a; Munawar et al. 2015a). Methods of measuring chlorophyll *a* as well as the depth sampled vary among agencies, which contributes to high variability in these data. The general pattern over time is that chlorophyll *a* levels in Lake Ontario's epilimnion declined in the mid-1990s (significant change point in 1996, P < 0.001, 95% CL 1994-1997) and have remained at a lower level since then (Fig. 4). In both the nearshore and the offshore, chlorophyll *a* levels are now indicative of an oligotrophic system (0.3-3 μg•L^{-1}; Wetzel 2001).

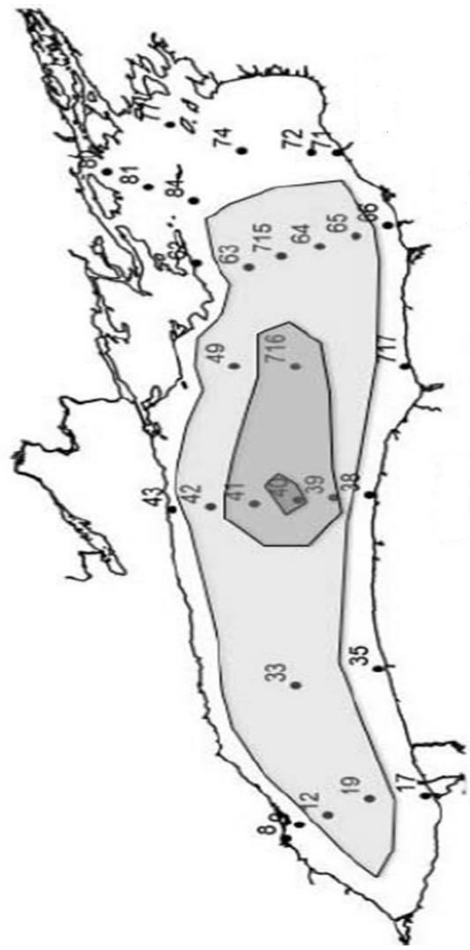
Fig. 4. Mean chlorophyll *a* concentrations (μg•L^{-1}) in the epilimnion in various areas of Lake Ontario during July-August, 1981-2013. Concentrations in the nearshore and eastern basin are shown in red; concentrations in the offshore are shown in blue. Symbols identify the sampling program that collected the data and are defined in the caption of Fig. 1. The line is the average of the mean concentrations measured by the different sampling programs, and the arrow marks a significant change point in the average in 1996 ($P < 0.001$, 95% CL 1994-1997). Modified from Holeck et al. (2015a, b).



In contrast to the lower chlorophyll *a* levels, the more-limited data for phytoplankton biomass (wet weight derived from measured biovolumes) do not show a decline. Munawar et al. (2015a) showed an increase in summer phytoplankton biomass from 2003 (0.2 g•m^{-3}) to 2008 (3.0 g•m^{-3}) and classified Lake Ontario as mesotrophic in 2008 based on biovolume and algal species composition. Reporting on the EPA GLNPO program, Reavie et al. (2014) showed that the biovolume of diatoms in the top 20 m of the water column in April was relatively stable from 2001 through 2011 whereas other important groups were more variable (dinoflagellates, chlorophytes, and cryptophytes). In August 2001-2011, phytoplankton biovolume in the epilimnion varied more than in April and mainly consisted of diatoms, dinoflagellates, chlorophytes, chrysophytes, cryptophytes, and small cyanobacteria. There was no indication of a change in phytoplankton biovolume from 2001 to 2011 in either April or August in Lake Ontario, which is in contrast to increases in phytoplankton biomass over this decade in Lake Erie and decreases in spring diatom biovolumes in Lakes Huron and Michigan (Reavie et al. 2014).

In summer 2008, there was a peak in chlorophyll below the thermocline (i.e., the deep chlorophyll layer, DCL) in a large portion of the lake (Fig. 5; Watkins et al. 2015b). However, the presence of a DCL may or may not equate to a biomass and productivity peak. At the dim light levels below the thermocline, algae will increase the amount of chlorophyll per unit biomass, and the dim light and cold temperature will limit productivity (Barbiero and Tuchman 2004). However, Twiss et al. (2012) and Watkins et al. (2015b) showed that algae in the DCL were productive. Large copepods and *M. diluviana* found in the DCL feed on these algae (Grossnickle 1982; Johannsson et al. 2003; O'Malley and Bunnell 2014). Thus, algae in the DCL likely contribute meaningfully to the primary and secondary production of the lake, and this production is in addition to the traditional measures of phytoplankton production in the epilimnion discussed above (Reavie et al. 2014; Munawar et al. 2015a). We are less confident, however, in assessing if there have been increases in the productivity, extent, and/or duration of the DCL over time. An increase in the biomass and production of algae in the DCL as well as an increase in the extent of the DCL in time and space are expected given the observed increase in water clarity (Fig. 3), which favors DCL formation (Watkins et al. 2015b). The contribution of the DCL to primary and secondary production in Lake Ontario is being investigated using CSMI samples from 2013.

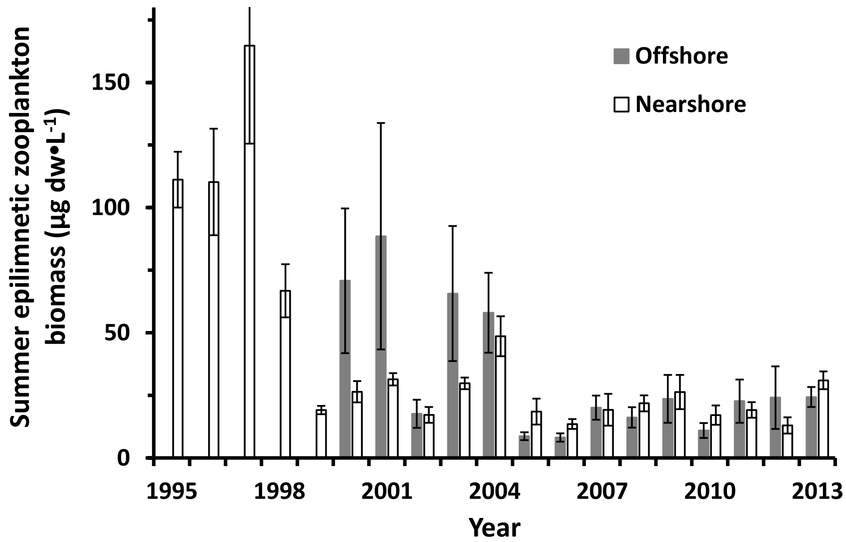
Fig. 5. Lake Ontario showing the extent and intensity of the deep chlorophyll layer (DCL) July 20-26, 2008. Darkest gray area (Station 40) had the strongest DCL with peak values at 13 μg•L^{-1} chlorophyll *a*. Intermediate shade of gray covers the area where chlorophyll *a* in the DCL was 8-10 μg•L^{-1}. Lightest shade of grey covers the area where chlorophyll *a* in the DCL was 3-8 μg•L^{-1}. In the unshaded areas of the lake, there was no DCL. Black dots show sampling locations. Detailed explanations are in Watkins et al. (2015b).



Zooplankton and Mysids

Although the average zooplankton biomass at nearshore sites (10-m bottom depth) in summer did not differ significantly (P = 0.49) between the 2008-2013 (21.4 µg dw•L^{-1}) and the 2003-2007 (26.0 µg dw•L^{-1}) reporting periods (Figs. 6, 7), comparing the averages masks a substantial decline that occurred in the previous reporting period. Change-point analysis of nearshore zooplankton abundance in 1995-2013 showed a significant downward break in total density in 2005 ($P < 0.01$, 95% CL 2000-2006) and in total density and biomass in 1998 (density: $P = 0.05$, 95% CL 1998-1998; biomass: $P < 0.001$, 95% CL 1998-1998). The 2005 break point was due to a decrease in cyclopoid copepods and coincided with an increase of the non-native predatory cladoceran *Bythotrephes longimanus*. The negative break point in 1998 was due to declines in bosminids and cyclopoids and coincided with an increase in the non-native predatory cladoceran *Cercopagis pengoi* (see also Makarewicz et al. 2001; Warner et al. 2006). In sum, total zooplankton density and biomass in summer declined markedly in Lake Ontario's nearshore waters during 1995-2013.

Fig. 6. Daytime crustacean zooplankton biomass (µg dw•L^{-1}) and density (number•L^{-1}) in the epilimnion of Lake Ontario's nearshore and offshore waters in July and August. Upper panel: average (±1 SE) biomass for 1995-2014 from the Biomonitoring Program (BMP) and Holeck et al. (2015b) with biomass calculated by use of the length-weight regressions in Watkins et al. (2011). Lower panel: average (±1 SE) density for 1981-1995 from the Fisheries and Oceans Canada Bioindex Program (Station 41) and for 1995-2014 from the BMP. The off-scale value for density in 1983 was 433. No offshore BMP data for 1995-1999 are available at this time.


Summer epilimnetic zooplankton biomass (µg dw•L-1)
0
50
100
150
Offshore
Nearshore
1995
1998
2001
2004
2007
2010
2013
Year

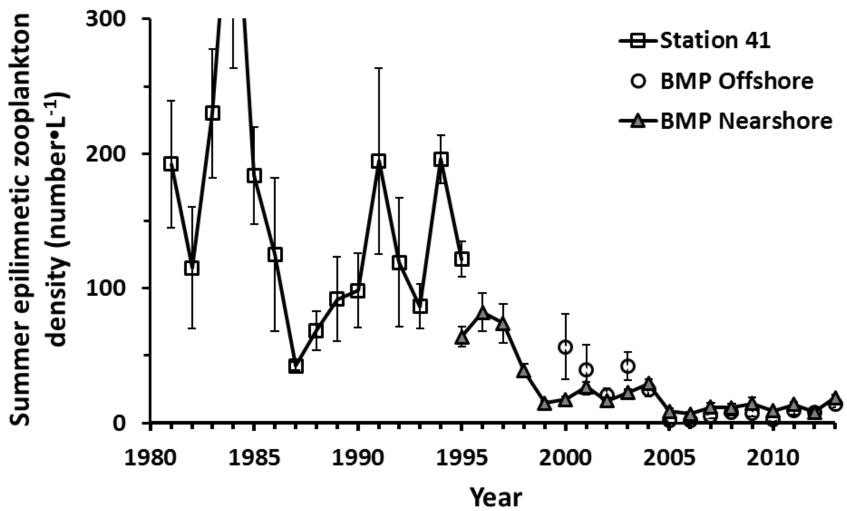
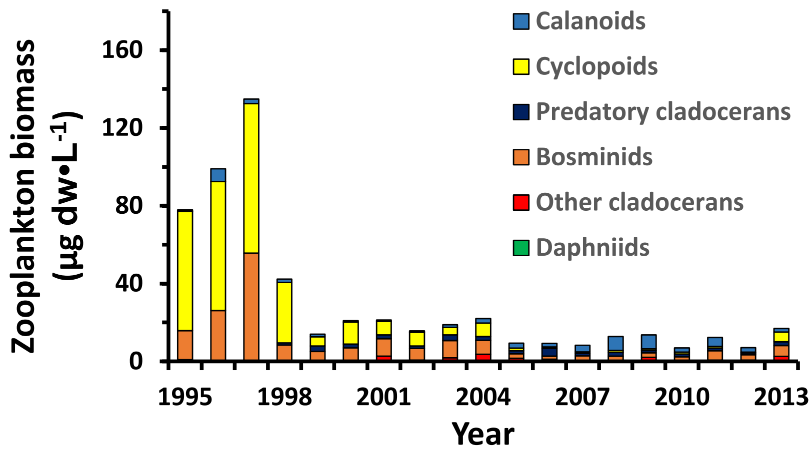
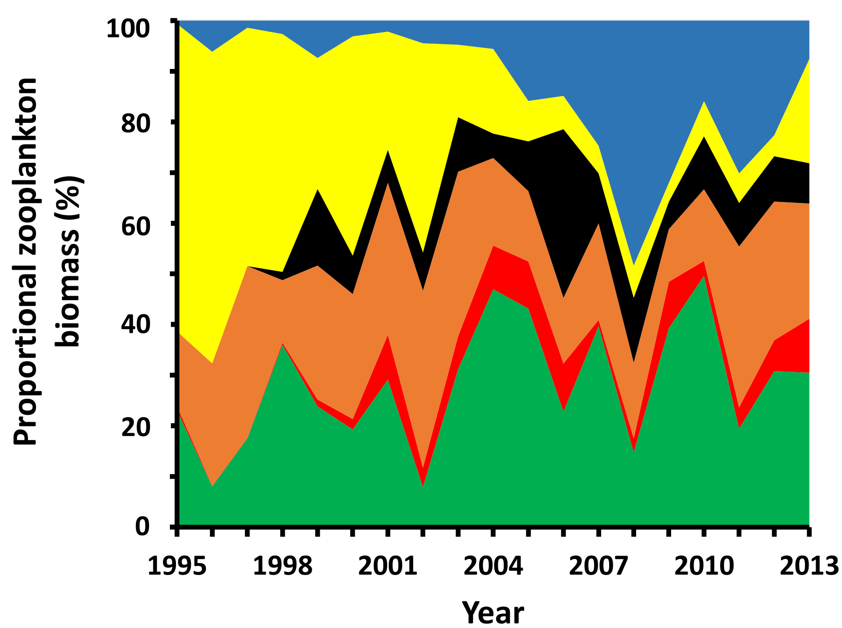


Fig. 7. Average composition of the crustacean zooplankton community during May-October, 1995-2013 at five nearshore stations in the open waters of Lake Ontario where the bottom depth is about 10 m. Stations are located in New York near the mouth of the Niagara River, Olcott, Sodus Bay, Sandy Pond, and Chaumont Bay (Biomonitoring Program; from Holeck et al. 2015b). Upper panel: average biomass (μg dw•L^{-1}) of various zooplankton groups. Lower panel: average biomass composition (%) of the zooplankton community.

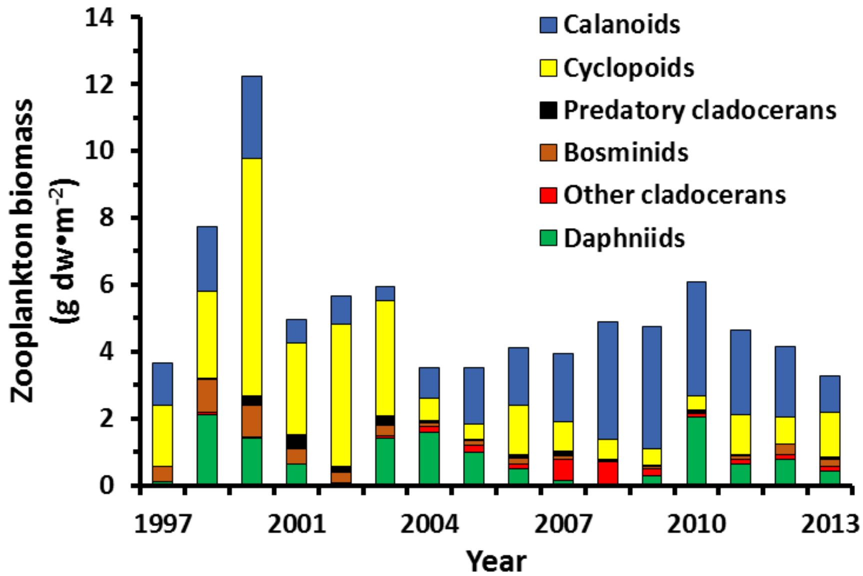

Zooplankton biomass
(µg dw•L^{-1})
160
120
80
40
0
1995
1998
2001
2004
2007
2010
2013
Year
Calanoids
Cyclopoids
Predatory cladocerans
Bosminids
Other cladocerans
Daphniids


Proportional zooplankton
biomass (%)
100
80
60
40
20
0
1995
1998
2001
2004
2007
2010
2013
Year

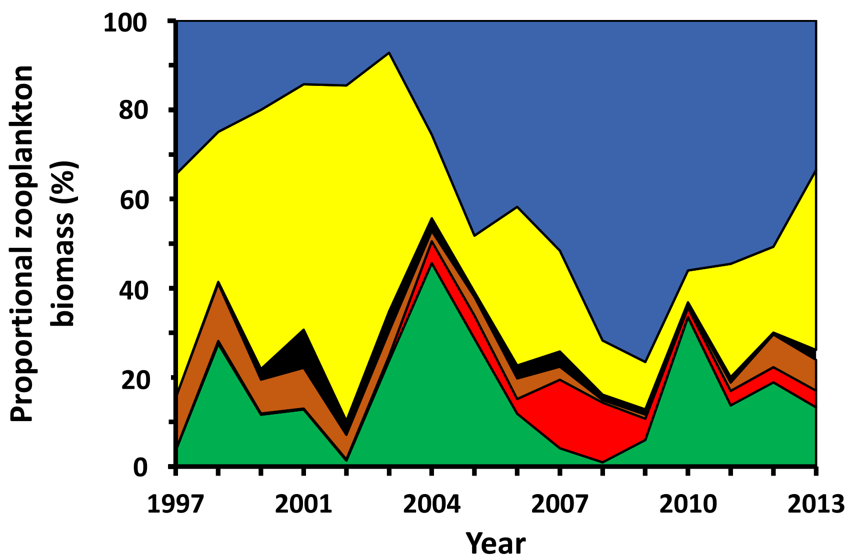
In the offshore, there was also no significant difference (*P* = 0.32) in epilimnetic zooplankton biomass between the two most-recent reporting periods (2008-2013 average: 20.3 μg dw•L^{-1}; 2003-2007 average: 32.1 μg dw•L^{-1}). However, change-point analysis showed a significant decline of zooplankton in 2005 not only in density, as in the nearshore, but also in biomass (density: $P < 0.01$, 95% CL 2003-2005; biomass: $P < 0.03$, 95% CL 2003-2005) (Fig. 6). The downturn in 2005 was due to decreases in both bosminids and cyclopoid copepods (Fig. 7). Barbiero et al. (2014) and Rudstam et al. (2015) proposed that *B. longimanus* increased due to a decline in Alewife abundance and that the predatory cladoceran caused the decline in bosminids and cyclopoid copepods in the epilimnion in 2005-2006. Documented effects of *B. longimanus* on the zooplankton community include direct predation and induction of vertical migration of herbivorous zooplankton to avoid this visual predator (Lehman and Cáceres 1993; Yan et al. 2001, 2011; Pangle et al. 2007). In Lake Ontario, *Daphnia mendotae* and cyclopoid copepods are more abundant in the metalimnion than in the epilimnion during the day, and both migrate towards the surface at night (Cornell University, unpublished data), a migration that results in avoidance of Alewife and *B. longimanus* predation during the day and *M. diluviana* predation during the night. Consistent with the hypothesized effect of predation by Alewife and *B. longimanus* on Lake Ontario's zooplankton community, when Alewife numbers rose in 2013, *B. longimanus* declined to the lowest levels since 2004, and bosminids and cyclopoid copepods increased (Holeck et al. 2015b).

During the current reporting period, in the offshore, the total biomass of crustacean zooplankton in 100-m vertical tows (excluding mysids) averaged 4.6 g dw•m^{-2} (range: 3.2-6.1), similar to the 4.2 g dw•m^{-2} (range: 3.5-6.0) average in the previous reporting period (Fig. 8; Barbiero et al. 2014). However, the average biomass of calanoid copepods in these 100-m tows during the current reporting period was 2.7 g dw•m^{-2} (range: 1.1-3.6), significantly ($P = 0.029$) more than the average of 1.4 g dw•m^{-2} (range: 0.4-2.0) in the previous reporting period (Fig. 8; Barbiero et al. 2014; Rudstam et al. 2015). This increase is attributed to two relatively large copepods, *Limnocalanus macrurus* and *Leptodiaptomus sicilis* that mainly reside below the thermocline and are, therefore, a small portion of the epilimnetic zooplankton biomass discussed above. Because of the increase in large deepwater calanoids, the total biomass of zooplankton in Lake Ontario's offshore waters did not decline during 2003-2013. Rudstam et al. (2015) suggested that the increase in the two large calanoids is due to an increase in the importance of the DCL to the overall productivity of Lake Ontario. Similar increases in large calanoids have occurred in Lakes Michigan and Huron. Because Lake Superior zooplankton are dominated by large calanoids, the compositions of zooplankton communities in Lakes Michigan, Huron and Ontario are approaching that of Lake Superior (Barbiero et al. 2012, 2014). The large calanoid copepods are rich in lipids making them a high-energy food resource for Alewife, Rainbow Smelt, and Cisco. The increase of deep-dwelling, lipid-rich zooplankton may be contributing to the improved condition (weight per unit length) of adult (≥age 2) Alewife in Lake Ontario, which began in 2003 and has persisted through 2013 (O'Gorman et al. 2008; Walsh et al. 2011; Walsh and Connerton 2014; see Offshore Pelagic Fish Community chapter in the full report).

Fig. 8. Average biomass (g dw•m^{-2}) of various zooplankton (crustacean) groups (upper panel) and the average biomass composition (%) of the zooplankton community (lower panel) during August, 1997-2013 in the water column (100 m to surface) of Lake Ontario (Environmental Protection Agency's Great Lakes National Program Office monitoring program; Barbiero et al. 2014; Cornell University, unpublished data). Biomass data were calculated using length-weight regressions in Watkins et al. (2011) and, therefore, differ from values presented in Barbiero et al. (2014).



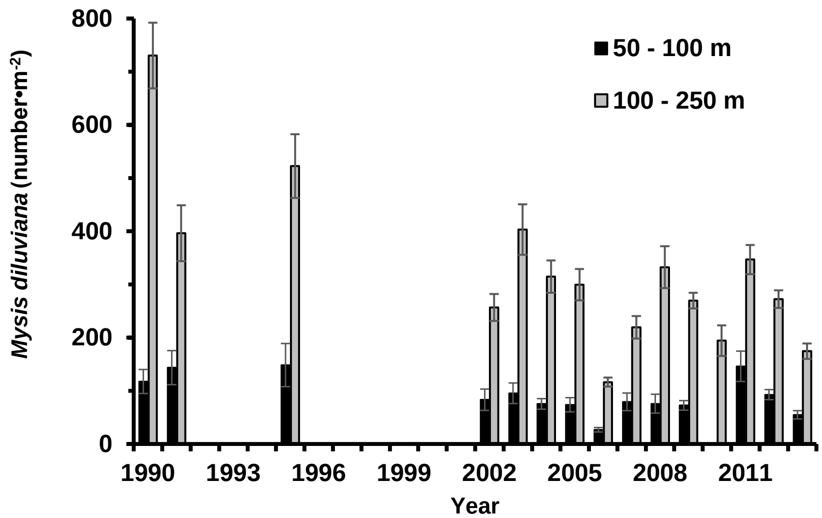
Calanoids
Cyclopoids
Predatory cladocerans
Bosminids
Other cladocerans
Daphniids
Zooplankton biomass
(g dw•m-2)
0
2
4
6
8
10
12
14
1997
2001
2004
2007
2010
2013
Year



Proportional zooplankton
biomass (%)
0
20
40
60
80
100
1997
2001
2004
2007
2010
2013
Year

The density of *M. diluviana* from 2008 to 2013, as measured offshore with vertical net tows in the fall, averaged 265•m^{-2} (range 174-347), which was similar to the average density of 271•m^{-2} (range 116-403) from 2003 to 2007 (Fisheries and Oceans Canada, unpublished data). Independent lakewide assessments of *M. diluviana* densities with acoustics and net tows in summer (July-September) averaged 118•m^{-2} in 2005, 228•m^{-2} in 2008, and 127•m^{-2} in 2013 (Rudstam et al. 2008; Watkins et al. 2015a; Cornell University, OMNRF, and DEC, unpublished data). *M. diluviana* was 33% of the total crustacean zooplankton biomass in 2008 (Watkins et al. 2015a). Although *M. diluviana* has declined 30% since the 1980s (Johannsson et al. 2011), there has been little change in its numbers over the last decade (Fig. 9). *M. diluviana* migrate from on and near bottom up to the lower metalimnion at night, and its nighttime distribution is largely predictable from its preference for low light and temperatures around 7^{o} C (Boscarino et al. 2009). *M. diluviana* is a major diet item of Rainbow Smelt (Lantry and Stewart 1993) and, in recent years, has become more important in the diet of Alewife in Lake Ontario (Stewart et al. 2009). Boscarino et al. (2010) suggested that the increased importance of *M. diluviana* to Alewife is due to higher water clarity, which made it more visible. *M. diluviana* is a major component of the food web in all of the Great Lakes except Lake Erie; aside from its importance as prey for benthic and pelagic fish, it is a major predator on zooplankton (Johannsson et al. 2003; Gal et al. 2006; Isaac et al. 2012).

Fig. 9. Average (±1 SE) density (number•m^{-2}) of *Mysis diluviana* in Lake Ontario over bottom depths of 50-100 m and 100-250 m during fall 1990-2013 as measured at night with vertical net tows. All data are from Fisheries and Oceans Canada (1990-2007 densities published in Johannsson et al. 2011). Data were not collected in 1992-1994, 1996-2001, or over 50-100 m in 2010.

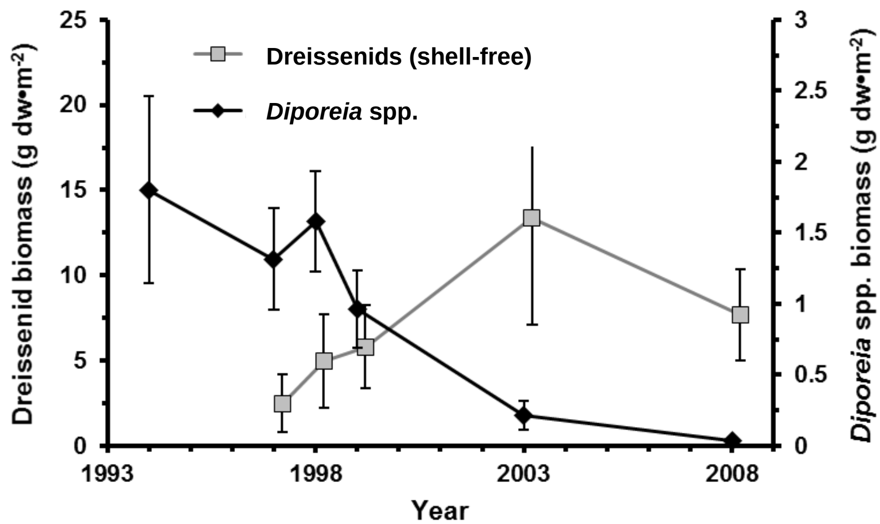


A non-native mysid, *Hemimysis anomala*, was first found in Lake Ontario in 2006 (Walsh et al. 2012). Like the native *M. diluviana*, the non-native mysid is a predator on zooplankton, a prey for a variety of fish, and lives on bottom during the day, migrating into the water column to feed at night (Lantry et al. 2012; Halpin et al. 2013). However, unlike the native mysid that lives offshore, *H. anomala* lives near shore, and its distribution rarely overlaps with that of *M. diluviana* (Walsh et al. 2012). Although *H. anomala* does affect zooplankton community composition when abundant (Ricciardi et al. 2012), it is not likely to be of major importance in Lake Ontario other than in rocky nearshore areas due to its preference for warmer temperatures (Sun et al. 2013) and need to find daytime hiding places from fish (Walsh et al. 2012).

Dreissenids and *Diporeia* spp.

Lake Ontario's benthic invertebrate community in the offshore has changed radically since the arrival of two dreissenids, zebra mussels in 1989 and quagga mussels (*D. rostriformis bugensis*) in 1991 (Mills et al. 1993, 2003). Dreissenid biomass that initially was dominated by zebra mussels is now wholly composed of quagga mussels; not a single zebra mussel was found in the lakewide benthic survey of 2008 (Birkett et al. 2015). Zebra mussels, however, do persist in shallow water and dominate on buoys and boats (Karatayev et al. 2013). Dreissenid biomass declined from 2003 to 2008 (Fig. 10). However, with an average density of 7.7 shell-free g dw•m^{-2} in 2008, quagga mussel biomass was 10-fold greater than that of any other benthic invertebrates in the lake (Birkett et al. 2015). Other benthos (oligochaetes, chironomids, and sphaeriids) were <0.3 g dw•m^{-2} in 2008.

Fig. 10. Average (±2 SE) lakewide biomass (g dw•m^{-2}) of dreissenids and *Diporeia* spp. in Lake Ontario, 1994-2008. Data for 1994-1999 from Lozano et al. (2001), data for 2003 from Watkins et al. (2007), and data for 2008 from Birkett et al. (2015).



The amphipod *Diporeia* spp., once the most-abundant benthic invertebrate in Lake Ontario, declined from 0.2 g dw•m^{-2} in 2003 to 0.03 g dw•m^{-2} in 2008 (Fig. 10; Birkett et al. 2015). Filter feeding by dreissenids is implicated in the decline of the spring diatom bloom in Lake Michigan, which, in turn, is considered a likely cause for the decline of *Diporeia* spp. in that lake (Vanderploeg et al. 2010). However, in Lake Ontario, *Diporeia* spp. declined without a concomitant decline in the spring diatom bloom raising some doubt about the hypothesis of diatom declines as a cause of *Diporeia* spp. declines across the Great Lakes (Watkins et al. 2013). A direct effect of dreissenids is also unlikely because *Diporeia* spp. declined prior to the arrival of dreissenids in many areas of Lake Ontario (Owens et al. 2003; Watkins et al. 2007, 2013) and Lake Michigan (Nalepa et al. 2009). Further, *Diporei*a spp. and quagga mussels co-exist in New York's Finger Lakes (Watkins et al. 2012). Alternative hypotheses for the decline of *Diporeia* spp. include various pathogens (Faisal and Winters 2011; Maity et al. 2012; Hewson et al. 2013). Whatever the cause of the original decline, it is now possible that quagga mussels physically exclude *Diporeia* spp. from some areas of the lake by completely covering the lake bed. Dreissenids have become better incorporated in the Lake Ontario food web as Round Goby, a specialist for feeding on mussels (Kornis et al. 2012; Naddafi and Rudstam 2014), spread throughout the lake and became important prey for a variety of fish (Johnson et al. 2005) and Double-crested Cormorants (*Phalacrocorax auritus*) (Johnson et al. 2010).

NEARSHORE FISH COMMUNITY[7]

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Lake Ontario's nearshore fish community consists of a diverse assemblage of warm- and cool-water species. The "nearshore zone," loosely separated from the "offshore zones" by the 15-m depth contour, consists of complex habitats spanning a gamut from vast open-coastal areas to sheltered embayments and wetlands. Lake Ontario's nearshore habitat has been affected to varying degrees by human activities. Although many areas are relatively unimpaired, some are severely degraded and have been designated as Areas of Concern (AOCs) (http://www.ec.gc.ca/raps-pas/; http://www2.epa.gov/great-lakes-aocs).

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[7]Complete publication including map of place names, other chapters, scientific fish names, and references is available at http://www.glfc.org/pubs/SpecialPubs/Sp17_02.pdf.

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Lake Ontario's nearshore fish community presents major challenges for fisheries management and biodiversity conservation due to ever-changing ecological drivers, such as nutrient input, invasive species, and climate. Management focuses on sustaining populations that support major fisheries—Walleye, Smallmouth Bass, and Yellow Perch—and rehabilitating two native species—Lake Sturgeon and American Eel (Table 1). Thus, the goal for the nearshore zone of Lake Ontario is (Stewart et al. 2013):

> *Protect, restore and sustain the diversity of the nearshore fish community, with an emphasis on self-sustaining native fishes such as Walleye, Yellow Perch, Lake Sturgeon, Smallmouth Bass, Largemouth Bass, Sunfish, Northern Pike, Muskellunge, and American Eel.*

We report herein on the status of major fish species and assemblages in the context of fish community objectives (FCOs) for the nearshore zone (Stewart et al. 2013) mainly by comparing status in the current reporting period (2008-2013) with that in the previous reporting period (2003-2007; Adkinson and Morrison 2014). Specific objectives are in italics at the start of each major section, and associated indicators of progress are given in Progress and Outlook subsections.

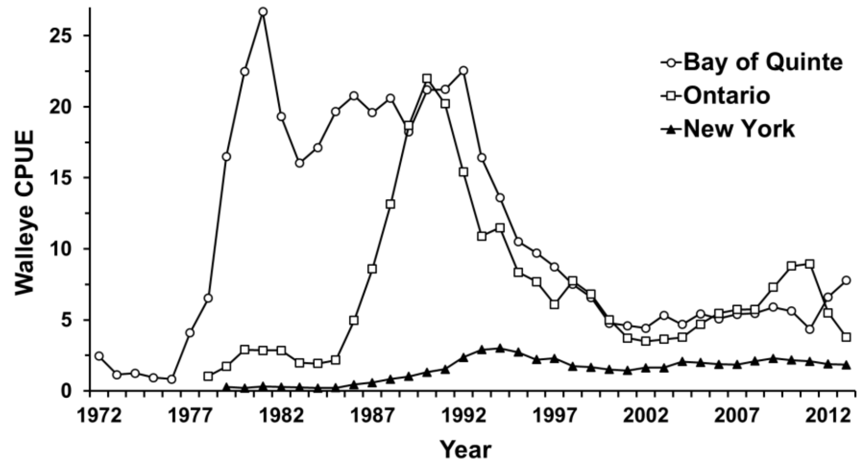
Percids, Centrarchids, and Esocids

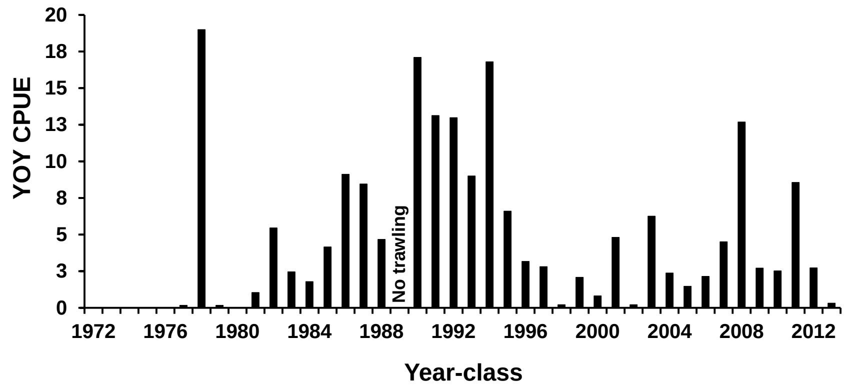
> *Maintain healthy, diverse fisheries—maintain, enhance and restore self-sustaining local populations of Walleye, Yellow Perch, Smallmouth Bass, Largemouth Bass, Sunfish, Muskellunge, and Northern Pike to provide high quality, diverse fisheries.*

Walleye

In this reporting period (2008-2013), adult Walleye abundance increased from the stable level achieved in the previous reporting period (2003-2007), which, in turn, followed a precipitous decline in the mid- to late 1990s (Lantry et al. 2014b). Relative to the last reporting period, the increase in catch-per-unit effort (CPUE, our proxy for abundance) in assessment gillnets was 25% in the Bay of Quinte, 33% in Ontario waters of the eastern basin, and 11% in New York waters of the eastern basin (Fig. 11). This increase was anticipated due to a higher occurrence of young Walleye in the 2003-2007 reporting period (Lantry et al. 2014b). Within the current reporting period, CPUE of young-of-the-year Walleye increased 47% in the Bay of Quinte largely due to strong year-classes in 2008 and 2011 (Fig. 11). A strong 2008 year-class was also evident in New York waters of the eastern basin (Lantry 2014). The Walleye angling fishery is not assessed every year, but, for the six years surveyed during the last two reporting periods (2003-2006, 2008, 2012), angling effort, harvest, and CPUE of Walleye in the Bay of Quinte has remained stable (OMNR 2013; OMNR 2014).

Fig. 11. Top panel: Moving averages of Walleye catch-per-unit effort (CPUE, fish•net^{-1}) in standard gillnets set overnight in Lake Ontario during summer in the Bay of Quinte (1972-2013), Ontario waters of the eastern basin (1978-2013), and New York waters of the eastern basin (1976-2013). Values for the first and last years of each time series are two-year averages whereas values for all other years are three-year averages plotted on the midpoint of each three-year period. Bottom panel: Young-of-the-year (YOY) Walleye CPUE (fish•trawl tow^{-1}) in bottom trawls towed for 6 min in the Bay of Quinte during August, 1972-2013 (excluding 1989). Methods described in Bowlby et al. (2010) and Lantry et al. (2014b).





In Ontario waters outside the Bay of Quinte and the eastern basin, trapnet surveys of the nearshore fish community conducted in and around embayments—East Lake (2013), West Lake (2013), and Weller's Bay (2007)—yielded catches of 1.3, 1.3, and 3.5 Walleye•24 hr^{-1}, respectively, compared to the upper Bay of Quinte mean catch of 3.0 for this (2008-2013) reporting period (OMNR 2009; OMNR 2014). In addition, and as part of ongoing Remedial Action Plans (RAPs), Walleye was stocked in Hamilton Harbour (110,000 summer fingerlings total for 2012 and 2013) and are scheduled to be stocked in the Toronto waterfront area to help diversify fish community trophic structure in these AOCs. In New York, Walleye was stocked into several embayments of Lake Ontario and the lower Niagara River (470,000 pond-reared fingerlings from 2008-2013) to enhance recreational fishing and to restore populations to waters they formerly occupied.

Progress and Outlook

The status/trend indicator for this FCO—maintaining or increasing Walleye fisheries, populations, and recruitment—was realized in the current reporting period. The major recreational fishery for Walleye in the Bay of Quinte remained stable. Abundance of Walleye increased in the Bay of Quinte and eastern basin, and, moreover, increased numbers of young suggest that Walleye abundance will remain stable or increase during the next reporting period. Outside the eastern basin, stocking young Walleye continued in New York and was initiated or planned in Ontario AOCs, which could lead to the establishment of additional populations. As Lantry et al. (2014b) highlighted in the previous State of Lake Ontario report (Adkinson and Morrison 2014), there is no expectation that the Walleye population will return to the high levels of the 1980s and early 1990s.

Yellow Perch

From the previous reporting period (2003-2007) to the current reporting period (2008-2013), Yellow Perch abundance in northeastern Lake Ontario decreased 41% in Ontario waters and increased 43% in New York waters (Fig. 12). In the Bay of Quinte, Yellow Perch abundance decreased by 35%. Lakewide, the commercial harvest of Yellow Perch during 2008-2013 was unchanged from that in 2003-2007 (Fig. 13).

Fig. 12. Moving averages of catch-per-unit effort (CPUE, fish•net^{-1}) of Yellow Perch in standard gillnets set overnight during summer in northeastern Lake Ontario (Ontario waters east of Brighton and New York's eastern basin waters) and the Bay of Quinte (1978-2013). Values for the first and last years of each time series are two-year averages whereas values for all other years are three-year averages plotted on the midpoint of each three-year period. Methods described in Bowlby et al. (2010) and Lantry (2014).

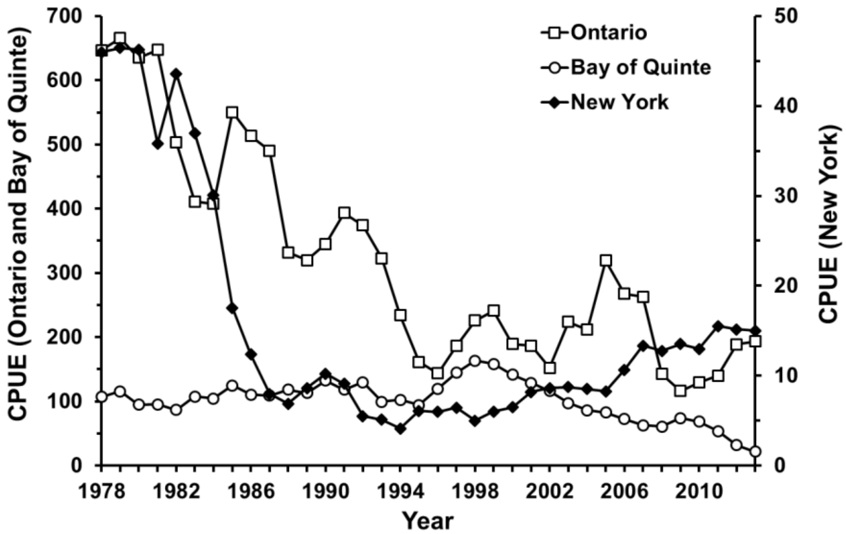
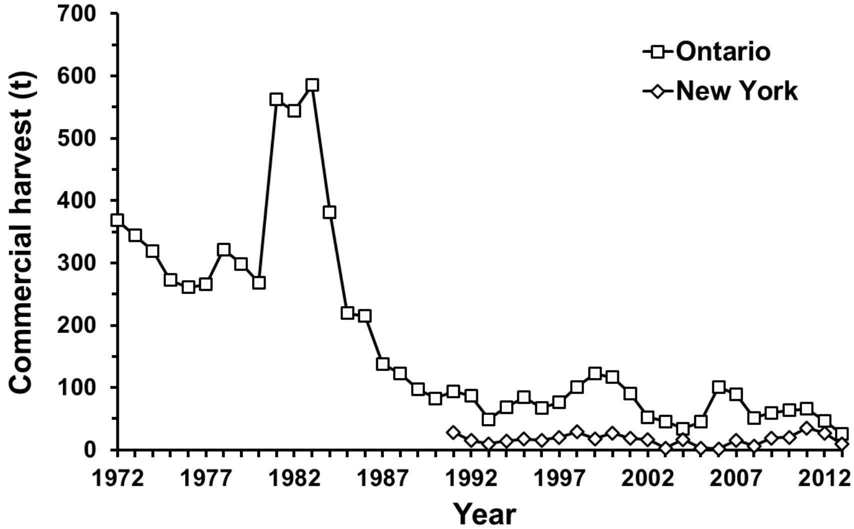


Fig. 13. Commercial harvest (t = metric tonnes) of Yellow Perch from Ontario and New York waters of Lake Ontario, 1972-2013 (OMNR 2014; LaPan 2014).



Yellow Perch abundance in Lake Ontario and the Bay of Quinte has been influenced by many factors over the last few decades, including lake productivity, Alewife abundance, and piscivore abundance, particularly that of the Double-crested Cormorant (*Phalacrocorax auritus*) (Hoyle et al. 2007; Lantry et al. 2014b). More recently, Round Goby has started to play an influential role in the Lake Ontario fish community in nearshore and offshore habitats (see update below). With its arrival, a new ecological pathway in the food web developed: dreissenids are eaten by Round Goby, which are, in turn, eaten by a host of top predators (Dietrich et al. 2006; Taraborelli et al. 2010; Hoyle et al. 2012; Lantry 2012; Rush et al. 2012). Resulting effects on Yellow Perch populations are complex. On the positive side, Round Goby buffer Yellow Perch from predation by Double-crested Cormorant (McCullough and Mazzocchi 2014; Johnson et al. 2014), and consumption of Round Goby by Yellow Perch contributed to increased Yellow Perch condition (Crane et al. 2015). On the negative side, changes in energy pathways wrought by dreissenids and Round Goby (citations above), may limit overall Yellow Perch carrying capacity.

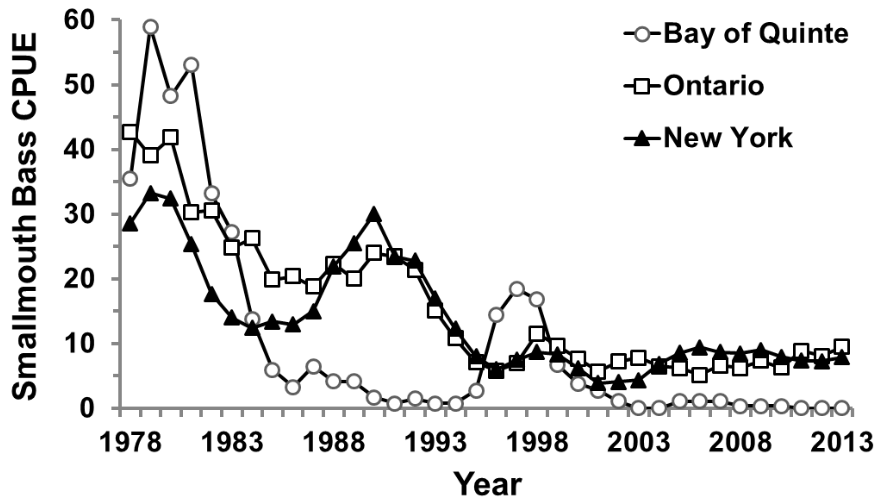
Progress and Outlook

The indicator of progress for Yellow Perch, maintaining or increasing fisheries, populations, and recruitment, showed mixed results for this reporting period. In New York waters of eastern Lake Ontario, Yellow Perch abundance increased and anglers were satisfied with the Yellow Perch fishery. In contrast, in Ontario waters of eastern Lake Ontario, Yellow Perch abundance decreased and Yellow Perch numbers were not sufficient to sustain the local commercial fishery. Disparate trends in the two jurisdictions suggest that stock dynamics are independent, exploitation rates are different, or both. Alternatively, stock dynamics may not be independent, but the timing of the expression of influential factors differs in the two jurisdictions, resulting in lags and leads in population trends. Although the Yellow Perch population in the Bay of Quinte is currently relatively low in abundance, the recreational fishery is focused on Walleye, and the commercial fishery, although negatively affected by low Yellow Perch abundance, harvests a variety of other fish. Looking ahead, over the short term, Yellow Perch abundance will likely not change markedly from current levels in the eastern basin of Lake Ontario. In the highly productive Bay of Quinte, however, it is reasonable to anticipate an increase in Yellow Perch abundance from the current low level.

Smallmouth Bass

During 2008-2013, Smallmouth Bass CPUEs in Ontario and New York waters of the eastern basin proper remained stable and were similar to those during the 2003-2007 reporting period (Fig. 14; Lantry 2014; Lantry et al. 2014b; OMNR 2014). In the Bay of Quinte, Smallmouth Bass numbers during 2008-2013, although stable, were 72% lower than in 2003-2007 (Fig. 14; Lantry et al. 2014b; OMNR 2014). Angler surveys were not conducted in the eastern basin during 2008-2013; however, anecdotal reports indicate that anglers were satisfied with catch rates and size of Smallmouth Bass.

Fig. 14. Moving averages of catch-per-unit effort (CPUE, fish•net^{-1}) of Smallmouth Bass in standard gillnets set overnight during summer in the Bay of Quinte and the eastern basin of Lake Ontario (Ontario and New York waters), 1978-2013. Values for the first and last years of each time series are two-year averages whereas values for all other years are three-year averages plotted on the midpoint of each three-year period. Methods described in Bowlby et al. (2010) and Lantry (2014).



For areas outside of Lake Ontario's eastern basin, stock-assessment data are lacking, but angler catch rates suggested that there were fewer Smallmouth Bass along the south shore of the main basin during 2008-2013 relative to the previous reporting period (Sanderson 2012; Lantry et al. 2014b). In southern Lake Ontario, each year during 2008-2013, angler catch rates were the lowest recorded in the 29 years surveyed and were about 50% lower than in the previous reporting period (Lantry and Eckert 2014; Lantry et al. 2014b; Sanderson and Lantry 2014).

Progress and Outlook

During this reporting period, 2008-2013, the indicator of progress towards the Smallmouth Bass FCO——maintaining or increasing fisheries, populations, and recruitment—was mixed. The indicator was met in the eastern basin where Smallmouth Bass numbers were relatively unchanged from the previous reporting period. As noted by Lantry et al. (2014b), Smallmouth Bass abundance will likely not return to the elevated levels that were present prior to the ecosystem changes of the 1990s, however, eastern basin anglers during this reporting period remained satisfied with catch rates and sizes of bass. The indicator was not met in the Bay of Quinte, where Smallmouth Bass numbers declined, or along the south shore of the main lake where angler catch rates remained mired at record lows.

Several factors may affect Smallmouth Bass abundance in the future. During this reporting period, growth and condition of Smallmouth Bass were at record highs, indicating that bass were not prey-limited. Faster growth and improved condition, due in part to feeding on abundant Round Goby (Crane et al. 2015; Lantry 2014), likely made Smallmouth Bass available for harvest by anglers at a younger age and lowered bass age at maturity, which, in turn, could reduce bass longevity. Additionally, Double-crested Cormorant predation on Smallmouth Bass was reduced substantially as a result of a cormorant dietary shift to Round Goby and, in the eastern basin, of effective management that reduced cormorant numbers (McCullough and Mazzocchi 2014; Johnson et al. 2014). Future changes to Round Goby abundance will affect food availability for bass and thus growth, condition, and maturity schedules, as well as affecting predation pressure on bass from Double-crested Cormorants. Lastly, summer water temperatures were relatively warm during 2010-2012, which may have contributed to production of strong year-classes of Smallmouth Bass (*cf*. Casselman 2002; Hoyle et al. 2007). Future plans are to evaluate how Round Goby, Double-crested Cormorant, and weather influence Smallmouth Bass population dynamics in the eastern basin.

Northern Pike and Other Esocids

Stock-assessment data are inadequate to say with confidence that the Northern Pike population during this reporting period, 2008-2013, is improved over the previous reporting period of 2003-2007. Northern Pike is an important component of the recreational fishery in some areas of Lake Ontario's nearshore zone, mostly in embayments and the eastern basin. Northern Pike recruitment is certainly lower than in the first half of the last century because water-level regulation has reduced the amount and availability of wetland and spawning habitats (Hoyle et al. 2007; Smith et al. 2007). What data are available on Northern Pike indicate that overall abundance in the lake is low relative to historical levels with most embayments maintaining moderate populations and small recreational fisheries (Lantry 2014; OMNR 2014).

As for other esocids, Muskellunge was present but rare (Hoyle et al. 2007), and Chain Pickerel was not present before the current reporting period. Chain Pickerel was first reported in Lake Ontario in 2008 with confirmed sightings in Ontario waters (Hoyle and Lake 2011) and reports by anglers fishing in New York waters (Lantry and Eckert 2014). The recent occurrence of Chain Pickerel in Lake Ontario is most likely due to range expansion as a result of a warmer climate in recent years (Hoyle and Lake 2011).

Progress and Outlook

Although Stewart et al. (2013) did not provide an indicator of progress for esocids, the objective for the nearshore fish community implies "maintaining or increasing fisheries, populations, and recruitment," but, regardless, population assessment was not thorough enough to say with confidence that esocids were maintained or improved during this reporting period (2008-2013). Northern Pike persisted in embayments and several nearshore areas, likely at or near levels that occurred during the previous reporting period indicating that abundance and the recreational fishery were likely maintained. Muskellunge remained rare during the current reporting period. Improved Northern Pike and Muskellunge abundance is dependent on a water-level regulation regime that would diversify wetland vegetation and improve spawning and nursery habitat for these species. The occurrence of

Chain Pickerel during the current reporting period indicated that the population expanded.

Lake Sturgeon

> *Restore Lake Sturgeon populations—increase abundance of naturally produced Lake Sturgeon to levels that would support sustainable fisheries.*

During the 2008-2013 reporting period, small numbers of Lake Sturgeon were caught in the eastern basin during fish community surveys (Fig. 15). The number caught was similar to that in the 2003-2007 reporting period. Before 1995, Lake Sturgeon was rarely caught in the eastern basin. In the lower Niagara River, the catch rate of Lake Sturgeon during 2010-2013 was higher than in 1998-2003 (Fig. 16).

Fig. 15. Lake Sturgeon catch-per-unit effort (CPUE, fish•net^{-1}) in standard gillnets set overnight in Ontario (ON) and New York (NY) waters of eastern Lake Ontario. New York CPUEs are from the warm-water fisheries assessment conducted in the eastern basin each August during 1976-2013 (Lantry 2014). Ontario CPUEs are from gillnets set in Ontario waters of the eastern basin at Flatt Point, Grape Island, and Melville Shoal during 1992-2013 (OMNR 2014). Moving averages are plotted on the midpoint of each three-year period, and values for the first and last years of each moving-average time series are two-year averages.

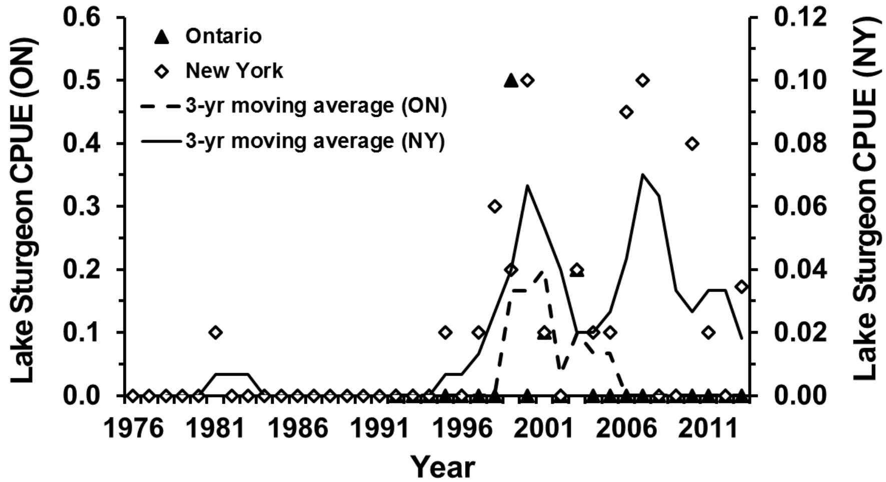
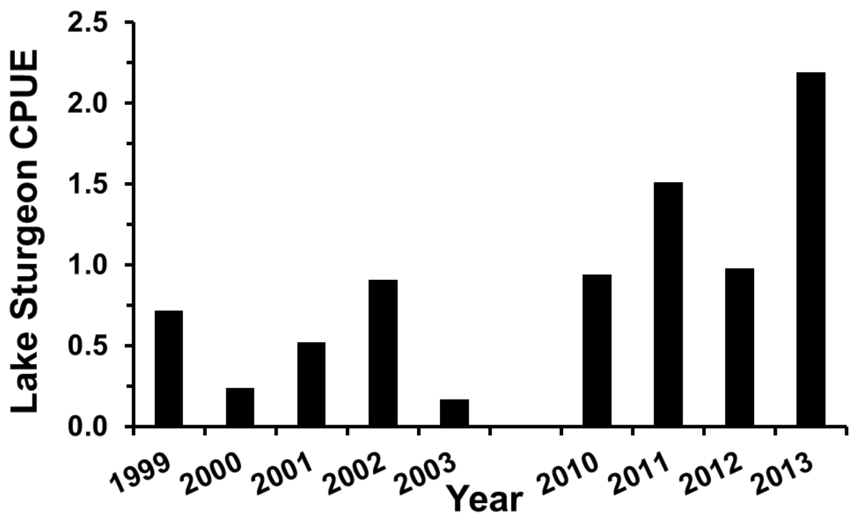


Fig. 16. Lake Sturgeon catch-per-unit effort (CPUE; fish•hour^{-1}•1,000 hooks^{-1}) with setlines in the lower Niagara River, 1999-2003 and 2010-2013 (Biesinger et al. 2014).



The numbers of mature Lake Sturgeon are not well quantified for most of the spawning areas surrounding Lake Ontario. However, some data are available to address the long-term progress indicator. In the lower Niagara River, Biesinger et al. (2014) reported a mark-recapture population estimate of 2,856 (95% CI, 1,637 to 5,093) mature and immature fish. In the St. Lawrence River, numbers of Lake Sturgeon counted at or near two artificial spawning beds constructed in the vicinity of the Iroquois Dam ranged between 122 and 395 at the peak of spawning activity in 2008-2013 (New York State DEC 2013). Evidence of egg deposition and emergence of larvae at the two spawning beds was also reported. Spawning populations of Lake Sturgeon are present in the Black River, New York (Klindt and Gordon 2014), and in the Trent River, Ontario (AM, personal observation), however, both populations are small, likely numbering <100 fish.

During the 2008-2013 reporting period, the New York State Department of Environmental Conservation in collaboration with the U.S. Fish and Wildlife Service stocked a total of 8,047 young Lake Sturgeon into New York tributaries of Lake Ontario and the St. Lawrence River, about 1,500 more than were stocked in the previous reporting period. The stocked fish were cultured from gametes collected in the St. Lawrence River below the Moses-Saunders Dam. Stocking locations extended from the Genesee River, New York, eastward to tributaries of the St. Lawrence River above Moses-Saunders Dam. Lake Sturgeon stocked in the lower Genesee River survived well and grew fast, demonstrating that stocking can increase sturgeon abundance in the lower river and that the lower river has highly suitable habitat for juvenile Lake Sturgeon (Dittman and Zollweg 2006). Lake Sturgeon stocked in the Genesee River and Oswego River, New York, is expected to spawn during the next reporting period (Chalupnicki et al. 2011).

Progress and Outlook

Whether advances were made during this reporting period towards meeting the intermediate-term progress indicator of increasing the abundance of Lake Sturgeon is conjectural. In the eastern basin, abundance was unchanged and stocking a greater number of juveniles in tributaries may have boosted abundance, but the increase in numbers stocked was small. In the lower Niagara River, however, Lake Sturgeon numbers have clearly increased in the past 14 years.

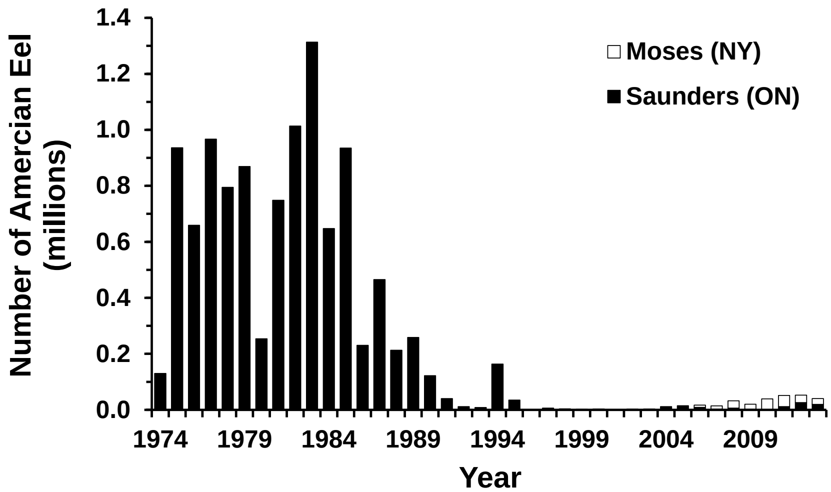
Meeting the long-term progress indicator of establishing four spawning populations with at least 750 mature fish seems achievable. Indeed, such a population may already exist in the lower Niagara River, and the survival of stocked fish in the lower Genesee River suggests that a spawning population could re-establish there. Moreover, there are already small spawning populations in other Lake Ontario tributaries and clear evidence of small numbers of fish successfully spawning in the upper St. Lawrence River (USLR).

American Eel

> *Restore American Eel abundance—increase abundance (recruitment and escapement) of naturally produced American Eel to levels that support sustainable fisheries.*

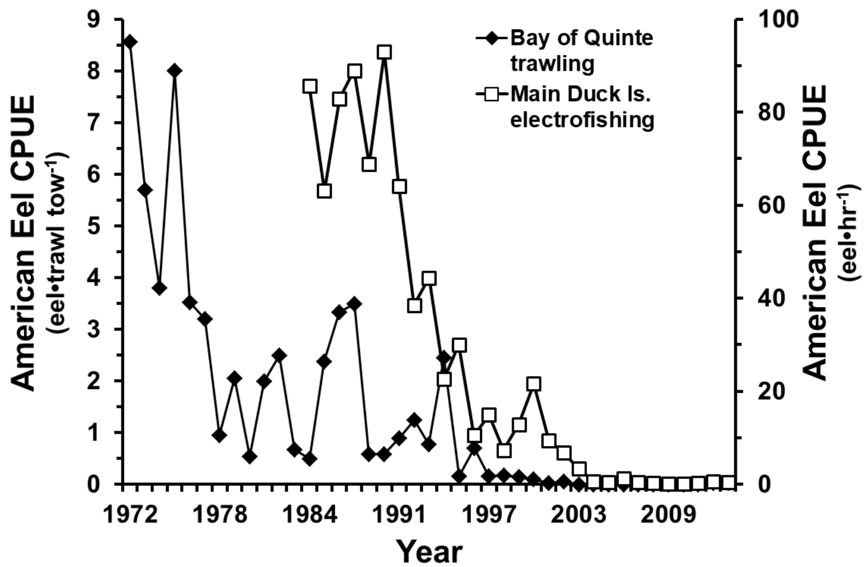
During the 2008-2013 reporting period, the number of yellow (life stage) American Eel migrating upstream each year via the eel ladders at the Moses-Saunders Dam averaged 39,300 (Fig. 17). This number was more than a 3-fold increase over the average in the 2003-2007 reporting period (12,000), suggesting that recruitment to Lake Ontario is increasing. However, despite the substantial increase in young American Eel ascending the ladders, recruitment during the current reporting period was less than 4% of the long-term target.

Fig. 17. Number of American Eel migrating up the eel ladder(s) at the Moses-Saunders Dam in the upper St. Lawrence River, 1974-2013. American Eel was not counted in 1996. Counting methods at the Saunders ladder in Ontario (ON) are described in Riveredge Associates and Kleinschmidt Associates (2014), and counting methods at the Moses ladder in New York (NY), opened in 2006, are described in Riveredge Associates (2014).



During the current reporting period, the bottom-trawl CPUE of yellow American Eel in the Bay of Quinte, one of two indices of eel abundance in eastern Lake Ontario, was 0.01 (Fig. 18)—two eels in 240 trawl tows, and both eels (one in 2012 and one in 2013) had been stocked (see below). No American Eel was captured in 200 bottom-trawl tows during 2003-2007. In contrast, in the 1970s and 1980s, American Eel CPUE was 3.05 in 239 trawl tows.

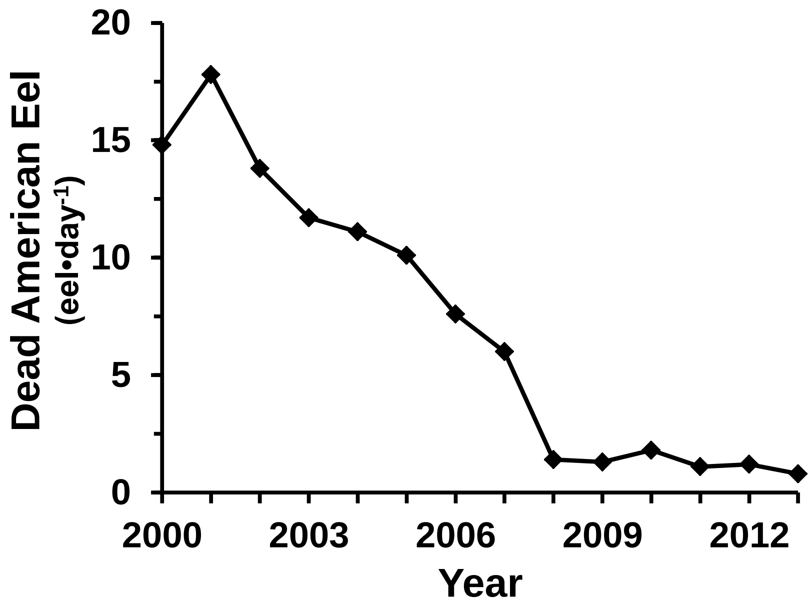
Fig. 18. Catch-per-unit effort (CPUE) of yellow (life stage) American Eel with bottom trawls (eel•trawl tow^{-1}) towed for six min at five locations in the Bay of Quinte during June-September, 1972-2013 (OMNR 2014) and with electrofishers (eel•hr^{-1}) after dark at Main Duck Island and nearby waters during July, 1984-2013 (Casselman and Marcogliese 2014).



The second index of abundance for American Eel in eastern Lake Ontario is the CPUE (hourly catch rate) from boat electrofishing after dark at Main Duck Island and nearby waters (Fig. 18). Nighttime electrofishing CPUE during 2008-2013 averaged 0.3 American Eel and the majority of the eel captured had been stocked (Casselman and Marcogliese 2014). The 0.3 CPUE during the current reporting period was lower than the 1.3 CPUE during the previous reporting period and but a small fraction of the 77.9 CPUE during the 1980s.

The numbers of American Eel leaving the Lake Ontario system are not tallied on a regular basis. Verreault and Dumont (2003) estimated that just less than half a million American Eels left the USLR and Lake Ontario annually during 1996 and 1997. A model that combines the 1996-1997 estimates of numbers of American eel leaving with trend-through-time counts of American Eel arriving (shown in Fig. 17) suggests that about 100,000 silver (life stage) eels left the USLR and Lake Ontario annually during 2001-2003. Surveys of dead American Eel in the tail waters of the Moses-Saunders Dam provide an indicator of the overall silver eel out-migration from the USLR and Lake Ontario (Fig. 19). The out-migration indicator declined from 14.4 American Eels•day^{-1} during 2001-2003 to 1.3 American Eels•day^{-1} during 2008-2013. This suggests that the numbers of silver American Eel leaving the system are declining and are far below the long-term target of at least 100,000 silver American Eels escaping annually.

Fig. 19. Number of dead American Eel found in the tail waters of the Moses-Saunders Dam on the St. Lawrence River during June to September, 2000-2013 (Riveredge Associates 2014).



As part of an action plan negotiated between the Ontario Power Generation, Ontario Ministry of Natural Resources and Forestry (OMNRF), and Fisheries and Oceans Canada, glass (life stage) American Eel obtained from commercial fisheries in New Brunswick and Nova Scotia were stocked in the USLR and the Bay of Quinte beginning in 2006. During the current reporting period, 3,447,000 American Eels were stocked (2008-2010), a 6-fold increase from the 576,000 American Eels stocked during the previous reporting period. Stocked American Eel was marked by immersion in oxytetracycline, creating a mark on their bones to distinguish them from natural migrants. Monitoring of stocked eel has shown that some survived over the seven-year period after stocking; however, the exact survival rate is unknown. The estimated density and biomass of stocked American Eel increased through 2013, despite the fact that no stocking occurred since 2010, most likely because eel became more vulnerable to capture as they grew. Based on a variety of surveys, stocked American Eel continued to disperse throughout Lake Ontario and its tributaries during the current reporting period. Some of the stocked American Eel matured and out-migrated from the system at an atypically young age (Verreault et al. 2010) and some matured as males, and male eel had never before been documented in this system (Pratt and Threader 2011). The mean size of stocked American Eel that was recaptured continued to increase. Four eels recaptured in 2013 were over 700-mm long, suggesting that some stocked American Eel may reach the lengths historically achieved by eel in this system, which was often longer than 1,000 mm.

Anguillicoloides crassus, a parasitic swimbladder nematode not previously reported in the St. Lawrence River system was first confirmed in American Eel captured at eel stocking sites in 2011. Two additional *A. crassus* were found in a sample of 116 American Eels in 2012, and one was found in a sample of 79 eels in 2013 (Pratt et al. 2015).

As part of the action plan, a trap-and-transport pilot project was initiated in 2008 to enhance the survival of out-migrating American Eel by transporting large yellow eel caught upstream of the Moses-Saunders and Beauharnois Dams to below the Beauharnois Dam on the St. Lawrence River. Transport of American Eel to below Beauharnois Dam avoids potential mortality of eel as it passes through hydropower generation turbines during its downstream migration. The pilot project transported an average of 1,249 eels (minimum length, 800 mm) annually around the two generating stations (Moses-Saunders and Beauharnois) during 2008-2013. Some of the American Eel moved in the trap-and-transport project was recaptured in the St. Lawrence River estuary and was physically and physiologically indistinguishable from naturally out-migrating silver eel (Couillard et al. 2014). After four years, 75% of the transported American Eel migrated towards the spawning grounds (Stanley 2012). To date, the trap-and-transport project has demonstrated that large yellow American Eel can be caught, held for brief periods, and transported successfully with limited mortality (Mathers and Pratt 2011). Trap and transport resulted in an estimated reduction in turbine mortality of about 250 American Eels per year during 2008-2013; however, it seems unlikely that the numbers of eel transported can be increased substantially with the current approach to capture. A binational effort to coordinate research aimed at reducing mortality of out-migrating silver eel from hydropower turbines is being facilitated through the Electric Power Research Institute's Eel Passage Research Centre.

Progress and Outlook

During the 2008-2013 reporting period, the number of yellow American Eel migrating upstream via the eel ladders at the Moses-Saunders Dam increased 3-fold over the 2003-2007 reporting period, meeting the progress indicator of increasing recruitment. However, despite the substantial increase, recruitment during the current reporting period was less than 4% of the long-term target. Estimating numbers of American Eel leaving the Lake Ontario system is very difficult and speculative. Nonetheless, modelling suggests that the number of silver American Eel leaving the system was not only far below the FCO long-term target but also declining. If true, the progress indicator of increasing escapement was not met during the current reporting period.

Round Goby

Lake Ontario's objectives for the fish community do not directly address the Round Goby, a non-native benthic fish, and thus there is no status/trend indicator for it. Nonetheless, since its relatively recent establishment in Lake Ontario, Round Goby has become important as predator and prey in nearshore and offshore waters, and, therefore, its status is important. The Round Goby was first documented in Lake Ontario in 1998 (Owens et al. 2003); first reported in angler catches in the Bay of Quinte in 1999 (Hoyle 2000) and in New York waters in 2001 (Eckert 2002); and first collected with bottom trawls in the Bay of Quinte in 2001, in New York waters off the south shore in 2002 (Walsh et al. 2006), and in Ontario waters off the northeast shore in 2003 (OMNR 2007). The Round Goby is a nearshore resident during summer but migrates to depths of 50-150 m during winter (Walsh et al. 2008a), so it is also a major component 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 *Mysis diluviana* and other invertebrates as well as small fish (French and Jude 2001; Walsh et al. 2007).

Round Goby abundance peaked during the current reporting period in 2008 in New York waters (Fig. 20) and in 2009 in northeastern Ontario waters (Fig. 21) but subsequently decreased such that, by 2013, abundance was similar to that in 2005-2006. Mean abundance in New York waters was 1.4 times greater in the current reporting period than in the previous reporting period (2003-2007), but this increase was largely driven by the 2008 abundance peak. In northeastern Ontario waters, mean abundance was 2.6 times greater during the current reporting period than during the previous reporting period even though abundance and biomass declined steadily during 2010-2013. In the Bay of Quinte, Round Goby abundance was consistently low during the current reporting period, and mean abundance and biomass indices were 33% and 80% lower, respectively, than in the previous reporting period (Fig. 21).

Fig. 20. Indices of the number and weight (g) of Round Goby in New York waters of Lake Ontario shoreward of the 180-m bottom contour, 2002-2013. Indices are sums of weighted catch-per-unit efforts from nine depth strata fished with bottom trawls towed for 10 min during April-May by the U.S. Geological Survey and the New York Department of Environmental Conservation. The mean catch in each depth stratum is weighted by the total area encompassed by that stratum in New York waters.

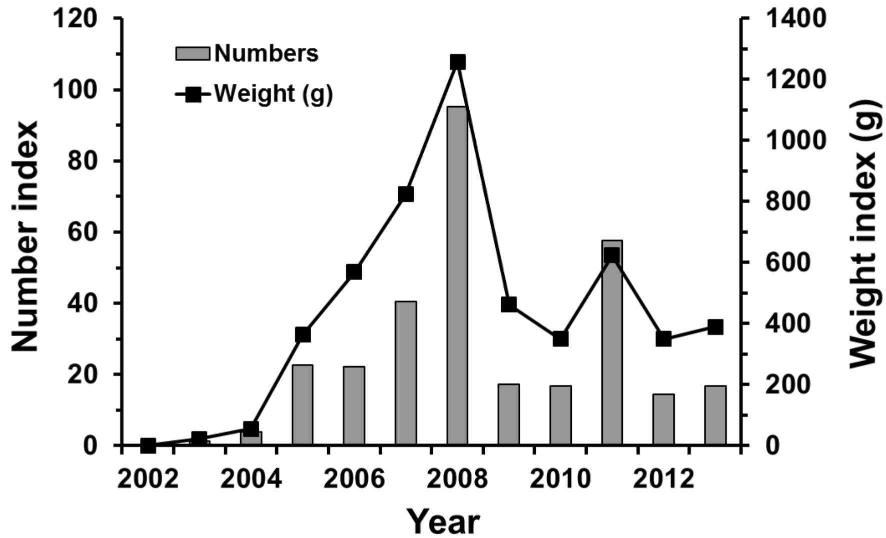
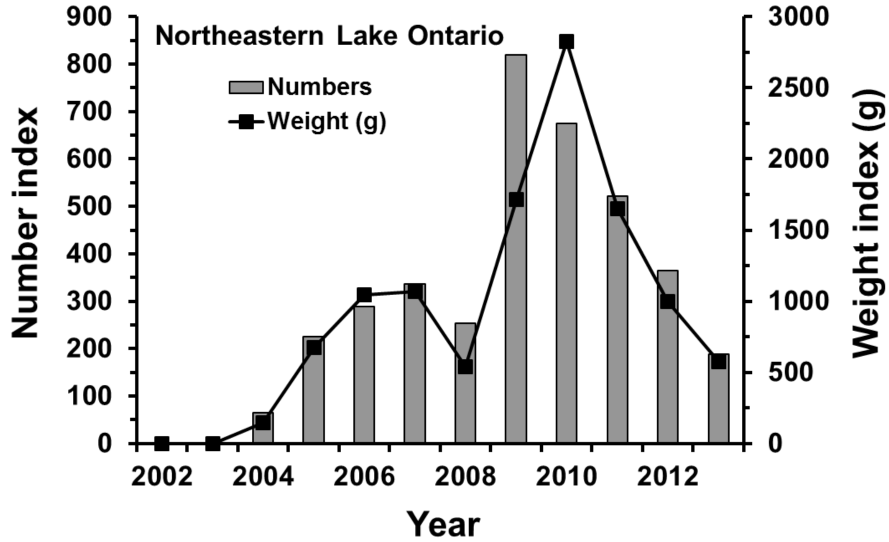
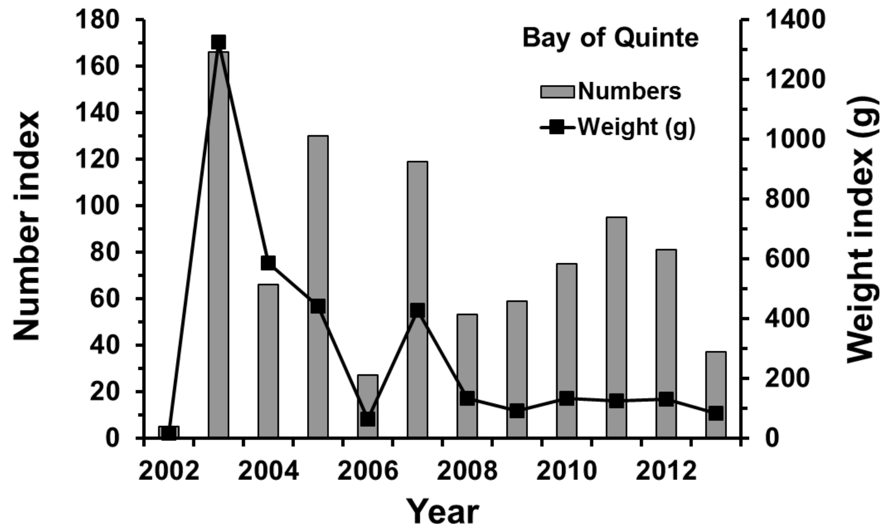


Fig. 21. Indices of the number and weight (g) of Round Goby in northeastern Ontario waters of Lake Ontario shoreward of the 90-m bottom contour and in the Bay of Quinte, 2002-2013. Indices are averages of the catch per tow with bottom trawls (fish•trawl tow^{-1}, g•trawl tow^{-1}) at various fixed locations within each of the two areas sampled. Trawling was conducted by the Ontario Ministry of Natural Resources and Forestry during July and August, and tows were standardized to 12-min duration. Round Goby was first caught in northeastern Lake Ontario in 2003 and in the Bay of Quinte in 2001.



Northeastern Lake Ontario
Numbers
Weight (g)
Number index
Weight index (g)
Year
900
800
700
600
500
400
300
200
100
0
3000
2500
2000
1500
1000
500
0
2002
2004
2006
2008
2010
2012



Bay of Quinte
Numbers
Weight (g)
Number index
Weight index (g)
Year
180
160
140
120
100
80
60
40
20
0
1400
1200
1000
800
600
400
200
0
2002
2004
2006
2008
2010
2012

Round Goby has become important in the diet of many fish, both nearshore and offshore (Dietrich et al. 2006; Taraborelli et al. 2010; Hoyle et al. 2012; Lantry 2012; Rush et al. 2012). Increased abundance of Round Goby and its occurrence in diets may have contributed to the much-improved condition and/or growth of recreationally important fish in the nearshore zone like Smallmouth Bass (Lantry 2012; Crane et al. 2015) and Walleye (Bowlby et al. 2010; Hoyle et al. 2012). In addition, Round Goby now occurs in the diets of salmon and trout in the offshore zones, making it one of the few fish linking Lake Ontario's nearshore and offshore food webs (Dietrich et al. 2006; Rush et al., 2012; U.S. Geological Survey, Lake Ontario Biological Station, unpublished data; OMNRF, Lake Ontario Management Unit, unpublished data).

Progress and Outlook

Round Goby has now been established in Lake Ontario for a little over a decade, and its ecological role and impacts, both positive and negative, are becoming more apparent. Positive impacts include buffering Yellow Perch and Smallmouth Bass from predation by a burgeoning population of Double-crested Cormorant (McCullough and Mazzocchi 2014; Johnson et al. 2014) and channeling energy from dreissenids up the food chain, which has increased condition and growth of piscivores (Crane et al. 2015). A negative impact is the recent decline in small-bodied native fish in open-coastal waters (see below), which appears linked to the presence of Round Goby and dreissenids. Round Goby population levels seem to have stabilized, and the species is expected to remain an important component of both nearshore and offshore food webs.

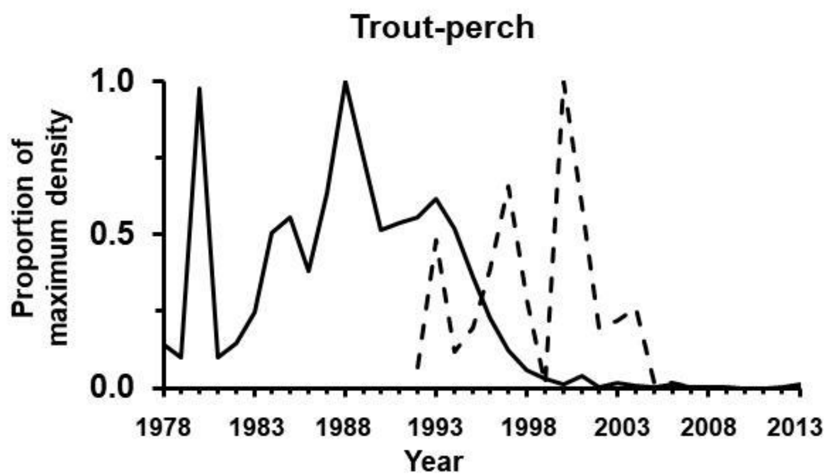
Native Fish Communities

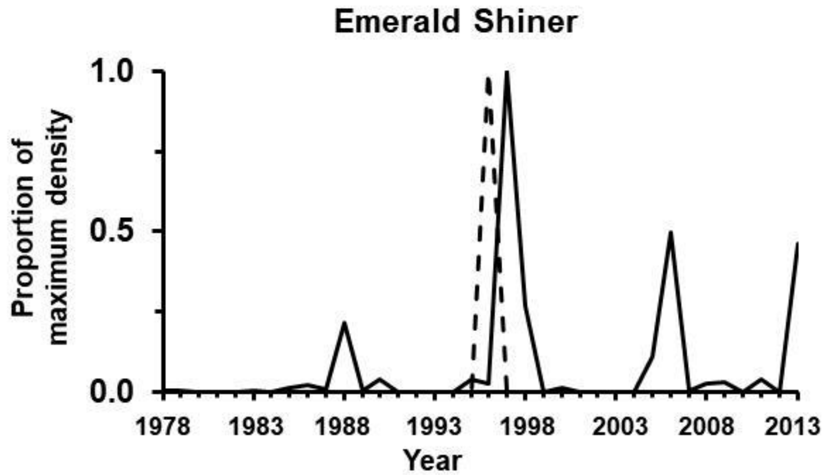
> *Maintain and restore native fish communities—maintain and restore native nearshore fish communities, including species that rely on nearshore habitat for part of their life cycle.*

In New York waters during the current reporting period (2008-2013), the density of each of the five most-common prey fish in the nearshore zone—Trout-perch, Johnny Darter, Spottail Shiner, Threespine Stickleback, and

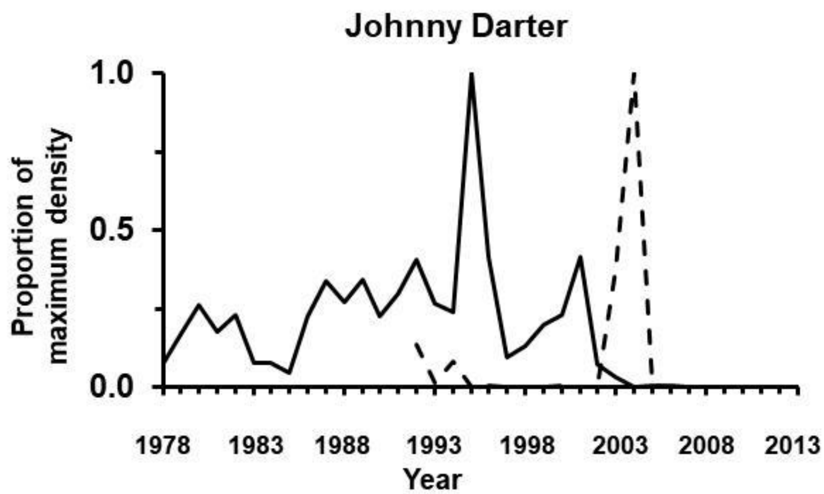
Emerald Shiner—was lower than in the previous reporting period (2003-2007) except for Spottail Shiner; its density was unchanged (Fig. 22). However, average densities in the current reporting period were reduced by 98% or more from historical (1978-2007) averages for Trout-perch, Johnny Darter, and Threespine Stickleback and by 90% for Spottail Shiner. The lone exception, Emerald Shiner, had an average density in the current reporting period that was 22% above the historical average.

Fig. 22. Relative density of five common species of native prey fish in two regions of Lake Ontario, in New York waters from Olcott to the mouth of the St. Lawrence River during 1978-2013 (solid line), and in Ontario waters of the eastern basin during 1992-2013 (dashed line). Prey-fish density was measured with bottom trawls by the U.S. Geological Survey and New York Department of Environmental Conservation in New York and by the Ontario Ministry of Natural Resources and Forestry in Ontario and is shown standardized to the proportion of the maximum density for each species in each region.

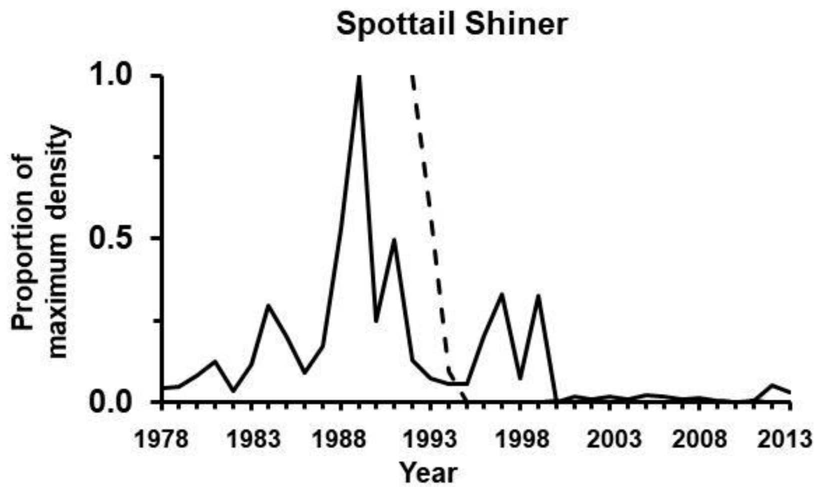


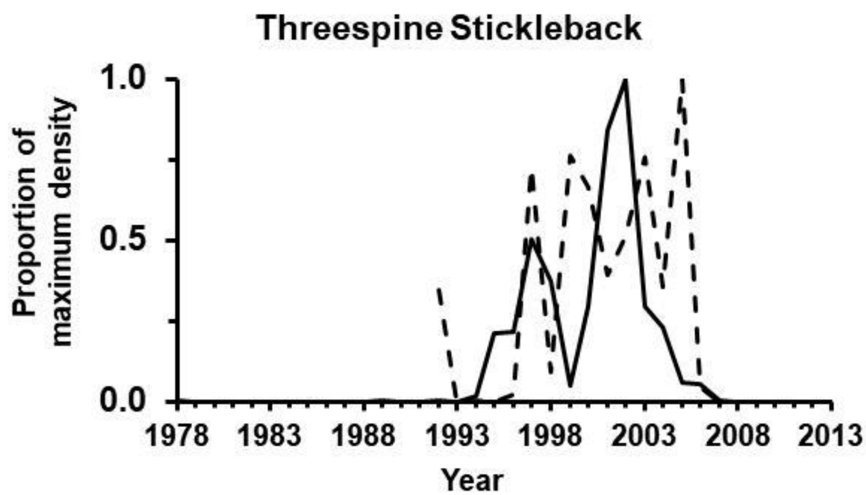


Emerald Shiner
Proportion of maximum density
1.0
0.5
0.0
1978
1983
1988
1993
1998
2003
2008
2013
Year



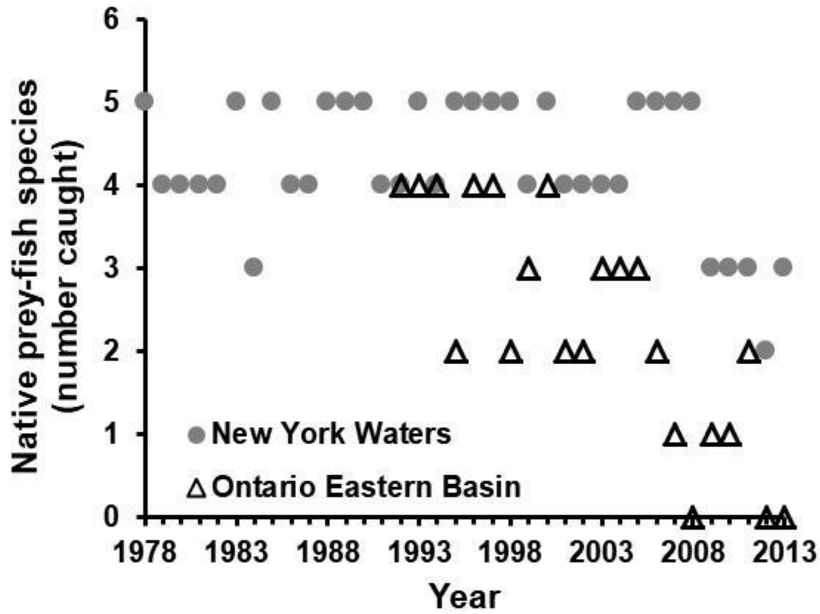
Johnny Darter
Proportion of maximum density
1.0
0.5
0.0
1978
1983
1988
1993
1998
2003
2008
2013
Year


Spottail Shiner
1.0
0.5
0.0
Proportion of maximum density
1978
1983
1988
1993
1998
2003
2008
2013
Year


Threespine Stickleback
1.0
0.5
0.0
Proportion of maximum density
1978
1983
1988
1993
1998
2003
2008
2013
Year

In Ontario waters during the current reporting period, the density of Trout-perch, Johnny Darter, and Threespine Stickleback was lower than in the previous reporting period, Emerald Shiner was unchanged, and Spottail Shiner increased slightly (Fig. 22). Similar to results in New York waters, average densities in the current reporting period were reduced by 98% or more from historical (1992-2007) averages for all five prey fish. As for frequency-of-occurrence of the five common prey species, during the current reporting period, bottom trawling in New York waters captured, on average, less than three out of the five species whereas, during the previous reporting period, trawling captured four or all five species each year (Fig. 23). In Ontario waters of the eastern basin, bottom trawling in the current reporting period averaged less than one of the five prey fish captured each year whereas, during the previous reporting, period trawling captured an average of between two and three of the five species. No surveys are designed specifically to assess the five native prey fish at a lakewide scale. However, bottom trawling in New York waters during April-November, 1978-2013, (mean number of tows 250, range: 179-311) and in Ontario waters of the eastern basin (mean number of tows 32, range: 24-42) during June-September, 1992-2013, show similar changes in density and occurrence of the five prey fish indicating that the two bottom-trawl assessments tracked lakewide changes in abundance. The timing of the decline in numbers of Trout-perch, Johnny Darter, Threespine Stickleback, and Spottail Shiner coincides with that of the increase in dreissenids and Round Goby suggesting these invasive species played a role in the declines in abundance of four of the five native prey fish.

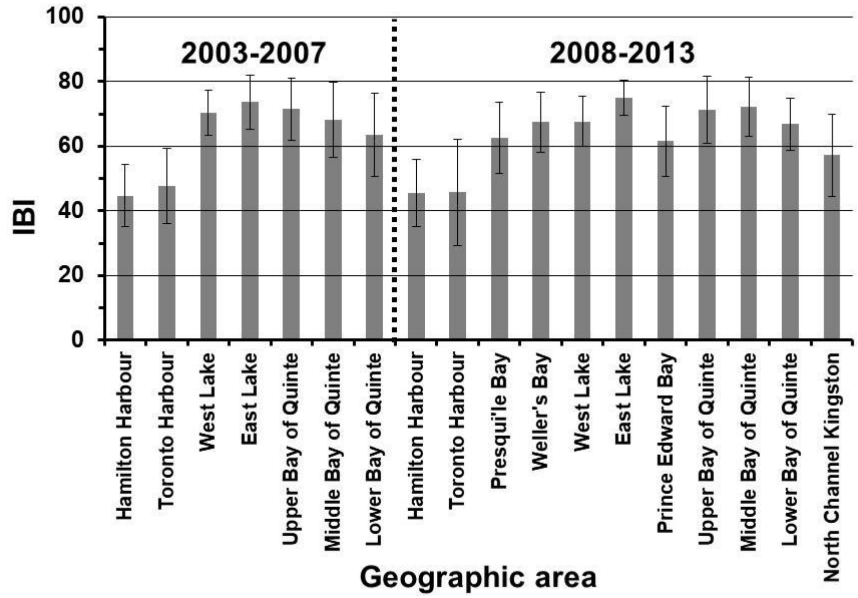
Fig. 23. Frequency-of-occurrence for five common species of native prey fish in the annual bottom-trawl catch from two regions of Lake Ontario, in New York waters from Olcott to the mouth of the St. Lawrence River during 1978-2013, and in Ontario waters of the eastern basin during 1992-2013. Bottom trawling was conducted by the U.S. Geological Survey and New York Department of Environmental Conservation in New York and by the Ontario Ministry of Natural Resources and Forestry in Ontario. The five prey fish are: Trout-perch, Johnny Darter, Spottail Shiner, Threespine Stickleback, and Emerald Shiner.



Biotic Integrity of Embayments and Sheltered Nearshore Areas in Ontario

Of the 11 embayments and sheltered nearshore areas sampled in Ontario during the 2008-2013 reporting period, an index of biotic integrity (IBI) indicated that fish communities were "good" (IBI = 60-80) in eight—Presqu'ile Bay, Weller's Bay, West Lake, East Lake, Prince Edward Bay, and three regions of the Bay of Quinte—and "fair" (IBI = 40-60) in three—Hamilton Harbour, Toronto Harbour, and North Channel Kingston (Fig. 24). Lowest IBI scores (IBI = 46) occurred at two AOCs, Hamilton Harbour and the Toronto Harbour, areas where intensive multi-agency RAPs are ongoing. The IBIs, based on trapnet sampling (Stirling 1999), were developed for evaluating fish community status in embayments and sheltered nearshore waters (Hoyle and Yuille 2016). The IBI consists of individual metrics that represent aspects of fish-assemblage integrity, such as taxonomic richness, habitat guilds, trophic guilds, and overall abundance and biomass. Observed ranges in IBI values reflect integrated effects of major factors influencing fish assemblages, including water quality, physical-habitat supply, invasive species, and trophic structure—especially piscivore abundance. The IBI accurately reflects contemporary differences in ecosystem health among geographic areas (Hoyle and Yuille 2016). Higher IBI values indicate greater native species richness, abundance, and biomass. No trends in IBI values were apparent between the two reporting periods for seven of the eleven areas sampled during both reporting periods (Fig. 24).

Fig. 24. Index of biotic integrity (IBI) for various Lake Ontario embayments and sheltered nearshore areas in Ontario that were sampled during 2003-2007 and 2008-2013. The IBIs are computed from catches in trapnets (Hoyle and Yuille 2016) that were fished according to an Ontario standard during fish community index netting (Stirling 1999). Areas and the years they were sampled are as follows: Hamilton Harbour (2006, 2008, 2010, 2012), Toronto Harbour (2006, 2007, 2010, 2012), Presqu'ile Bay (2008), Weller's Bay (2008), West Lake (2007, 2013), East Lake (2007, 2013), Prince Edward Bay (2009, 2013), upper Bay of Quinte (2003-2005, 2007-2013), middle and lower Bay of Quinte (2003-2005, 2009, 2011), and North Channel Kingston (2009). Error bars are ±1 SD.

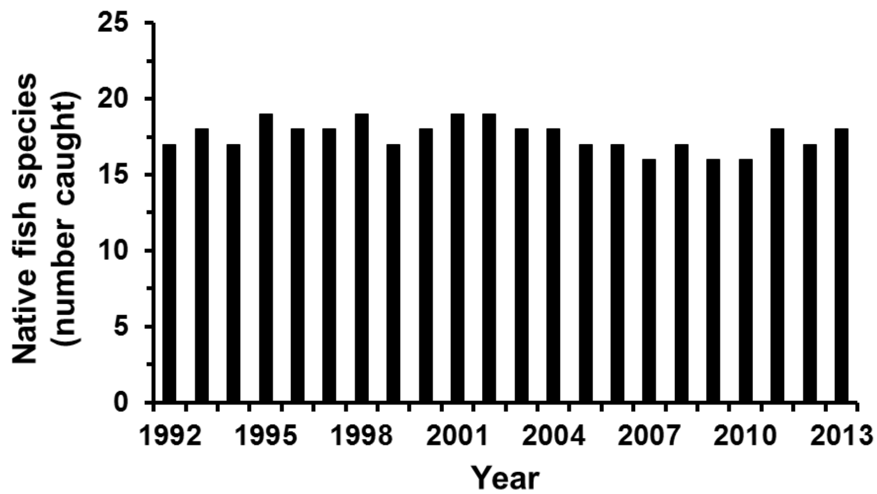


Native Species Richness and Diversity in the Bay of Quinte

The richness and diversity of the native fish community based on bottom trawling in the Bay of Quinte was further evaluated using three indices—Shannon's Diversity Index (H'), Pielou's Evenness Index (J'), and Simpson's Diversity Index (1-D). Diversity indices combine information on the number of species in a community (richness) and their relative abundance (evenness). Shannon's Diversity Index is sensitive to changes in the number of rare species in the community whereas Simpson's Diversity Index is sensitive to changes in abundance of the most-common species. Therefore, both indices were used to provide a more-robust interpretation of diversity. Values of Shannon's Diversity Index typically range from 1.5 to 3.5 and rarely are >4; values of Simpson's Diversity Index range from 0 to 1; and, for both indices, the higher the value, the greater the diversity. Values of Pielou's Evenness Index range from 0 to 1 with evenness (similarity of abundances among species) increasing with the index value.

The Bay of Quinte has a rich native fish community, as evidenced by the catch of 38 species of native fish from 1992 to 2013 (Bowlby et al. 2010). During the current reporting period, on average, 17 species of native fish were caught each year (Fig. 25), and values of the diversity indices were 4.64 (H') and 0.98 (1-D) and of the evenness index 0.95 (J'). In the previous reporting period, the average number of native species caught was 17.2, and average values of the three indices were 4.80 (H'), 0.99 (1-D), and 0.98 (J'). Thus, there was little change between the two reporting periods in richness, diversity, or evenness in the bay's native fish community. Moreover, a comparison of the current and previous reporting periods with earlier years suggests that there has been little change in these three attributes during the entire 22-year period of record. During 1992-2002, the catch of native species averaged 18.1, and the various indices averaged 4.65 (H'), 0.98 (1-D), and 0.95 (J').

Fig. 25. Number of native fish species caught with bottom trawls in the Bay of Quinte by the Ontario Ministry of Natural Resources and Forestry during 1992-2013.



Progress and Outlook

The status/trend indicator of maintaining or increasing native fish-species richness and diversity has not been met in the open-coastal areas of Lake Ontario; in fact, dreissenids and Round Goby have likely permanently reset this status/trend indicator's benchmark. By comparison, native species richness and diversity were maintained in the Bay of Quinte and in other Ontario embayments and sheltered nearshore areas.

OFFSHORE PELAGIC FISH COMMUNITY[9]

Michael J. Connerton[10], Jana R. Lantry, Maureen G. Walsh, Brian C. Weidel, James A. Hoyle, Marc D. Desjardins, Jeremy P. Holden, James H. Johnson, Michael J. Yuille, James N. Bowlby, Scott E. Prindle, Colin C. Lake, and Thomas J. Stewart

Lake Ontario's offshore zone, as defined by Stewart et al. (2013), comprises all waters of the lake where the bottom depth is ≥15 m excluding those waters in embayments. When the lake is thermally stratified during June-October, the offshore pelagic zone includes the upper-warm and middle-cool layers of water that serve as important habitat for Alewife (Table 1) and other prey fish and for predators like salmon and trout. Early changes in the fish community of the offshore pelagic zone are well documented elsewhere (e.g., Smith 1972; Christie 1973) as are more-recent changes (e.g., Owens et al. 2003; Mills et al. 2003). Currently, the offshore fish community consists of a mix of native and non-native species. Native species are those that were

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[9]Complete publication including map of place names, other chapters, scientific fish names, and references is available at http://www.glfc.org/pubs/SpecialPubs/Sp17_02.pdf.

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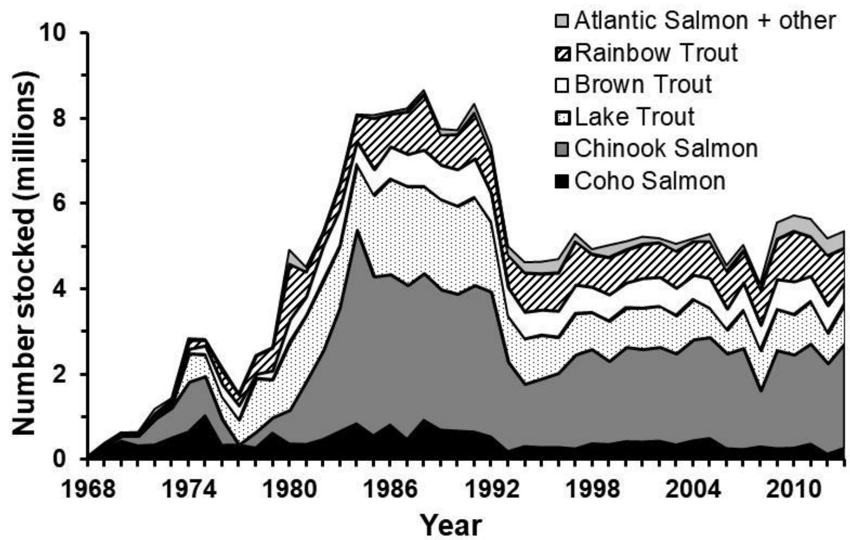
present prior to European colonization and include predators like Atlantic Salmon and prey fish like Cisco, Emerald Shiner, and Threespine Stickleback. Non-native species are those that were introduced unintentionally like Alewife and Rainbow Smelt or that were introduced intentionally like Chinook Salmon, Coho Salmon, Rainbow Trout, and Brown Trout. Non-native salmon and trout were introduced originally by fisheries managers to provide fishing opportunities and later to reduce an overabundance of Alewife.

Alewife is the most-abundant prey fish in the offshore pelagic zone, and it dominates the diets of native and introduced predators (Brandt 1986; Lantry 2001). Alewife can have direct and indirect negative effects on other fish through competition for food and/or predation on their larvae (Madenjian et al. 2008). Alewife also contains thiaminase, an enzyme that catalyzes the breakdown of thiamine, and fish that eat mainly Alewife can become thiamine deficient, which impairs their reproduction (Honeyfield et al. 2005). Except for that of the Alewife, prey-fish populations in the offshore pelagic zone are depressed and not large enough to sustain the zone's predators. Alewife remains necessary for a functional ecosystem that is required to sustain a highly valued, trophy sport fishery (Stewart et al. 2013). Wild production of salmon and trout occurs in Lake Ontario tributaries, contributing to in-lake populations (Rand et al. 1993; Connerton et al. 2009; Connerton et al. 2014c). Stocking hatchery-reared fish (Fig. 26), however, remains an essential tool for managing Lake Ontario's diverse salmon and trout fisheries and for achieving the offshore pelagic-zone goal (Stewart et al. 2013):

> *Maintain the offshore pelagic fish community, that is characterized by a diversity of trout and salmon species, including Chinook Salmon, Coho Salmon, Rainbow Trout, Brown Trout, and Atlantic Salmon, in balance with prey-fish populations and lower trophic levels.*

Fig. 26. Number of salmon and trout >3 g stocked annually into Lake Ontario, 1968-2013. "Other" salmon and trout include Splake (1968-1976), Kokanee (1968-1972), and Brook Trout (1980-1981).



Here we review the fish community objectives (FCOs) for Lake Ontario's offshore pelagic zone (Stewart et al. 2013) and evaluate whether those objectives were met during this reporting period (2008-2013) by assessing the status of the objectives' indicators. We also compare the status of indicators in this reporting period with those in the previous reporting period (2003-2007; Connerton et al. 2014b). Specific objectives are in italics at the start of each major section, and associated indicators of progress are given in Progress and Outlook subsections.

Chinook Salmon

Maintain the Chinook Salmon fishery—maintain Chinook Salmon as the top offshore pelagic predator supporting trophy recreational lake and tributary fisheries through stocking.

Stocking

During the current reporting period (2008-2013), the number of spring fingerling Chinook Salmon stocked averaged 2.13 million annually, a 7% decline compared with the previous reporting period (2003-2007) (Fig. 26). Most of the stocking shortfall occurred in 2008 when the number of Chinook Salmon released was reduced 42% to 1.33 million because of dry and warm weather in fall 2007. Below-normal precipitation in fall 2007 led to low flow in New York's Salmon River, substantially reducing the numbers of adult salmon entering the Salmon River Hatchery (SRH) and thus a shortfall in the number of eggs collected. Furthermore, warm weather in the fall elevated tributary water temperatures, lowering egg quality and fertilization rates at the SRH and at the Ontario Ministry of Natural Resources and Forestry's (OMNRF) egg collection site on the Credit River. There were smaller stocking shortfalls of Chinook Salmon in 2010 (by 4%) and 2012 (by 8%) due to lower than normal egg-to-fry survival at the SRH.

Although stocking remains vital for sustaining the Chinook Salmon fishery and predator demand, a study conducted during this reporting period suggests that wild reproduction of Chinook Salmon is also important. From 2008-2011, all Chinook Salmon stocked into Lake Ontario were given an adipose fin clip to determine the proportions of wild Chinook Salmon in the fishery. Sampling Chinook Salmon harvested by anglers in the open lake from 2010-2013 found that an average of 50% of the age-2 and age-3 salmon had an adipose fin and thus were wild (Connerton et al. 2014c). On average, two- and three-year-old fish made up 86% of the Chinook Salmon harvested by anglers in the open lake from 2008-2013 (Lantry and Eckert 2014).

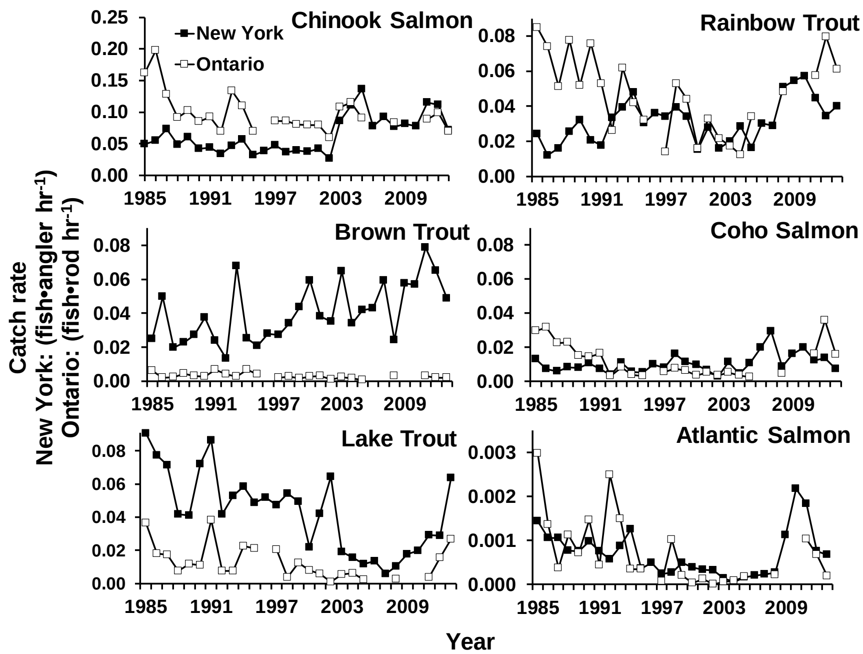
During this reporting period, a mass tagging study conducted to compare the efficacy of two methods used to stock spring fingerling Chinook Salmon in

Lake Ontario—direct stocking and pen stocking—found that both methods resulted in high homing to, and low straying rates from, stocking sites, but that pen-stocked fish made a 2-fold greater contribution to the lake fishery per number stocked than did direct-stocked fish (Connerton et al. 2014c). In direct stocking, the fish are simply released at the stocking site. In pen stocking, the fish are placed in net pens at the stocking site where they are held and fed for a few weeks and then released when ready to smolt or when the water becomes too warm. The proportion of Chinook Salmon stocked from pens has increased in New York and Ontario since 1999 effectively leading to increases in recruitment of hatchery-reared fish even though the total numbers of fish stocked has remained relatively unchanged.

Catch Rates

During the current reporting period (2008-2013), Chinook Salmon remained the top offshore pelagic predator with the highest angler catch rates in the open lake among all salmon and trout (Fig. 27; Connerton et al. 2014c; Lantry and Eckert 2014; OMNR 2014). Catch rates in New York and Ontario waters of the open lake from 2008-2013 were maintained at rates similar to those during the previous reporting period (2003-2007) (Fig. 27). In New York, although the average catch rate of Chinook Salmon in this reporting period decreased by 12% compared to the previous reporting period, catch rates in five of six years were among the 10 highest of the 29-year data series, with 2011 and 2012 ranking the second and third highest. Angler catch rates in New York have remained high for 11 consecutive years (2003-2013) and were more than 2-fold higher than catch rates during 1985-2002 (Connerton et al. 2014b; Lantry and Eckert 2014). In Ontario, the average Chinook Salmon catch rate during this reporting period (angler surveys conducted in four years) declined by 18% compared to the previous reporting period (angler surveys conducted in 2003-2005). Catch rates in 2003-2005, however, were atypically high, about 18% higher than the previous 10-year average (Fig. 27; OMNR 2014).

Fig. 27. Catch rates (New York: fish•angler hr^{-1}; Ontario: fish•rod hr^{-1}) of Chinook Salmon, Rainbow Trout, Coho Salmon, Lake Trout, and Atlantic Salmon in the open waters of Lake Ontario during April 15-September 30, 1985-2013. In New York, the angler survey is conducted in southern and eastern Lake Ontario, and the catch rates shown are for charter boats only (Lantry and Eckert 2014). In Ontario, the angler survey is conducted in western Lake Ontario, and the catch rates shown are for all fishing boats (OMNR 2014). Note that scales of the Chinook Salmon and Atlantic Salmon panels differ from those in the other panels and from each other.

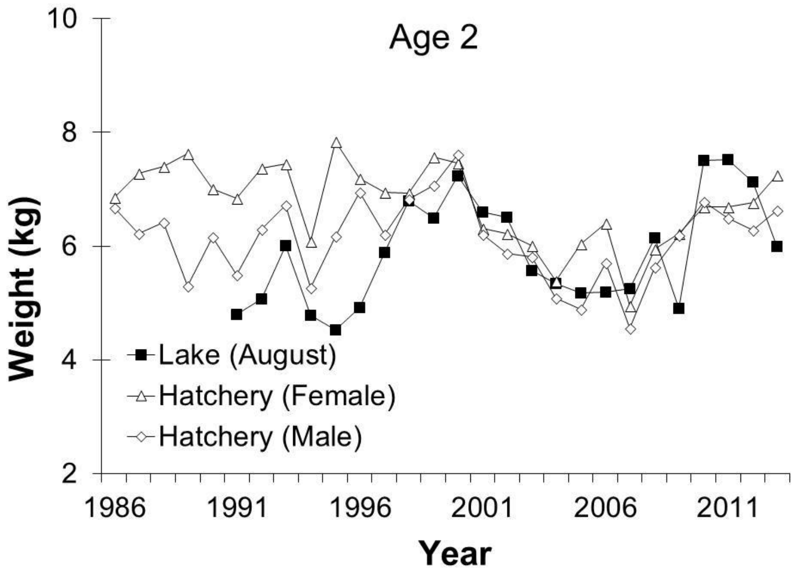


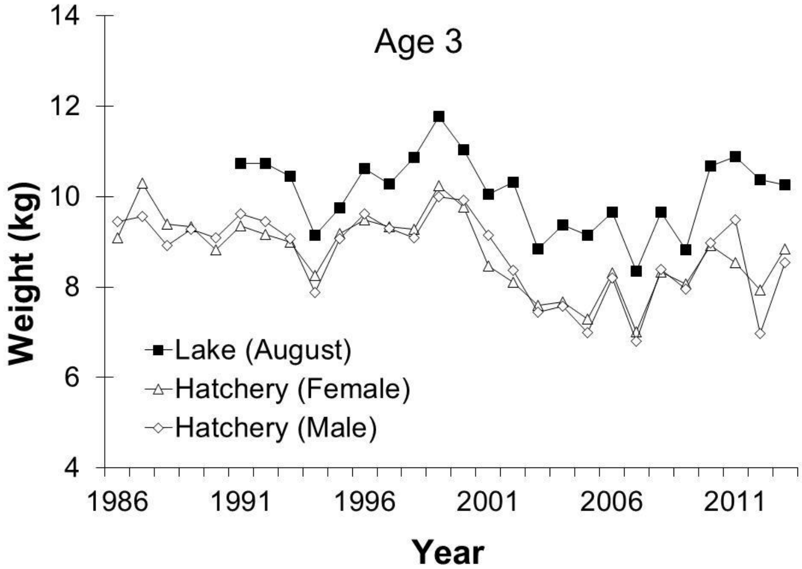
As for Chinook Salmon catch rates in Lake Ontario tributaries, only limited data are available in New York, and no data are available in Ontario. During the current reporting period, angler surveys on New York tributaries were conducted only during fall 2011 whereas, during the previous reporting period, they were conducted each fall during 2004-2006 (Bishop and Penney-Sabia 2005; Prindle and Bishop 2013). During fall 2011, the angler catch rate of Chinook Salmon in New York tributaries declined by 35% from the average catch rate during the falls of 2004-2006. High catch rates in 2004-2006 were likely due to the strong 2002 and moderately strong 2003 year-classes present in the 2004-2006 spawning runs (Lantry and Eckert 2014; Prindle and Bishop 2014). In contrast, the fall 2011 run was dominated by a strong 2009 year-class and included a weak 2008 year-class likely resulting from low stocking and low wild reproduction in 2008 (Bishop et al. 2014; Lantry and Eckert 2014; Prindle and Bishop 2014).

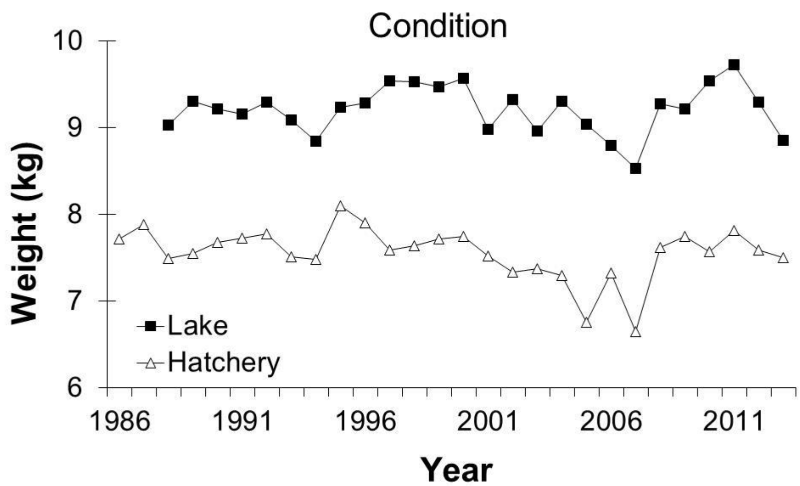
Growth and Condition

Chinook Salmon growth and condition are monitored by both the New York State Department of Environmental Conservation (DEC) and the OMNRF; however, in this report, only data collected by the DEC are used to track trends. During the current reporting period (2008-2013), the average weight of an age-3 Chinook Salmon creeled in New York during the August lake fishery was 10.1 kg (22.3 lbs), 21% heavier than in the 2007 benchmark year and nearly 12% heavier than the average during the previous reporting period (2003-2007) (Fig. 28; Lantry and Eckert 2014). Age-3 female and male Chinook Salmon returning to the SRH in October 2008-2013 averaged 23% and 20% heavier, respectively, than in October 2007 (Prindle and Bishop 2014). Increases in average weight above the 2007 benchmark were even greater for age-2 Chinook Salmon during the current reporting period. Age-2 fish in the lake averaged 24% heavier than in 2007, and those returning to the SRH averaged 33% (female) and 39% (males) heavier. Likewise, condition, as measured by the predicted weight of a 914-mm (36-inch) Chinook Salmon, increased during the recent reporting period relative to 2007 by 9% in the lake in August and by 15% at the SRH in October (Lantry and Eckert 2014; Prindle and Bishop 2014).

Fig. 28. Average weight (kg) of age-2 and age-3 Chinook Salmon (top panels) caught by anglers in the New York waters of Lake Ontario in August, 1991-2013 (Lantry and Eckert 2014) and at the hatchery on the Salmon River, New York, in October 1986-2013 (Prindle and Bishop 2014). Condition (weight of a 914-mm fish predicted from a length-weight regression) of Chinook Salmon (bottom panel) caught by anglers in the New York waters of Lake Ontario in August 1988-2013 and at the hatchery on the Salmon River, New York, in October 1986-2013. Note that the scale of the age-3 panel differs from that of the age-2 and condition panels.




Age 3
Weight (kg)
Lake (August)
Hatchery (Female)
Hatchery (Male)
Year


Condition
Weight (kg)
Lake
Hatchery
Year

Progress and Outlook

The status/trend indicators for the objective of maintaining the fishery for Chinook Salmon were met during 2008-2013 with Chinook remaining the top pelagic predator in the offshore zone and continuing to support a trophy fishery through stocking. Although the catch rate, one of two status/trend indicators for Chinook Salmon, was down marginally in the lake compared to the previous reporting period, fishing quality was good to excellent with catch rates more than twice the 1985-2002 average in New York and near the long-term average in Ontario. In the tributaries, fishing quality was moderate, but this conclusion was based only on one season of data in New York. Angler surveys are scheduled for Ontario tributaries in 2014-2015 and for New York tributaries in 2015-2016. Chinook Salmon fishing quality in the tributaries is influenced by many factors, including stream flow and the presence of strong or weak year-classes. Therefore, tributary angler surveys conducted only once during a five- or six-year reporting cycle may not be frequent enough to reasonably compare fishing quality between reporting periods except at a very-gross level.

Chinook Salmon growth and condition, the second status/trend indicator for this FCO, improved during this reporting period. Both indicators were well above the 2007 benchmarks.

Stocking of Chinook Salmon during this reporting period was generally maintained close to the level of the previous reporting period, except in one year when reduced tributary flows hampered egg collection and warm-water temperatures lowered egg quality and fertilization rates leading to production shortfalls. Such conditions during the fall spawning run are unprecedented for Lake Ontario. Agencies may need to adopt new procedures (e.g., adjusting timing of egg collections, increasing egg take to meet production targets, etc.) if climate change leads to lower flows and warmer stream temperatures in fall.

Atlantic Salmon

> *Restore Atlantic Salmon populations and fisheries—restore self-sustaining populations to levels supporting sustainable recreational fisheries in the lake and selected tributaries and also provide recreational fisheries where appropriate through stocking.*

During this reporting period (2008-2013) considerable effort was directed toward the enhancement of Atlantic Salmon populations and achievement of the Atlantic Salmon FCO. In Ontario, the OMNRF made a commitment in 2006, along with the Ontario Federation of Anglers and Hunters and more than 40 partners, to restore a self-sustaining Atlantic Salmon population to Lake Ontario. The Lake Ontario Atlantic Salmon Restoration Program includes building fish-culture capacity, rehabilitating habitat, addressing restoration challenges through directed research, and engaging local communities. Atlantic Salmon restoration efforts are focused on a few, high-quality cold-water streams, such as the Credit River, Duffins Creek, and Cobourg Brook. Recently, the Province of Ontario has expanded habitat-restoration activities and the stocking of surplus hatchery fish into Bronte Creek and the Humber River.

In New York, Atlantic Salmon has been stocked for put-grow-and-take recreational fisheries. In 2009, however, the U.S. Geological Survey (USGS) initiated a program aimed at establishing a self-sustaining population in the Salmon River.

Stocking

Changes in management objectives for Atlantic Salmon during the 2008-2013 reporting period led to much-higher numbers stocked than during the 2003-2007 reporting period (Fig. 26). In Ontario, average stocking (excluding eggs and fry) increased 2.5 times from roughly 77,000 to 242,000 per year. Fry stocking increased from 195,000 to 460,000 to meet restoration-plan objectives. In New York, average stocking doubled from 54,000 to 100,000 fish per year due to stocking conducted by the USGS (Connerton 2014; OMNR 2014). Agencies are evaluating the performance of several strains of Atlantic Salmon. The USGS intends to develop a Lake Ontario strain of Atlantic Salmon by using gametes collected from adults returning to the Salmon River, New York. The OMNRF is assessing genetically the relative contribution/survival of three strains of Atlantic Salmon (LeHave, Sebago, and Lac St. Jean), each stocked at three different life stages (spring fingerlings, fall fingerlings, and spring yearlings) with the intent of selecting the best-performing life stage and strain for future use (Stewart et al 2014a).

Angler Catch

Atlantic Salmon made up a very-small portion of the total open-lake salmon and trout catch during both reporting periods—0.1% during 2008-2013 and 0.5% during 2003-2007. The catch of Atlantic Salmon during 2008-2013 averaged 1,007 fish per year, more than 6-fold higher than the 159-fish average in 2003-2007. Average catch rate in the open-lake boat fishery during 2008-2013 was about 6-fold higher than in the 2003-2007 reporting period in New York and about 4-fold higher in Ontario (Fig. 27). Although Atlantic Salmon catch rates in this reporting period were similar to the higher catch rates of the late 1980s and early 1990s, they remain relatively low, about 2% of the average catch rates of all other salmon and trout (OMNR 2013; Lantry and Eckert 2014). Catch rates in the Salmon River, New York, have also improved, providing a small but valuable fishery in the summer months (F. Verdoliva, New York State DEC, personal communication, 2013).

Returning Spawners and Wild Production

Monitoring of Atlantic Salmon at different life stages increased substantially during this reporting period (2008-2013) in order to evaluate newly implemented restoration initiatives. In Ontario, fish stocked in the Credit River, Duffins Creek, and Cobourg Brook survived and grew well, and first-year density and growth targets were met (Stewart et al. 2014a). Stocking in high-quality habitats of these tributaries succeeded in producing smolt-sized fish, and out-migration of smolts from the Credit River to Lake Ontario was documented in the springs of 2011-2013 by use of rotary screw traps (OMNR 2012, 2013, 2014; Stewart et al. 2014a). The recently implemented stocking regime, however, has only resulted in low numbers of adults returning to Ontario streams, fewer than 50 per year in the Credit River based on fishway counts, with some adults also documented in Cobourg Brook and Duffins Creek (Stewart et al. 2014a). Some of the Atlantic Salmon returning to the Credit River is spawning successfully (Fitzsimons et al. 2013). Genetic analysis of smolts from the Credit River detected small numbers of potentially wild fish. Roughly 4% of the smolts sampled in 2012 and 2013 showed genetic-strain assignments indicative of wild matings of LaHave and Sebago parents (Stewart et al. 2014a). Implementing thorough sampling programs to document small runs across multiple watersheds has been challenging, and sampling programs have been opportunistic rather than comprehensive (OMNR 2012, 2013; Stewart et al. 2014a). In New York's Salmon River, increased runs of Atlantic Salmon are supporting a stream fishery and wild parr were produced each year from 2009-2011 and in 2013 (USGS, Tunison Laboratory of Aquatic Sciences, unpublished data). Whether wild-produced fish are contributing to the lake and stream fisheries is unknown.

Progress and Outlook

Efforts to achieve the FCO of Atlantic Salmon restoration produced mixed results this reporting period with status/trend indicators both negative (returns of spawning adults) and positive (wild production and angler catch). Although restoration stream environments were found suitable to support fish stocked at early life stages, the number of adults returning to the streams has not been sufficient to establish self-sustaining populations. Nonetheless, much progress has been made since 2007, the last year of the previous reporting period. Angler catch rates of Atlantic Salmon in the open lake are up, wild production of juveniles occurred in two tributaries, and an attractive, albeit small, fishery developed on the Salmon River, New York. Several years of assessment have provided insights regarding Ontario's stocking program, and refinements should lead to program improvements. In 2014, the OMNRF held an Atlantic Salmon Restoration Science Workshop where Atlantic Salmon experts from the OMNRF and other organizations reviewed recently collected Lake Ontario data to make program recommendations and refinements (Stewart et al. 2014a). Ultimately, the restoration of Atlantic Salmon populations is a long-term goal that requires time and patience. Achievement of this FCO is unlikely within the first decade of the program's initiation.

Prey Fish

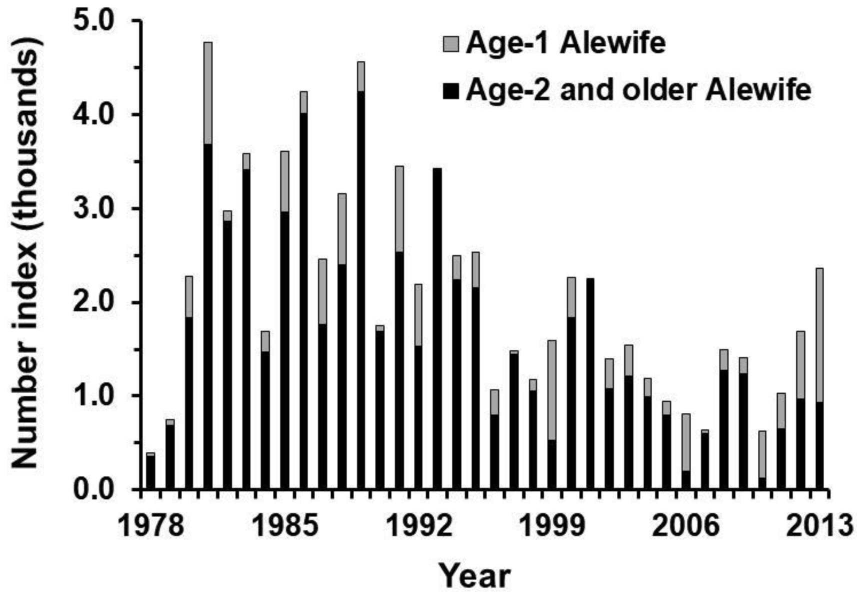
Increase prey-fish diversity—maintain and restore a diverse prey-fish community that includes Alewife, Cisco (Lake Herring), Rainbow Smelt, Emerald Shiner, and Threespine Stickleback.

Status and trends of the prey-fish community in the offshore pelagic zone are tracked annually by the USGS, DEC, and OMNRF. Sources of data include bottom-trawl assessments conducted in New York waters by the DEC and USGS since 1978 (O'Gorman et al. 2000; Owens et al. 2003; Walsh et al. 2014), lakewide hydroacoustic surveys conducted jointly by the OMNRF and DEC since 1997 (Connerton et al. 2014a), and index gillnetting and bottom trawling conducted by the OMNRF in Ontario waters of the eastern basin and in the Bay of Quinte since 1992 (OMNR 2014).

Alewife

During the current reporting period (2008-2013), Lake Ontario's Alewife population was generally maintained at levels similar to those in the previous reporting period (2003-2007), with some fluctuations in abundance due to wide swings in numbers of age-1 Alewife, the youngest age-group in assessment catches (Fig. 29). For five years during 2008-2013, abundance of adult (≥age 2) Alewife was similar to or higher than in 2003-2007, and, in one year (2010), abundance of adults was the lowest on record (previous record low was in 2006). Record-low adult abundance in 2010 was due largely to only one strong year-class (2005) having been produced in the previous reporting period. Despite the record low, however, indices of adult Alewife abundance during the current reporting period trended upward and averaged 13% higher than the average of the previous reporting period when indices trended downward. Three moderate to strong year-classes produced from 2009-2011 fueled the rebound of adult numbers during the current reporting period.

Fig. 29. 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, 1978-2013. Note that year-class strength is indexed at age 1, so 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 2013 indicates a strong 2012 year-class).



Adult Alewife condition (weight relative to length) during the current reporting period was similar to that in the previous reporting period but was about 35% higher than during the 1990s and early 2000s. Persistently high condition since 2003 indicates that food availability for adult Alewife was not limiting (Walsh et al. 2014). Condition may be benefitting from Alewife feeding on *Bythotrephes longimanus* (Walsh et al. 2008b), whose abundance increased after 2003 (Holeck et al 2014), and/or from Alewife shifting to feeding on zooplankton communities deeper in the water column (Holeck et al. 2014) and on *Mysis diluviana* (Stewart et al. 2009).

The abundance index for age-1 Alewife during 2008-2013 averaged 0.57, more than double the index average of 0.26 during 2003-2007 (Fig. 29). The 2012 year-class, assessed at age 1 in spring 2013, was the largest year-class during the 35-year time series. During the previous reporting period, there was one strong year-class in 2005 and one weak year-class in 2006 (Fig. 29). Alewife year-class strength is influenced by several factors, including the number of adult Alewife in the spawning stock and water temperatures in summer and winter, all of which affect reproduction, growth, and survival of young-of-the-year (YOY) Alewife (O'Gorman et al. 2004). The Alewife population in 2013 was dominated by young fish (94% of the population was ≤age 4), which should lead to an increase in the spawning stock in coming years.

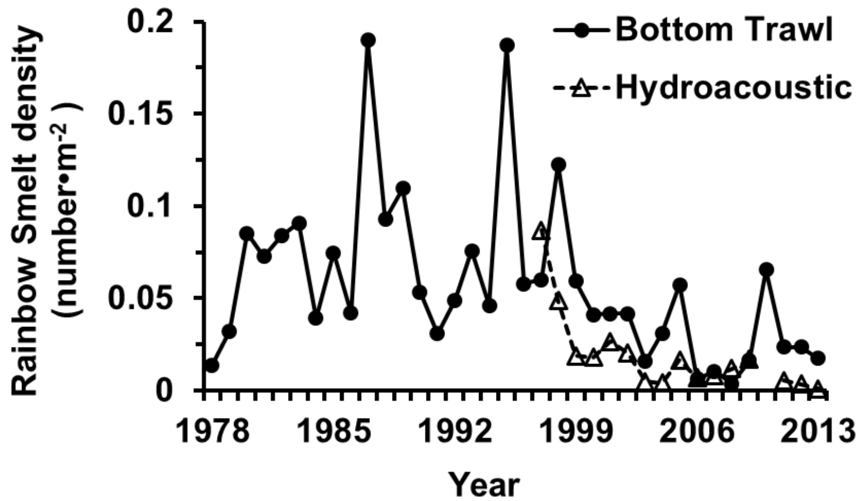
Rainbow Smelt

Rainbow Smelt status during the current reporting period (2008-2013) was unchanged from that in the previous reporting period (2003-2007) (Fig. 30). Average densities in USGS/DEC bottom trawls in southern Lake Ontario were about 4% higher, and average densities determined by hydroacoustics in lakewide assessments conducted by OMNRF/DEC were about 4% lower in this reporting period compared to the previous period. Rainbow Smelt densities assessed with bottom trawls are correlated with those assessed with hydroacoustics (r = 0.64, n = 16, P < 0.01), and both assessment methods show that densities have declined since the late 1990s. Average bottom-trawl densities of Rainbow Smelt during this reporting period were 44% of the 1978-2007 average, and average hydroacoustic densities were 33% of the 1997-2007 average.

The average weight of a 100-mm Rainbow Smelt (an index of condition) in bottom trawls during 2008-2013 was equal to that in 2003-2007, but it was 5% lower than the long-term average, indicating that food for young smelt was limited during the current and previous reporting periods. Rainbow Smelt ≥150 mm averaged 2% of the catch from 2008-2013, indicating low survival to older ages, but this has been the case since 1986 when Lake Trout numbers began to rise.

Rainbow Smelt constituted an average of 30% of all fish caught in bottom trawls in the 1980s and 1990s whereas the current average contribution is about 9% of all trawl-caught fish. Over the same span of years, Alewife increased from 60% to 87% of the total catch (Weidel and Connerton 2014).

Fig. 30. Density of Rainbow Smelt, age 1 and older, in the New York waters of Lake Ontario as determined via bottom trawls conducted by the U.S. Geological Survey and New York State Department of Environmental Conservation (DEC) in late spring, 1978-2013 (Weidel and Connerton 2014) and in all waters of Lake Ontario as determined via hydroacoustics conducted by the Ontario Ministry of Natural Resources and Forestry and DEC in summer, 1997-2013 (Connerton et al. 2014a).



Emerald Shiner and Threespine Stickleback

No survey is designed to specifically assess Threespine Stickleback and Emerald Shiner. Both species, however, are caught in offshore waters during bottom-trawl assessments conducted along the New York shore of Lake Ontario (Walsh et al. 2014) and in Ontario waters of the eastern basin (OMNR 2014), providing a rough index of their abundance. The status of Threespine Stickleback and Emerald Shiner is more thoroughly reviewed in the Nearshore Fish Community chapter (in the full report) because they are more associated with the nearshore zone than the offshore zones. Nonetheless, we report herein incidental catches of Threespine Stickleback and Emerald Shiner in the offshore because they are also part of the prey-fish community in the offshore pelagic zone and because they are specifically listed as status/trend indicators for the offshore pelagic zone in the FCOs.

Overall, Threespine Stickleback and Emerald Shiner were rare in the offshore zone during 2008-2013. Threespine Stickleback was not caught in offshore Ontario waters of the eastern basin during the current reporting period (OMNR 2014). Threespine Stickleback was last caught in the eastern basin in 2006. In offshore New York waters, only six Threespine Stickleback were caught from 2008-2013 (0.27 per 1,000 min trawled) compared with 17,830 caught from 2003-2007 (1,532 per 1,000 min trawled) (Connerton et al. 2014b). After being essentially absent during the 1980s, Threespine Stickleback numbers rose to a high level during the 1990s, and the elevated numbers persisted until 2003 when a rapid decline began (see Nearshore Fish Community chapter in the full report; Fig. 22).

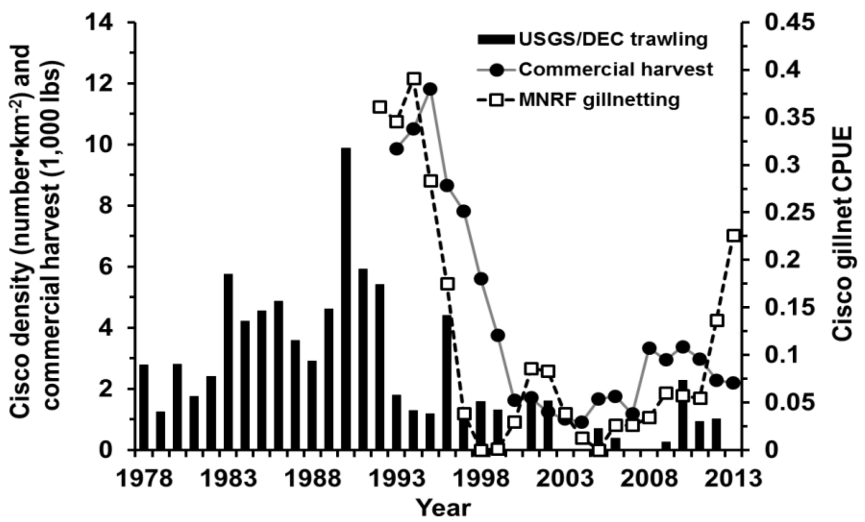
In New York waters, catches of Emerald Shiner during this reporting period averaged 23% lower compared to the 2003-2007 reporting period. Emerald Shiner occurs in New York bottom-trawl catches sporadically, and, when it does occur, it is usually in southwestern Lake Ontario at depths from 35 to 135 m during April-May (Owens et al. 2003). Emerald Shiner is rarely caught in OMNRF trawls in the eastern basin of Lake Ontario, and there were none caught in this reporting period or during the previous reporting period.

Cisco

In this reporting period (2008-2013), the status of Cisco (formerly Lake Herring) in Lake Ontario was better than that in the previous reporting period (2003-2007) when catches were at or near all-time lows (Fig. 31). Although there is no assessment of the magnitude of spawning populations of Cisco in embayments, a status/trend indicator was gleaned from incidental catches during bottom-trawl assessments of other fish in New York waters, from index bottom trawling and gillnetting in the eastern basin and Bay of Quinte, and from incidental catches by the commercial fishery operating in eastern Ontario waters. Cisco abundance in New York waters along the south shore and in the eastern basin (Walsh et al. 2014), averaged 7.5 fish•km^{-2} during 2008-2013 compared with an average of 2.2 fish•km^{-2} during 2003-2007 (Fig. 31). Even with this seemingly large increase, however, abundance from 2008-2013 was only about one-sixth that during 1978-2002. The bulk of the Cisco in Lake Ontario is in the eastern basin (Owens et al. 2003), and index gillnetting there in Ontario waters and in the

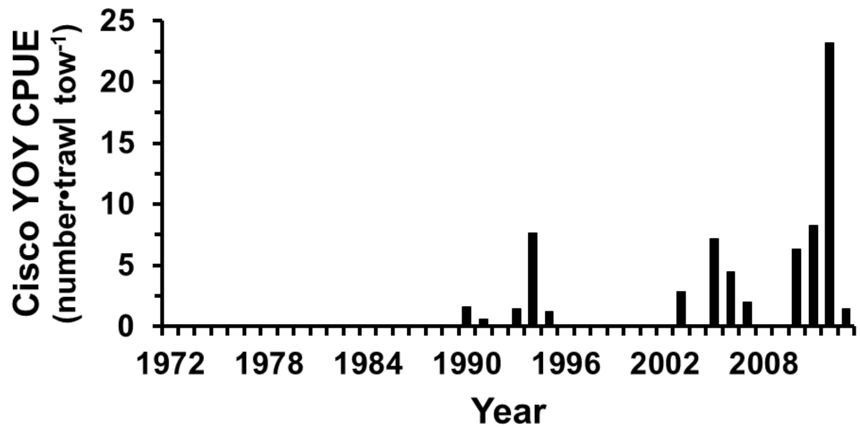
Bay of Quinte (OMNR 2014) indicated trends in abundance similar to those in New York waters—high catches in the 1980s, declining catches in the 1990s, low and fluctuating catches throughout the 2000s, and improving catches in 2008-2013 (Fig. 31). Incidental commercial harvest of Cisco during the current reporting period was consistent with the improved status of Cisco indicated by agency surveys. The average commercial harvest of Cisco in Ontario waters of the eastern basin and the Bay of Quinte from 2008-2013 (1,300 lbs) was 2.2 times greater than the average annual harvest from 2003-2007 (Fig. 31).

Fig. 31. Density of Cisco in New York waters of Lake Ontario as determined via bottom trawling conducted by the U.S. Geological Survey and New York State Department of Environmental Conservation (USGS/DEC) during April-October, 1978-2013. Each year, about 250 tows (range: 179-311) of mostly 10-min duration were made at depths of 8-180 m (Weidel et al. 2014). Commercial harvest refers to Cisco taken in the Ontario waters of the eastern basin and in the Bay of Quinte, 1993-2013 (OMNR 2014). MNRF gillnetting is a two-year moving average of Cisco catch-per-unit effort (CPUE) in gillnets set overnight by the Ontario Ministry of Natural Resources and Forestry (OMNRF) at six sites near shore and three sites offshore in Ontario waters of the eastern basin during 1992-2013 (OMNR 2014). Averages are plotted on the first year of each two-year period, and the CPUE for 2013 is for that year only.



Cisco spawning success also improved during the current reporting period. Bottom trawling near the outlet of the Bay of Quinte, the only index of Cisco spawning success for Lake Ontario, indicated a 2-fold increase in YOY with catches averaging 6.6 fish per trawl tow during 2008-2013 compared with 3.3 fish per trawl tow during 2003-2007 (Fig. 32).

Fig. 32. Catch-per-unit effort (CPUE) of young-of-the-year (YOY) Cisco with a ¾ Western (Poly) bottom trawl towed for ¼ mile in the Bay of Quinte during 1972-2013 (OMNR 2014); 8-12 tows were made each year.



Progress and Outlook

For this reporting period (2008-2013), the status/trend indicator for prey fish in the offshore pelagic zone, which specifies increased or maintained populations and increased diversity, was positive (population maintained or increased) for Alewife, Rainbow Smelt, and Cisco; negative (population declined) for Threespine Stickleback and Emerald Shiner; and, equivocal for community diversity. Diversity was maintained, albeit at the low level seen since declining midway through the previous reporting period (2003-2007) (Weidel and Connerton 2014). Generally, prey-fish diversity in the offshore pelagic zone has declined over the past 30 years because of the increasing dominance of Alewife and declining numbers of Cisco, Rainbow Smelt, Emerald Shiner, and Threespine Stickleback (Weidel and Connerton 2014). Alewife predation on larvae is likely an important mechanism controlling pelagic prey-fish populations (Madenjian et al. 2008). Maintaining sufficient numbers of Alewife to support a quality Chinook Salmon fishery may limit increased prey-fish diversity in Lake Ontario.

The Alewife population, aside from being maintained in this reporting period, was improved by four successive moderate to strong year-classes produced in 2009-2012. Also, adult Alewife remained in good condition. This leaves the population in a relatively strong state with an increasing spawning stock going into the next reporting period. Persistence of the Alewife population within the range of recent years will continue to depend on periodic production of strong year-classes. Persistence would be jeopardized if low adult numbers coincide with repeated weak year-classes due to cool summers and/or cold winters. Evaluating predator-prey balance requires monitoring not only predator growth and condition but also Alewife abundance and condition as well as patterns in Alewife year-class strength.

Although Cisco status improved in this reporting period compared to the previous reporting period, populations are still mainly restricted to the eastern basin and its embayments. Given that remnant spawning stocks are small and isolated, restoration stocking is likely necessary for expansion of Cisco to its historical distribution (Fitzsimons and O'Gorman 2004). To this end, research to develop Cisco culture techniques, to determine Cisco spawning habitat requirements, and to restore Cisco spawning areas were initiated during this reporting period. In New York, culturing of Cisco eggs collected from Chaumont Bay by the DEC began at the USGS's Tunison Laboratory of Aquatic Sciences, and, in 2012-2013, the resulting fall fingerlings were stocked (9,000 per year) into Irondequoit Bay, an embayment that historically had a Cisco spawning run (Stone 1938). The Nature Conservancy partnered with the USGS, DEC, and Cornell University to locate, characterize, and quantify Cisco spawning habitat in Chaumont Bay. They are also verifying the presence/absence of spawning Cisco in south-shore embayments where the fish spawned historically and are under consideration for stocking by the USGS and DEC. The U.S. Fish and Wildlife Service and Cornell University have also mapped Cisco spawning areas in Chaumont Bay with side-scan sonar and will use these data to determine the extent of suitable spawning habitat in south-shore embayments where Cisco spawned historically. In Ontario, multi-agency efforts are underway in Hamilton Harbour to restore Cisco spawning shoals at two locations, and an Area of Concern delisting target for oxygen was established based on Cisco habitat requirements. Re-establishing Cisco in those areas where they historically spawned will require ongoing research and the development of assessment programs to index spawning abundance in embayments.

Predator-Prey Balance

> *Maintain predator/prey balance—maintain abundance of top predators (stocked and wild) in balance with available prey fish.*

Chinook Salmon grew faster and were in better condition during this reporting period (2008-2013) than in the benchmark year of 2007 (Fig. 28). Abundance of Alewife, the main prey of all salmon and trout (Lantry 2001), was adequate for maintaining predator-prey balance during the current reporting period despite adult abundance falling to a record low in 2010 (see above). A 42% shortfall in Chinook Salmon stocking in 2008 may well have contributed to maintaining predator-prey balance during the period of low adult Alewife abundance (Figs. 26, 29). Condition of adult Alewife, however, was high during 2008-2013, which reduced the number needed to fuel predator growth (Rand et al. 1994), and moderate to strong year-classes were produced in 2009-2012, providing substantial numbers of subadult Alewife for predators.

Progress and Outlook

The status/trend indicator for the FCO of predator-prey balance—maintaining average growth and condition of Chinook Salmon at or above 2007 levels—was met during this reporting period (2008-2013). Chinook Salmon condition was higher and growth faster than in 2007 and this occurred while the Alewife population expanded after a record low and while adult Alewife remained in good condition. Numbers of Chinook Salmon in Lake Ontario were adequate to maintain a trophy Chinook Salmon fishery with high catch rates. The status of Chinook Salmon and Alewife at the end of the current reporting period appear favorable for maintaining predator-prey balance in the next reporting period. Nonetheless, continued monitoring of Chinook Salmon growth and condition is needed to forewarn of ecosystem changes causing predator-prey imbalance as has happened in Lakes Huron and Michigan (Riley et al. 2008; Claramunt et al. 2012).

Rainbow Trout

Maintain Rainbow Trout (steelhead) fisheries—maintain fisheries through stocking and, where appropriate, enhance naturally produced populations supporting recreational lake and tributary fisheries for Rainbow Trout.

Stocking

The number of Rainbow Trout stocked per year during the current reporting period (2008-2013) averaged 964,000, 17% more than during the previous reporting period (2003-2007) (Fig. 26). Most of the increase was due to the stocking of surplus hatchery production in New York waters (Connerton 2014), including 317,000 yearlings in 2010-2011, 268,000 fall fingerlings in 2009-2010, and 337,000 fall fingerlings in 2012. Although Rainbow Trout is usually stocked as spring yearlings, some fall fingerlings were stocked during this reporting period because of a glut of fingerlings at the SRH for three years due to good egg and fry survival, lack of fry culling, and minimum mortality from disease. In Ontario, the OMNRF also augmented routine stocking with surplus hatchery production; on average, about 40,000 additional Rainbow Trout yearlings were released each year in the current reporting period.

Catch Rates

In the open lake and in tributaries, Rainbow Trout catch rates during the 2008-2013 reporting period exceeded those in the 2003-2007 reporting period. In the lake, the average catch rate during 2008-2013 was nearly 2-fold higher in New York waters and nearly 3-fold higher in Ontario waters, compared to the respective average rates during 2003-2007 (Fig. 27; Lantry and Eckert 2014; OMNR 2014). In the tributaries, three fall to spring angler surveys were conducted in New York during 2003-2013—two during the previous reporting period (2005-2006 and 2006-2007) and one during the current reporting period (2011-2012) (Prindle and Bishop 2013). During 2011-2012, Rainbow Trout catch rates at each of the three major eastern tributaries (Salmon, Black, and Oswego Rivers) were more than 2-fold higher than in 2005-2006 and 2006-2007 (Prindle and Bishop 2013). At two major western tributaries (Oak Orchard and Eighteen Mile Creeks), however, catch rates during 2011-2012 were 23% lower than in 2005-2006 and 12% lower than in 2006-2007.

Population Size, Recruitment, and Growth

The number of Rainbow Trout returning to the fishway in the Ganaraska River, Ontario, a north-shore river that hosts a self-sustaining population of Rainbow Trout and is not stocked, increased during this reporting period and was, on average, 54% higher than during the previous reporting period. However, fishway counts in the previous reporting period were the lowest since the 1970s (OMNR 2014). Self-sustaining populations of Rainbow Trout exist as well in other north-shore tributaries east of Toronto, an area where Rainbow Trout is not stocked.

Recruitment of naturally produced Rainbow Trout was not evaluated in the heavily stocked Salmon River, New York. Nonetheless, wild fish are certainly being produced in the river as evidenced by the presence of YOY Rainbow Trout, a life stage younger than that routinely stocked (D. Bishop, New York State DEC, personal communication, 2014). Wild production from all Lake Ontario's tributaries made up 18-33% of the in-lake population from 1979 to 1995 (Rand et al. 1993; Bowlby and Stanfield 2001).

Weight of age-3 female Rainbow Trout returning to the SRH trended upward through the 2008-2013 reporting period, although the six-year average of 2,762 g (6.1 lbs) was essentially identical to the five-year average of 2,754 g (6.1 lbs) in the 2003-2007 reporting period (Prindle and Bishop 2014). In contrast, weight of age-3 males was about 10% lower in the current reporting period. At the Ganaraska River fishway, condition of returning female and male Rainbow Trout, as indexed by the predicted weight of 635-mm (25-inch) fish, also trended upward during 2008-2013, and average conditions differed <1% from those in 2003-2007. Similarly, in New York waters, condition of Rainbow Trout (predicted weight of a 660-mm (26-inch) fish) in the open-lake fishery during 2008-2013 differed a mere 3% from condition during 2003-2007 (Lantry and Eckert 2014).

Progress and Outlook

For the Rainbow Trout FCO, the status/trend indicator of maintaining or increasing catch rates was met in the open lake during this reporting period as catch rates rose 2- to 3-fold. In the tributaries, any change in catch rates is conjectural due to a scarcity of data—only one fall through spring angler survey was completed in the tributaries during this reporting period, and it only covered New York tributaries. The sharply higher in-lake catch rate for Rainbow Trout was likely due, in part, to an increase in the numbers of Rainbow Trout in Lake Ontario. Increasing returns to the Ganaraska River fishway met another status/trend indicator for this FCO—maintaining or increasing returns to the Ganaraska River.

Despite the seeming increase in size of the population, growth and condition of Rainbow Trout in this reporting period were essentially unchanged from the previous reporting period in both the lake and rivers meeting the status/trend indicator of maintaining growth of adult Rainbow Trout. We do not know to what extent the apparent increase in the Rainbow Trout population may be attributed to a rise in stocking, survival, or wild reproduction. Stocking increased during the current reporting period but not enough to account for a 2- to 3-fold increase in angler catch rates in the lake. The increase in minimum harvestable length from 457 mm (18 inch) to 533 mm (21 inch) in New York in 2006 may have contributed to increased catch rates through higher survival. In addition, the daily harvest limit was reduced from 3 fish to 1 fish in New York tributaries in 2004. The number of Rainbow Trout returning to the fishway in the Ganaraska River (never stocked) increased during this reporting period, indicating an uptick in production of wild fish in that tributary. However, whether similar increases in production of wild fish occurred in other tributaries is not known. The outlook for Rainbow Trout is positive for the next reporting period for as long as Alewife numbers continue to be adequate for sustaining growth and for as long as stocking is maintained at or near planned levels.

Brown Trout and Coho Salmon

Maintain Brown Trout and Coho Salmon fisheries—maintain the recreational lake and tributary fisheries for Brown Trout and Coho Salmon through stocking.

Stocking

Numbers of Brown Trout stocked in Lake Ontario each year averaged 639,000 in this reporting period (2008-2013), 5% above the yearly average in the previous reporting period (2003-2007) (Fig. 26). Coho Salmon stocking during this reporting period ranged from 140,000 to 370,000 fish per year, and, overall, the average number stocked each year declined by about 25% from the previous reporting period. The falloff in hatchery production of Coho Salmon was due to a lack of females at Ontario's egg collection site on the Credit River in 2009, 2010, and 2012 and to poor fertilization rates of eggs at New York's SRH in 2008 and 2012. Low rates of egg fertilization were possibly due to elevated water temperatures during egg take, changes in hatchery practices, or poor condition of the fish, but the exact cause(s) is unknown.

Catch Rates

Brown Trout catch rates in New York waters of Lake Ontario during the 2008-2013 reporting period increased 14% compared to the 2003-2007 reporting period (Fig. 27; Lantry and Eckert 2014). In Ontario waters, angler success in the Brown Trout fishery is not well documented because the angler survey typically begins after the fishery directed at Brown Trout occurs. Thus, the Ontario angler survey shows low and highly variable catch rates for Brown Trout through the entire time series (Connerton et al. 2014b; OMNR 2014). In the tributaries, limited data from New York show no consistent change in Brown Trout catch rates in the two most-recent reporting periods. Comparing catch rates in 2011-2012 to those in 2005-2006 and 2006-2007, the change ranged from a 479% increase in the Oswego River to an 83% decrease in Eighteen Mile Creek (Prindle and Bishop 2013). There are no data on catch rates from Ontario tributaries during the current reporting period.

Coho Salmon catch rates in New York waters of the lake during 2008-2013 averaged 14% lower than in the previous reporting period (Fig. 27; Lantry and Eckert 2014). Even though catch rates during 2010 and 2009 were the 3rd and 4th highest on record, the average for the current reporting period was lower than in the previous reporting period because the first- and second-highest catch rates of the 29-year survey occurred in 2003-2007 (Fig.17; Lantry and Eckert 2014). Ontario anglers experienced record-high catch rates of Coho Salmon in 2011-2013, and the average catch rate for the current reporting period was 373% higher than during 2003-2007 (OMNR 2014). In New York tributaries, the Coho Salmon fishery occurs primarily during the fall in the Salmon River, and the catch rate there in 2011 was more than 3.2 and 1.3 times higher than in 2005 and 2006, respectively (Prindle and Bishop 2013).

Progress and Outlook

The status/trend indicator for the Brown Trout and Coho Salmon FCO—maintaining or increasing catch rates in the lake and tributaries—was positive for this reporting period. In New York, Brown Trout catch rates increased in the lake and in some tributaries, while Brown Trout catch rates in Ontario waters of the lake were unreliable due to survey timing. As for Coho Salmon, catch rates in the lake during 2008-2013 were high in Ontario and New York.

Natural reproduction of Brown Trout and Coho Salmon occurs in tributaries to Lake Ontario, but it is unknown to what extent the naturally produced fish contribute to lake and tributary fisheries. For both species, the lake fishery is dominated by age-2 fish, and their abundance appears heavily dependent on the numbers stocked (Lantry and Eckert 2014). Many factors influence hatchery production and post-release survival of stocked fish, thereby making it difficult to predict the future status of Brown Trout and Coho Salmon fisheries. Still, the agencies continue to work on assessing and enhancing these fisheries. The OMNRF is considering changing where Brown Trout is stocked, shifting locations and concentrating stocking into fewer areas to support high-potential shoreline and tributary fisheries. The agency also plans to conduct a creel survey on Ontario tributaries to the lake in 2014-2015 to assess fishing quality and other aspects of the fisheries there. The DEC is currently studying the factors leading to low fertilization rates of Coho Salmon eggs at the SRH. The agency also plans a tagging study to compare the returns of Coho Salmon stocked as fall fingerlings with those stocked as spring yearlings.

DEEP PELAGIC AND OFFSHORE BENTHIC FISH COMMUNITY[11]

Brian F. Lantry[12], Jana R. Lantry, Brian C. Weidel, Maureen G. Walsh, James A. Hoyle, Jeremy Holden, Kevin Tallon, Michael J. Connerton, and James H. Johnson

Lake Ontario's offshore zone, as defined by Stewart et al. (2013), is that area of the main lake where the water depth is ≥15 m with the benthic zone therein being the lake bottom and water near bottom. The deep pelagic is the water above the benthic zone but below the thermocline in summer. Today's fish community in the deep pelagic and offshore benthic zone comprises Lake Trout, Lake Whitefish, Round Whitefish, Burbot, Slimy Sculpin, Deepwater Sculpin, Sea Lamprey, Rainbow Smelt, and, from fall through early spring, Alewife and Round Goby (Table 1). Of these 10 fish, Sea Lamprey, Rainbow Smelt, Alewife, and Round Goby are not native to Lake Ontario. Historically, native Lake Trout and Burbot were the major

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[11]Complete publication including map of place names, other chapters, scientific fish names, and references is available at http://www.glfc.org/pubs/SpecialPubs/Sp17_02.pdf.

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piscivores; deepwater ciscoes (Bloater, Kiyi, and Shortnose Cisco) were the dominant native planktivore; and Lake Whitefish, Round Whitefish, Deepwater Sculpin, and Slimy Sculpin were the dominant native benthivores. By the 1950s, Lake Trout was extirpated and Burbot numbers were greatly reduced (Christie 1973; Elrod et al. 1995). By the 1960s, Deepwater Sculpin was considered extirpated (Mills et al. 2003; Owens et al. 2003), deepwater ciscoes were scarce (Wells 1969), and Lake Whitefish was common only in the eastern basin (Hoyle et al. 2003; Owens et al. 2003). By the 1970s, deepwater ciscoes were extirpated or nearly so, and, of the nine native fish that once flourished in the offshore benthic zone, only one, Slimy Sculpin, remained abundant (Owens et al. 2003).

Deepwater Sculpin began to recover in the late 1990s (Lantry et al. 2007), and efforts to restore other native fish to the deep pelagic and offshore benthic zone are now focused on Lake Trout and deepwater ciscoes. The international restoration effort for Lake Trout began in the early 1970s and has been ongoing ever since (Elrod et al. 1995; Lantry and Lantry 2014). Similar efforts to restore deepwater ciscoes began in the 2000s. Lake Trout restoration was initially guided by a published plan formally adopted by the Lake Ontario Committee (LOC) (Schneider et al. 1983) and later by an unpublished revision of that plan, A Management Strategy for Lake Ontario Lake Trout (Schneider, C., Schaner, T., Orsatti, S., Lary, S., and Busch, D. 1997). The revised plan was recognized by the LOC in March 1998 (Stewart et al. 1999; Lantry et al. 2014a) and hereafter is referred to as the 1998 Lake Trout Management Plan (LTMP). A restoration strategy for deepwater cisco is currently being reviewed by the LOC.

Self-sustaining populations of Lake Whitefish, Round Whitefish, Burbot, Deepwater Sculpin, and Slimy Sculpin currently exist in the deep pelagic and offshore benthic zone of Lake Ontario, but the size of most are below historical norms. Stocked Lake Trout is present, but its reproductive output is insufficient to sustain a population, and the once-abundant deepwater ciscoes are gone. Hence, the goal for the deep pelagic and offshore benthic zone is (Stewart et al. 2013):

Protect and restore the diversity of the offshore benthic fish community composed of a mix of self-sustaining native species including Lake Trout, Burbot, Lake Whitefish, Round Whitefish, deepwater ciscoes, Slimy Sculpin, and Deepwater Sculpin.

Re-establishing flourishing populations of native fish, however, is hampered by the direct and indirect effects of non-native species–Sea Lamprey kill Lake Trout and Burbot (Schneider et al. 1996; Stapanian et al. 2008); Alewife impairs the reproductive success of Lake Trout that eat it (Fitzsimons et. al. 2003) and also preys on the fry of Lake Trout (Krueger et al. 1995) and, most likely, Burbot, and Deepwater Sculpin (Madenjian et al. 2008); dreissenids are linked to the near disappearance of one of the two important invertebrates eaten by fish in the offshore benthic zone, *Diporeia* spp. (Watkins et al. 2007); Rainbow Smelt, circumstantial evidence suggests, eat larval Lake Whitefish (Casselman and Scott 1992; Casselman et al. 1996); and, more recently, the proliferation of Round Goby was followed by a decline in numbers of Slimy Sculpin, suggesting that the newest invasive fish suppresses sculpin (see below). Despite the numerous impediments, some progress was made towards the goal of protecting and restoring the fish community in the deep pelagic and offshore benthic zone during the 2008-2013 reporting period. We report herein on progress since the 2003-2007 reporting period as well as on setbacks using, as our metric, the fish community objective's (FCO) status/trend indicators that are given in the Progress and Outlook sections below (Stewart et al. 2013). Specific objectives are in italics at the start of each major section.

Lake Trout

Restore Lake Trout populations—restore self-sustaining populations to function as the top deepwater predator that can support sustainable recreational fisheries.

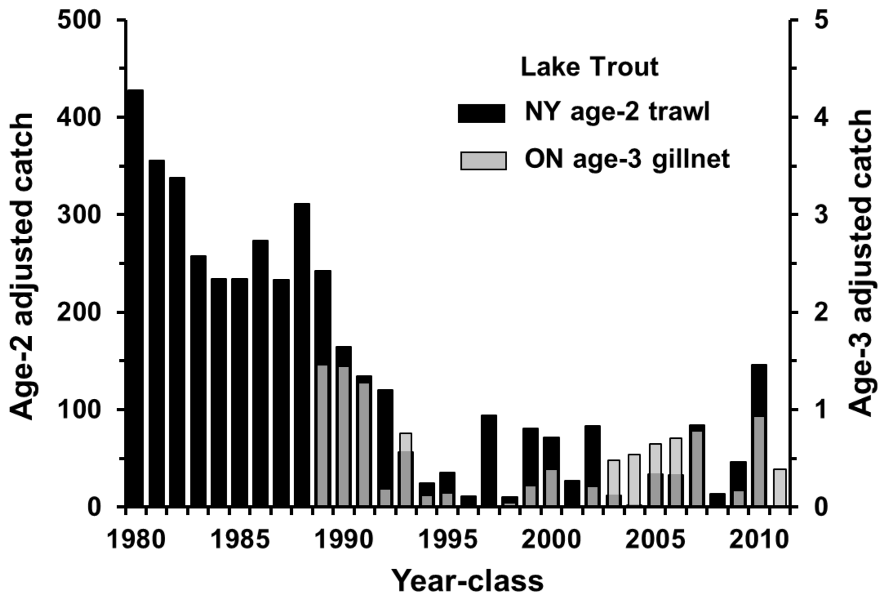
Stocked Lake Trout

During the current reporting period (2008-2013), annual stocking of yearling Lake Trout in Ontario waters averaged 464,000. In New York waters, no yearling Lake Trout were stocked in 2012 and annual releases of yearlings in the other five years of the reporting period averaged 471,000. Fall fingerling Lake Trout was also stocked during the current reporting period, an average of 123,000 each year in 2010 and 2012 in New York, and 104,000 in 2012 in Ontario. In the previous reporting period (2003-2007), no fall fingerlings were stocked, and annual releases of yearlings averaged 446,000 in Ontario and 350,000 in New York. In 1993, fishery managers reduced the number of yearling Lake Trout stocked each year from 2 million to 1 million equally divided between New York and Ontario following recommendations from an international panel of scientists who reviewed predator-prey balance in Lake Ontario and after an extensive public review (Fig. 26; Elrod et al. 1995; Rudstam 1996; Lantry et al. 2014a).

During the current reporting period, stocking of yearling Lake Trout in New York was reduced in 2010 due to a moratorium on the transport of fish eggs into Vermont to the U.S. Fish and Wildlife Service's (FWS) White River National Fish Hatchery (WRH) and was eliminated in 2012 due to concerns about spreading the invasive freshwater diatom *Didymosphenia geminata* (didymo or rock snot) following flooding of the WRH during Hurricane Irene in fall 2011 (Connerton 2014). Lake Trout stocked in New York waters is reared in national fish hatcheries by the FWS. During the previous reporting period, infrastructure problems and the outbreak of disease at the FWS Alleghany National Fish Hatchery reduced stocking in 2005 and 2006, respectively.

In the first four years of the current reporting period, survival of yearling Lake Trout stocked in New York waters (2006-2009 year-classes) was low, <25% of index values prior to 1992, and similar to that in the previous reporting period (Fig. 33). In the fifth year of the current reporting period, however, survival was more than double the average survival in the first four years of the reporting period, and the survival index rose to 49% of that in 1982-1991, the initial years of large-scale stocking, when survival was quite high (Figs. 16, 23). For the sixth and final year of the current reporting period (2013), no survival index could be calculated because no yearling Lake Trout was stocked in 2012. The relative survival of each stocked year-class of yearling Lake Trout in New York waters is determined one year after release based on the number of yearlings stocked and the number of age-2 Lake Trout from the stocked year-class caught in bottom trawls during a standard assessment conducted in July/August (Lantry and Lantry 2014). The index of survival is calculated as the catch of age-2 Lake Trout adjusted to a stocking level of 500,000 spring yearlings.

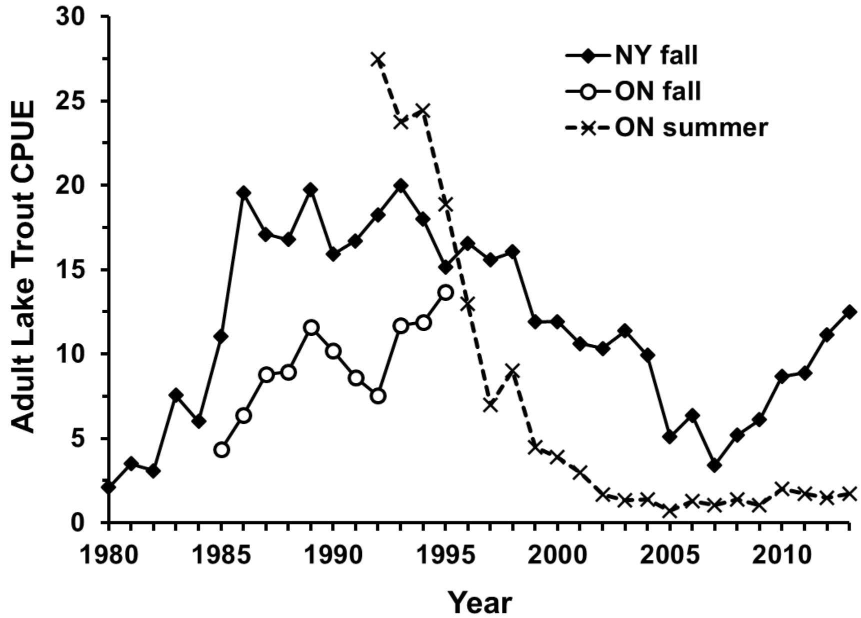
Fig. 33. First-year survival of the 1980-2011 year-classes of Lake Trout stocked as yearlings in Lake Ontario during 1981-2012. Survival is indexed in New York (NY) waters as the total catch of age-2 fish in July/August bottom trawling per 500,000 yearlings stocked one year earlier in New York and is 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 500,000 yearlings stocked two years earlier in the same area. Lake Trout in the 2011 year-class was not stocked in New York waters in 2012, and no data exist for Lake Trout of the 1996, 1997, and 2001 year-classes stocked in Ontario waters.



During the current reporting period, survival of yearling Lake Trout stocked in eastern Ontario waters, as determined from the number of age-3 fish caught in gillnets during a midsummer assessment, was highly variable (Fig. 33). The 2008 year-class had the lowest survival in the entire time series (0 age-3 fish caught), which began in 1990, whereas the 2007 and 2010 year-classes survived better than most of the year-classes stocked since 1992. Overall, average survival of stocked yearlings during the current reporting period was similar to the average for the time series and similar to that in the previous reporting period.

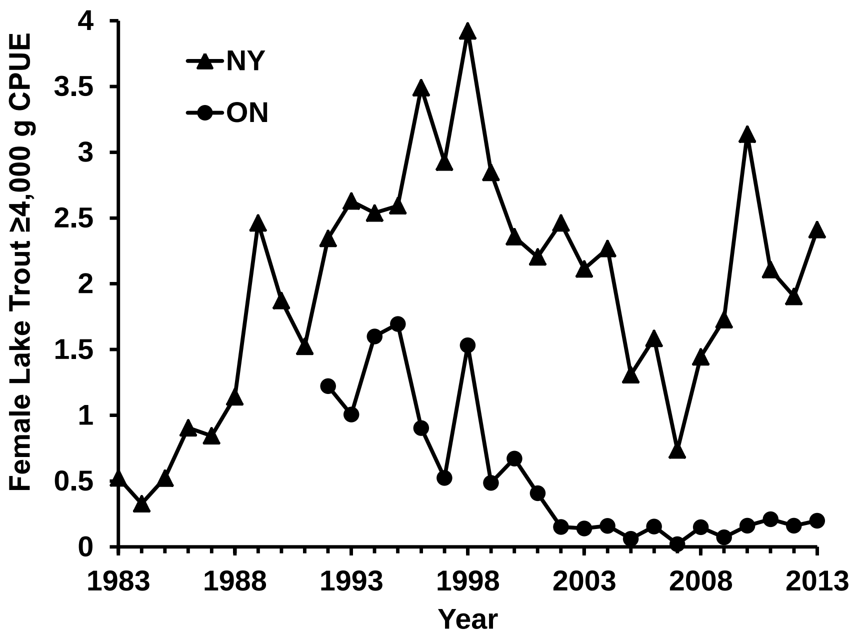
During the current reporting period (2008-2013), abundance of adult Lake Trout in New York waters of Lake Ontario increased each year, and, in 2013, it was more than double that of the low levels reached in the final years of the previous reporting period (2003-2007) (Fig. 34). Abundance in the current reporting period trended higher in Ontario waters as well, but there the upward movement was less pronounced. In New York waters, abundance had bottomed out between 2005 and 2007 following a period of relative stability between 1999 and 2004. Falling abundance of adult Lake Trout was associated with increased Sea Lamprey predation and declines in survival of stocked yearling Lake Trout during 1991-1997 (Lantry and Lantry 2014). Predation due to Sea Lamprey was again brought under control by 2008 and remained under control during the remainder of the current reporting period (see below) while recruitment of fish to the adult population remained relatively unchanged—survival of stocked yearlings has, with few exceptions, been low since 1995, and there was no great flux in numbers of yearlings stocked prior to 2008 (Figs. 16, 23). Thus, enhanced Sea Lamprey control appears responsible for the swift increase in abundance of adult Lake Trout in New York waters during 2008-2013 and its return to levels similar to those during 1999-2004. On both sides of the lake, however, adult Lake Trout was not as abundant in 2013 as it was prior to the 1993 halving of stocking (Fig. 34) and the post-1991 decline in survival of stocked yearlings (Fig. 33).

Fig. 34. Catch-per-unit effort (CPUE) of adult Lake Trout in graded-mesh gillnets set overnight in Lake Ontario during 1980-2013. Fall CPUEs are for all New York (NY) waters and all Ontario (ON) waters whereas the summer CPUE is for eastern Ontario waters only.



The catch-per-unit effort (CPUE) of mature female Lake Trout in New York waters, which had declined below the management target of 2.0 during the previous reporting period (Lantry et al. 2014a), recovered during 2010-2013 to levels near or above the target (Fig. 35). In Ontario waters, the CPUE for mature females has been below the target of 1.1 since 1999, although it consistently increased during the current reporting period (Fig. 35). The 1998 LTMP established targets of 2.0 and 1.1 for the CPUE of mature female Lake Trout ≥4000 g during annual gillnet surveys in New York and Ontario waters. The targets were set at 0.75% of the CPUE of age-7 and older females during 1992-1994. Spawning in those years produced the first widespread occurrence of "natural" fish beyond the fry stage in annual assessments (O'Gorman et al. 1998; Owens et al. 2003).

Fig. 35. Catch-per-unit effort (CPUE) of mature female Lake Trout ≥4,000 g in graded-mesh gillnets set overnight in Lake Ontario during September in New York (NY) waters and during summer in Ontario (ON) waters, 1983-2013.



Catch/Harvest Rates of Lake Trout

During the 2008-2013 reporting period, angler catch and harvest rates for Lake Trout in New York waters increased from the low and relatively stable rates during the 2003-2007 reporting period (Fig. 27; Lantry and Eckert 2014). Although Lake Trout catch rates (fish•angler hr^{-1} on charter boats) during 2008-2010 (range: 0.010-0.020) remained similar to the low catch rates during 2003-2007 (range: 0.006-0.019), they rose sharply thereafter, to 0.029 in 2011-2012, and, by 2013, the final year of the current reporting period, the catch rate was 0.064, the highest catch rate since 2002. Lake Trout harvest rates increased each year during the current reporting period, rising from 0.007 in 2008 to 0.048 in 2013, and were mostly well above the 0.004-0.011 harvest rates in the previous reporting period. The 2013 harvest rate was higher than in any year since 1991. Accelerating Lake Trout catch rates in the later years of the current reporting period were likely due to the increasing numbers of Lake Trout in New York waters (Fig. 34). A sharp rise of the Lake Trout harvest rate in 2013 may simply have been due to the large numbers of fish in the recovering population that were legally available for harvest because of a 2006 regulation change. From October 1992 to October 2006, anglers could harvest three Lake Trout per day, but none of the harvested fish could be 635- to 762-mm (25- to 30-inch) long. In October 2006, the regulation changed, reducing the daily harvest limit to two Lake Trout and permitting one to be within the 635- to 762-mm slot.

In Ontario, angler surveys were conducted during the current reporting period in 2008, 2011, 2012, and 2013 in the western basin of the lake (OMNR 2014). For Lake Trout, the mean catch rate (fish•angler hr^{-1}) increased to 0.0142 in the current reporting period from 0.0045 in the previous reporting period (2003, 2004, and 2005 surveys). Although the Lake Trout catch rate fell below 0.003 fish per angler hour in 2008, a record low, it increased in each of the subsequent survey years, reaching 0.027 fish•angler hr^{-1} in 2013 (Fig. 27). Harvest remained relatively low, however, due to a high release rate. In 2013, >96% of Lake Trout caught were released.

The lakewide harvest of Lake Trout during the current reporting period was maintained at the target of <30,000 fish per jurisdiction established in the 1998 LTMP. The number of Lake Trout harvested by New York anglers during 2008-2013 averaged 8,100, ranging from 2,900 in 2008 to 21,000 in 2013. For comparison, the total harvest of Lake Trout by anglers in Ontario waters averaged 450 fish per year in the western basin of Lake Ontario during the current reporting period. Harvest of Lake Trout in all Ontario waters is about 3.5 times that in the western basin (Brenden et al. 2011), which suggests that the total harvest of Lake Trout in Ontario averaged 1,600 fish per year during 2008-2013.

During the current reporting period, Ontario commercial fisheries reported an average yearly bycatch of 3,317 kg of Lake Trout and an average release rate of 79% of the fish caught. Although, currently no quota exists for the commercial harvest of Lake Trout in Ontario waters of Lake Ontario, some commercial fisheries (primarily the gillnet fishery) do capture Lake Trout and are required to report them as bycatch. Based on the mean weight of Lake Trout caught in the Ontario Ministry of Natural Resources and Forestry's (OMNRF) gillnet survey, the annual bycatch in the commercial fishery is about 1,200 fish. In New York waters, the small commercial fishery does not target Lake Trout and is not permitted to harvest Lake Trout as bycatch (LaPan 2014).

Wild Lake Trout

For wild Lake Trout in New York waters, annual abundance targets in the 1998 LTMP—26 age-2 fish caught with bottom trawls in July surveys and a CPUE of 2.0 mature female fish >4,000 g caught with gillnets in September surveys (Lantry et al. 2014a)—were not met during the current or the previous reporting period. During 2008-2013, the numbers of young wild Lake Trout caught in bottom trawls during July/August surveys of New York waters remained low (≤2 age-1 and ≤3 age-2 fish per year) and similar to those for the 2003-2007 reporting period (≤1 age-1 and ≤4 age-2 fish per year). No wild young-of-the-year (YOY) Lake Trout were caught during July/August in either reporting period. The catch of mature wild females in New York waters also remained low with the September gillnet CPUE of all unclipped female Lake Trout ≥4,000 g ranging from 0.04 to 0.08 for 2008-2013 and from 0.02 to 0.14 for 2003-2007. Although there is no target for catches of wild Lake Trout in Ontario waters, it is encouraging that wild YOY Lake Trout were captured during the current reporting period in the eastern basin—1 in 2010, 2 in 2012, and 11 in 2013 (OMNR 2014).

Progress and Outlook

The stocked-population status/trend indicator of progress, increasing abundance of stocked Lake Trout, was clearly met for adult Lake Trout during the 2008-2013 reporting period—CPUEs of adults increased in both New York and Ontario—but whether it was met for juveniles is uncertain. The absence of yearling stocking in New York in 2012 reduced juvenile Lake Trout numbers, although this may have been offset somewhat by the relatively high survival of yearlings stocked there in 2011. Although fall fingerlings were stocked by New York and Ontario, they gave but a small boost to juvenile numbers because survival of those stocked as fingerlings was far lower than for those stocked as yearlings (BFL, U.S. Geological Survey (USGS), unpublished data). The outlook is for a leveling off of stocked Lake Trout abundance over the next five years as long as the Sea Lamprey population is suppressed to at or below the target level (see below).

Although the status/trend indicator for angler catch and harvest rates in the FCOs does not specify targets, the 1998 LTMP target of <30,000 Lake Trout harvested in each jurisdiction (Lantry et al. 2014a; OMNR 2014) was met during 2008-2013. Angler catch and harvest rates are increasing, but, because anglers prefer to target other salmonids (Lantry and Eckert 2014; OMNR 2014) and because many of the Lake Trout caught by anglers are released alive, particularly in Ontario, we suspect that the management target will also be met during 2014-2018.

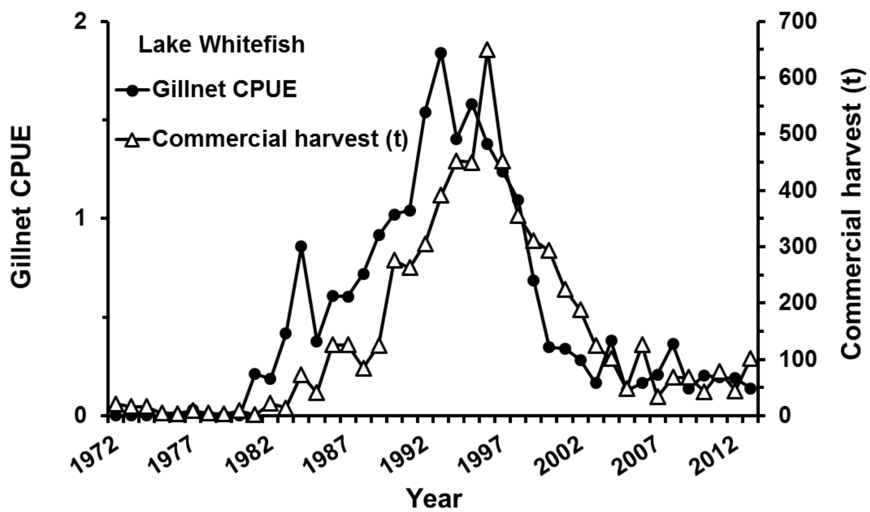
The status/trend indicator for wild Lake Trout, increasing populations across a range of age-groups sufficient to maintain self-sustaining populations, was not met during 2008-2013. Low catches of naturally produced juveniles persisted, and wild adults made up a small fraction of assessment catches. Wild YOY Lake Trout are being caught in Ontario waters of the eastern basin but only in small numbers. Clearly there are not enough wild fish in Lake Ontario to sustain a population. The recovery of the adult population of stocked Lake Trout during the current reporting period, however, has doubled the number of mature females, which should enhance natural reproduction during the next reporting period. Even so, 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 overcoming the impediment to reproduction associated with a diet dominated by Alewife, a fish with a high amount of thiaminase (Elrod et al. 1995; Fitzsimons et al. 2003; Lantry et al. 2014a). The outlook for overcoming the thiaminase impediment over the next five years looks encouraging, however, because of the recent addition of Round Goby to Lake Ontario's prey-fish community (Weidel et al. 2014). Round Goby is low in thiaminase and is being eaten by Lake Trout, which may increase the thiamine levels of female Lake Trout sufficiently to boost in-lake reproduction (Dietrich et al. 2006; Rush et al. 2012). Experience with lake trout from Lakes Huron and Superior, however, suggests that native prey may be necessary to achieve the goal of a self-sustaining Lake Trout population. Thus, the ongoing recovery of native Deepwater Sculpin (see below), the rebuilding of native Cisco populations (see Offshore Pelagic Fish Community chapter in the full report), and the reintroduction of deepwater ciscoes (see below) should provide greater opportunities for healthy prey alternatives for Lake Ontario's Lake Trout and improve the potential for natural reproduction.

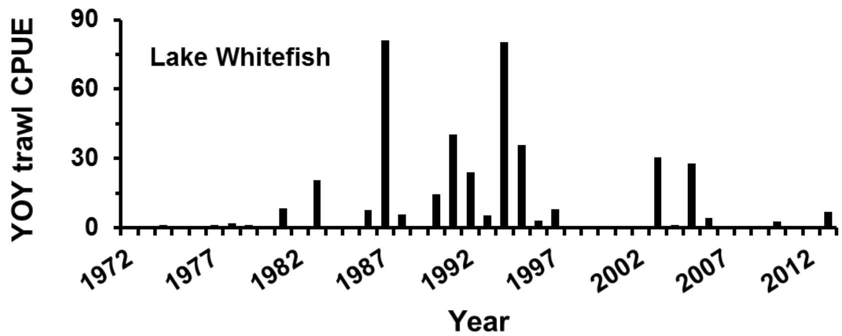
Lake Whitefish

> *Increase Lake Whitefish abundance—increase abundance in northeastern waters and re-establish historic spawning populations in other areas.*

In Ontario waters of eastern Lake Ontario, Lake Whitefish CPUE in index gillnets was stable during 2008-2013 and similar to that in the preceding 2003-2007 reporting period as a result of two relatively strong year-classes produced in 2003 and 2005 (Fig. 36). Size of Lake Whitefish year-classes produced during 2008-2013, as measured in the Bay of Quinte and eastern Ontario waters, declined 85% from that in 2003-2008. Commercial harvest of Lake Whitefish in Ontario waters declined by 22% from the previous to the current reporting period (Fig. 36). Comparing the number of age-classes present in the two reporting periods, the number in index gillnets remained at 11 whereas, in the commercial harvest, the number rose from 17 to 22. The large number of year-classes speaks both to the remarkable size and longevity of Lake Whitefish year-classes produced in the late 1980s and early 1990s as well as to the continued production of year-classes in subsequent years, albeit at a much-reduced level.

Fig. 36. Catch-per-unit effort (CPUE) of (top panel) subadult and adult Lake Whitefish in graded-mesh gillnets set in Ontario waters of eastern Lake Ontario during 1972-2013 by the Ontario Ministry of Natural Resources and Forestry (OMNRF) 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 1972-2013 by the OMNRF. Also shown (top panel) is the commercial harvest (t = metric tonnes) of Lake Whitefish in Ontario waters of Lake Ontario during 1972-2013.





Progress and Outlook

The status/trend indicator for Lake Whitefish, increasing spawning populations in the Bay of Quinte and eastern Lake Ontario, was not met during 2008-2013. Lake Whitefish abundance and commercial harvest have been stable at a low level since 2003. Production of detectable numbers of YOY has been sporadic since 2005. Lake Whitefish has been profoundly affected by the disruption to the benthic invertebrate community, which coincided with the invasion of dreissenid mussels and, in particular, with the subsequent loss of *Diporeia* spp., a mainstay of Lake Whitefish diet (Hoyle 2015). With no indication that *Diporeia* spp. populations can recover (Watkins et al., 2007), the outlook for an increase in Lake Whitefish abundance is poor.

Prey Fish

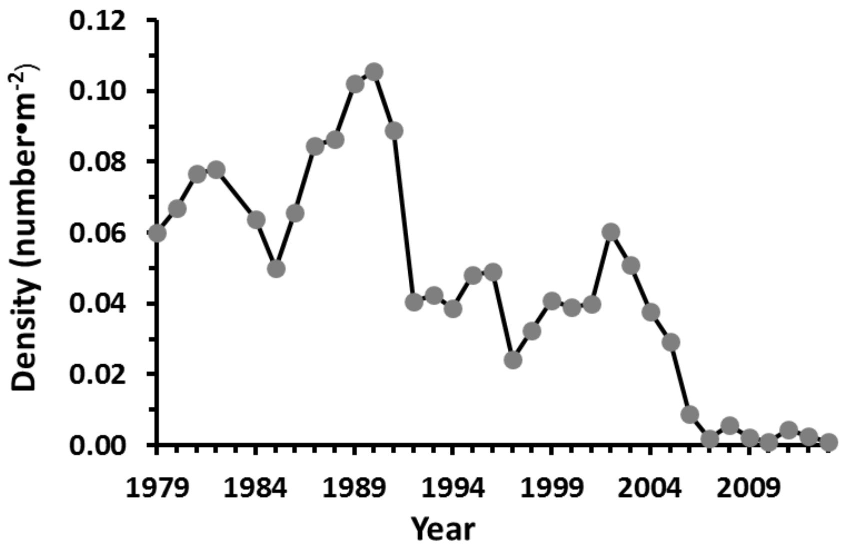
Increase prey-fish diversity—maintain and restore a diverse prey-fish community that includes deepwater ciscoes, Slimy Sculpin, and Deepwater Sculpin.

Slimy Sculpin

In the current reporting period, Slimy Sculpin abundance in southern Lake Ontario was stable, but, since the previous reporting period, the population has declined (Fig. 37). Over the entire period of record, 1979-2013, Slimy Sculpin abundance has decreased by two orders of magnitude, with sharp declines in 1990-1992 and 2002-2007. The abundance decline in 1990-1992 was attributed to the establishment of dreissenids and to the subsequent reduction of the fish's preferred food, *Diporeia* spp. (Owens and Dittman 2003). The abundance decline in 2002-2007 occurred at the same time Round Goby was proliferating, suggesting a causal link. Bottom-trawl catches show that Slimy Sculpin and Round Goby distributions overlap in late fall and in early spring, strongly suggesting that the distributions also overlap during the intervening winter months, providing a seven-month window for competition and predation (Weidel et al. 2014). Moreover, large Round Goby has been shown to eat fish in the offshore benthic zone (Walsh et al. 2007). Although Slimy Sculpin has declined in southern Lake Ontario since observations began in the late 1970s, its density over the 2008-2013 reporting period (range: 0.01-0.04 $g \bullet m^{-2}$) was similar to that in Lake Michigan (range: 0.01-0.1 $g \bullet m^{-2}$) (Madenjian et al. 2014).

Slimy Sculpin once dominated the benthic prey-fish community of southern Lake Ontario (Wells 1969). Currently, Slimy Sculpin is the second most-abundant benthic prey fish, behind Round Goby, in the offshore zone from late fall through early spring. Important drivers of Slimy Sculpin population dynamics in Lake Ontario likely include: nutrient loading and primary production declines (Holeck et al. 2013; Flint 1986), Round Goby predation and competition (Bergstrom and Mensinger 2009), Lake Trout predation (Owens and Bergstedt 1994), and near loss of the sculpin's historically dominant prey, *Diporeia* spp. (Lozano et al. 2001).

Fig. 37. Slimy Sculpin density (number•m^{-2}) in southern Lake Ontario as assessed from area swept with bottom trawls towed at 8-175 m by the U.S. Geological Survey during fall, 1979-2013 (Weidel et al. 2014). No trawling was conducted in 1983.



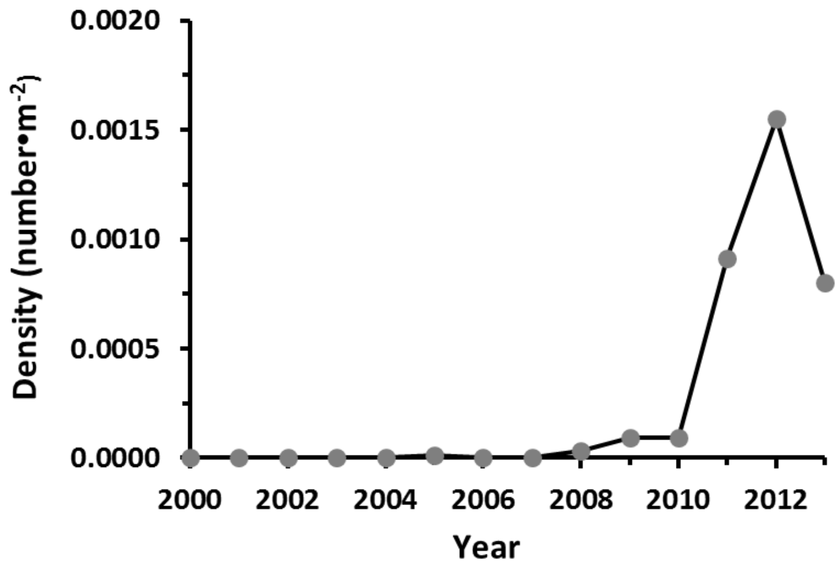
Progress and Outlook

The lack of a directional change in Slimy Sculpin density from 2008-2013 shows that the status/trend indicator of maintaining the Slimy Sculpin population was met during the current reporting period. Density from 2008-2013 was, however, much lower than in the first three years of the previous reporting period so, across the 11-year span of the two reporting periods, the status/trend indicator was not met. Given the reduced trophic state of Lake Ontario, the scarcity of energy-rich *Diporeia* spp. prey and the competition and predation from abundant Round Goby, Slimy Sculpin density is likely to remain at the level in the current reporting period or possibly decline further.

Deepwater Sculpin

Deepwater Sculpin density in southern Lake Ontario has increased from that in the 2003-2007 reporting period (Fig. 38). This native benthic prey fish was described as abundant in the lake during the early 1900s (Christie 1973) but was absent or rare in bottom-trawl catches in New York waters from 1979 through 2005 (Lantry et al. 2007). Lantry et al. (2007) and others have proposed that the recent resurgence of Deepwater Sculpin may have resulted from reduced predation on its pelagic larvae by the depressed Alewife population in the 2000s. Juvenile and adult Deepwater Sculpin inhabit the deepest regions of the lake bottom and are rarely found shallower than 50 m. This species has been described as an "indicator of well-being" of the deep-water ecosystem" (http://www.registrelep-sararegistry.gc.ca/species/speciesDetails_e.cfm?sid=76).

Fig. 38. Deepwater Sculpin density (number•m^{-2}) in southern Lake Ontario as assessed by area swept with bottom trawls towed at 8-175 m by the U.S. Geological Survey during fall, 2000-2013 (Weidel et al. 2014).



Progress and Outlook

The increase in Deepwater Sculpin density during 2008-2013 met the status/trend indicator of increasing populations. Moreover, the resurgence of Deepwater Sculpin has increased prey-fish diversity, an important FCO for the offshore benthic zone. The decline in Deepwater Sculpin density in 2013 suggests that this population may have reached its maximum density given the current trophic status of Lake Ontario. There is potential for the population to decline if Deepwater Sculpin becomes an important prey of the rebounding Lake Trout population.

Deepwater Ciscoes

A first of its kind reintroduction of deepwater ciscoes, absent from Lake Ontario since the 1960s, began in Lake Ontario during the current (2008-2013) reporting period. Efforts to reintroduce deepwater ciscoes during the previous 2003-2007 reporting period 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, and developing culture methods for producing fish for stocking (Dietrich et al. 2007). A collaboration between the FWS, New York State Department of Environmental Conservation, USGS, OMNRF, and the Great Lakes Fishery Commission advanced reintroduction efforts during 2008-2013 with the winter collection of Bloater eggs from Lake Michigan and the experimental rearing of these eggs at the USGS's Tunison Lab in Cortland, New York, and at the OMNRF's White Lake Fish Hatchery in Sharbot Lake, Ontario. A significant milestone was achieved in the final years of the current reporting period when some of the hatchery-reared Bloater were stocked in Lake Ontario. In 2012, some 8,500 fall fingerlings (≈101 mm, total length (TL)) were stocked by boat offshore of Oswego, New York, and, in 2013, some 15,200 yearlings (≈146 mm, TL) were stocked by boat offshore of Long Point, Prince Edward County, Ontario. In addition, the OMNRF is currently holding Bloater from several year-classes in an attempt to establish a captive brood stock.

Progress and Outlook

Although the 2008-2013 reporting period was too early to expect deepwater ciscoes in agency assessment catches, the status/trend indicator of progress, the successful rearing and stocking of substantial numbers of Bloater during 2012-2013, represents significant progress towards meeting one of the offshore benthic zone's FCOs—increasing prey-fish diversity. Completion of the Deepwater Cisco Management Plan, improvement of egg collection, and Bloater culture research are all needed to ensure the success of deepwater cisco restoration in Lake Ontario. Successful releases of nearly 24,000 Bloater during 2012-2013 have substantially enhanced the outlook for meeting the status/trend indicator of detection of deepwater ciscoes, even though any caught during the next reporting period are likely to be of stocked, and not wild, origin. In the future, production of Bloater for stocking will likely accelerate because of planned experiments with different techniques for egg collection from Lake Michigan (bottom trawling instead of gillnetting), egg collection from fish in the hatchery (brood-stock development and hormone-induced spawning), and fish culture in the hatchery (feeding and temperature control).

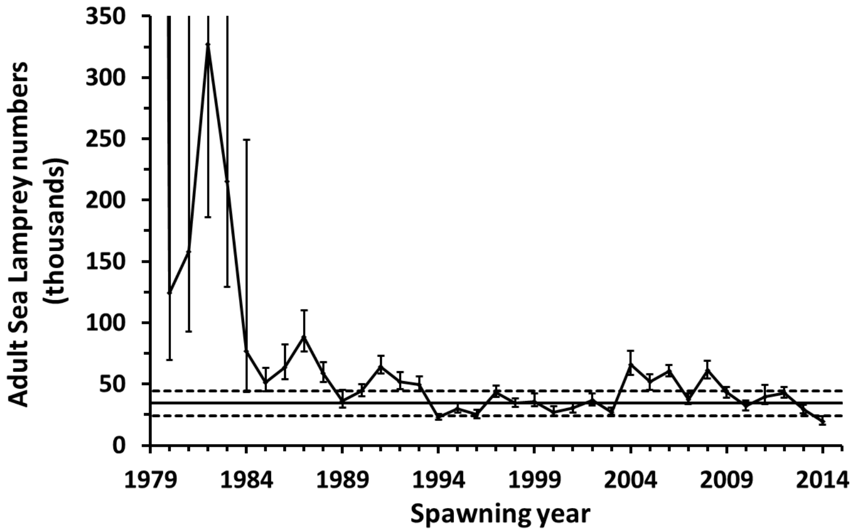
Sea Lamprey

Control Sea Lamprey—suppress abundance of Sea Lamprey to levels that will not impede achievement of objectives for Lake Trout and other fish.

Spawning-Phase Sea Lamprey

During the current reporting period, the average number of spawning Sea Lamprey in Lake Ontario (41,200) was 15% lower than in the previous reporting period (48,600). In addition, there was a clear downward trend in Sea Lamprey numbers during 2008-2013, with the 2013 lakewide estimate of 29,300 animals at the lower end of the target range of 34,200 ± 10,000 identified in the Sea Lamprey Management Plan (Fig. 39; Neave 2012). Although the cause of elevated numbers of spawning Sea Lamprey during 2004-2008 is unknown, it may have been due, in whole or in part, to increasing production from the Moira and Trent Rivers in Ontario, or from Sandy Creek in New York, a new Sea Lamprey producing stream identified in 2007. Improved suppression of adult Sea Lamprey during 2008-2013 may have been due to conducting treatments in the early spring, when lamprey larvae are most susceptible to lampricide, rather than later in the season, and to continuing efforts to identify and treat (when required) new lamprey-producing tributaries.

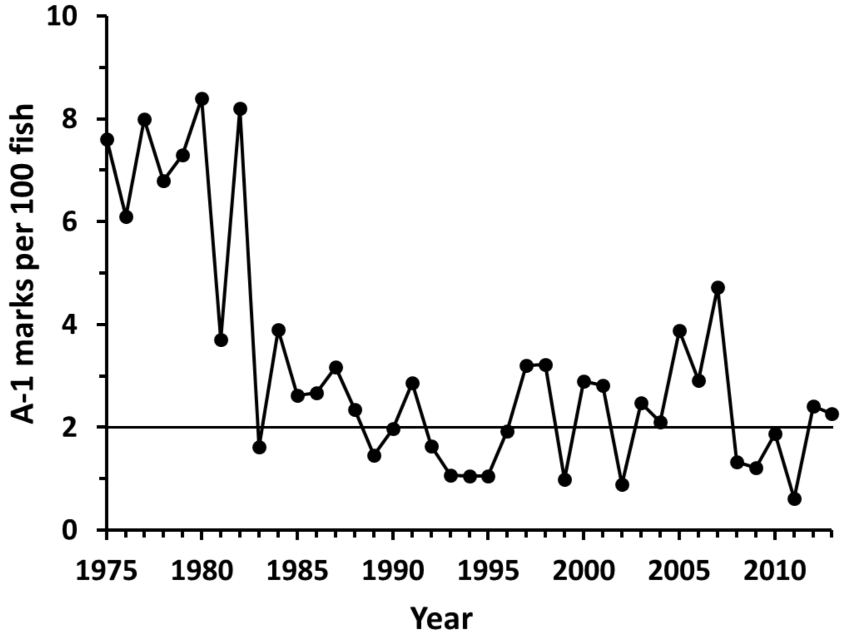
Fig. 39. Number (±95% CI) of adult Sea Lamprey spawning in tributaries to Lake Ontario, 1980-2014. Population estimates were generated by a dynamic model described in Mullet et al. (2003). The horizontal line shows the updated target of 34,200 ± 10,000 for adult Sea Lamprey.



A-I Marks on Lake Trout

Lake Trout marking largely met the target during the current reporting period with the rate of Type A, Stage I (Ebener et al. 2006) marking on Lake Trout narrowly exceeding the target ceiling of 2.0 per 100 fish (Lantry et al. 2014c) twice, at the target ceiling once, and below the ceiling thrice. In contrast, during 2003-2007, marking exceeded the target ceiling in four of the five years (Fig. 40).

Fig. 40. Frequency of Type A, Stage I (A-I; Ebener et al. 2006) marks on Lake Trout >432 mm in Lake Ontario during 1975-2013. Sea Lamprey spawns one year after marking Lake Trout. The horizontal line shows the target ceiling of 2.0 marks per 100 Lake Trout >432 mm (Lantry et al. 2014c).



Progress and Outlook

The status/trend indicator for Sea Lamprey was met during 2008-2013, spawning-phase adults were held within the target range (±1.0 CI), and their numbers were lower than in the previous reporting period. With the discovery and treatment of substantial new populations in tributaries and the adjustment of treatment schedules to spring, the outlook for the next reporting period is for continued suppression of adult Sea Lamprey to target levels or below.

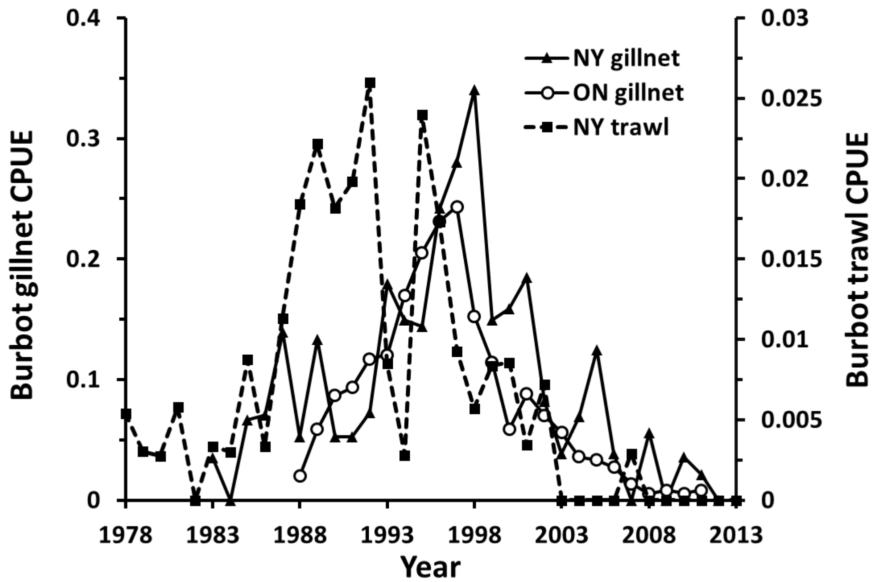
The status/trend indicator for A-I marking rates on Lake Trout was also met during 2008-2013; marking rates were below target in half of the years and were markedly lower than in the previous reporting period. Sea Lamprey control in Lake Ontario has been relatively consistent, and, overall, the Sea

Lamprey population has been maintained at reduced levels since 1985. No future reduction in Sea Lamprey control for Lake Ontario is expected because suppressing Sea Lamprey numbers to the target level remains a priority. With the recovery of adult Lake Trout abundance to early 2000s levels providing more hosts for Sea Lamprey (see above) and the suppression of Sea Lamprey to target numbers, the outlook for the next reporting period is for maintenance of the target marking rate.

Burbot

Although there is no specific Lake Ontario FCO for Burbot, its status is important to reaching the overarching goal for the offshore benthic zone of "protecting and restoring the zone's fish community to achieve a mix of self-sustaining native species." Assessment catches of Burbot during 2008-2013 were lower than in the previous reporting period, approaching zero in New York and Ontario waters (Fig. 41). Increases in Burbot abundance in the 1980s were attributed to reduced numbers of Sea Lamprey, buffering from Sea Lamprey predation by Lake Trout, and an easing of Alewife predation on pelagic Burbot larvae (Stapanian et al. 2008). Subsequent declines in Burbot abundance in the late 1990s corresponded to declines in Lake Trout abundance, suggesting that predation by Sea Lamprey on Burbot increased as the number of alternative hosts declined. The outlook for Burbot remains uncertain but should be improving during the next five years because of a relaxation in predation by Sea Lamprey due to enhanced lamprey control and to a larger Lake Trout population providing more alternative hosts for lamprey, both of which favor Burbot recruitment.

Fig. 41. Catch-per-unit effort (CPUE) of Burbot with bottom trawls and gillnets, Lake Ontario, 1978-2013. 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.



PROGRESS ON LAKE ONTARIO: A FISHERY MANAGEMENT PERSPECTIVE[13]

Steven R. LaPan[14] and Andy Todd

Fish community objectives (FCOs) for Lake Ontario published in 2013 (Stewart et al. 2013) describe the fundamental dilemma of managing for a diverse trout and salmon fishery while also trying to restore native species. The recreational fisheries for introduced trout and salmon are largely supported by invasive Alewife (Table 1) while native species are to varying degrees negatively impacted by Alewife. In addition, the ongoing combined impacts of invasive species, reduced nutrient levels, and climate change have impacted lakewide productivity, energy flow, and food-web dynamics, which pose major challenges to attaining the FCOs. Despite these challenges, Lake Ontario's fish communities and fisheries have been remarkably resilient and generally performed well during this reporting period. As the agency representatives of the Lake Ontario Committee (LOC), we herein offer our general perspective regarding progress toward attaining our FCOs during 2008-2013. We note that population and fishery trends by species can vary greatly by lake region, often confounding our ability to draw definitive conclusions regarding trends.

Nearshore FCOs were generally met during the reporting period. Of the noteworthy exceptions, continued poor recruitment of American Eel to the St. Lawrence River/Lake Ontario system (system) remains a significant concern, however, management and ecosystem issues outside the Great

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[13]Complete publication including map of place names, other chapters, scientific fish names, and references is available at http://www.glfc.org/pubs/SpecialPubs/Sp17_02.pdf.

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Lakes basin are thought to be important drivers affecting overall population recovery. An ongoing, binational research initiative is underway directed at reducing hydroelectric turbine mortality of outmigrating silver eels. This research is currently focusing on the development of technologies that can guide downstream migrating eels into collection devices, allowing captured eels to be transported and released below the Beauharnois Dam in Quebec (lowermost hydroelectric dam in the system).

Of the species exhibiting “mixed” performance, both Yellow Perch and Smallmouth Bass abundance declined in the Bay of Quinte, and Smallmouth Bass declined along the south shore of New York. Although Yellow Perch abundance is expected to increase in the near future, the same cannot be said for Smallmouth Bass. Factors affecting Smallmouth Bass recruitment, including increased growth rates and maturation schedules, are poorly understood and should be investigated further. Even though evidence of progress toward Lake Sturgeon population restoration during the reporting period was limited, gillnet catches of Lake Sturgeon of a variety of sizes and at numerous locations indicate natural recruitment and improved population status.

The FCOs for Chinook Salmon, Rainbow Trout, Brown Trout, and Coho Salmon were met during the reporting period. Catch rates for Chinook Salmon, Rainbow Trout, Brown Trout, and Coho Salmon were relatively high and, in some cases, at or near record levels. Progress toward restoring Atlantic Salmon in several tributaries was mixed; however, significant benchmarks, including documentation of natural reproduction and increased angler catches, were achieved providing optimism for the future.

Diversity in the pelagic prey-fish community remains relatively static and low, and, excepting Threespine Stickleback and Emerald Shiner, abundance of Alewife, Rainbow Smelt, and Cisco was either maintained or increased. Increased Cisco catches are encouraging, and efforts to restore spawning stocks at historical spawning sites will hopefully expand the present eastern basin range of Cisco into the main lake basin.

Based on Chinook Salmon growth and condition and indices of Alewife abundance and body condition, Lake Ontario's Alewife population appears to be in balance with predator demand. Also, the production of several successive moderate to strong Alewife year-classes should increase the adult spawning population in the near term. Preliminary research results suggest that, on average, approximately 50% of Chinook Salmon harvested from Lake Ontario are of "wild" origin. As has been the case on Lakes Huron and Michigan, the presence of substantial natural reproduction of Chinook Salmon in Lake Ontario may present future challenges in meeting the FCO that seeks maintenance of predator-prey balance.

The adult Lake Trout population increased during the reporting period; however, the primary indicator for Lake Trout restoration, increasing populations of wild lake trout across a range of age-groups sufficient to maintain self-sustaining populations, was not met. In New York waters, the abundance of mature females rose to levels not seen since the late 1990s, which should lead to increased natural reproduction in future years. The LOC remains committed to continuing efforts to restore self-sustaining Lake Trout populations in Lake Ontario.

Lake Whitefish abundance remains relatively stable at lower levels, and, given ongoing disruption in the lower food web (e.g., the dramatic population decline in *Diporeia* spp.), the prospects for meeting this FCO are challenging. Increased abundance of Deepwater Sculpin effectively increased diversity of the benthic prey-fish community; nevertheless, this was coincident with stable but lower numbers of Slimy Sculpin. Important advances in Bloater culture during the reporting period will greatly enhance the LOC's ongoing, highly collaborative effort to reintroduce this species to Lake Ontario. Lake Ontario continues to benefit from the most-effective Sea Lamprey control program in the Great Lakes, and the LOC expresses its sincere gratitude to the Great Lakes Fishery Commission, Fisheries and Oceans Canada, and the U.S. Fish and Wildlife Service for their ongoing commitment to further reduce Sea Lamprey populations.

After a thorough review of the state of Lake Ontario in 2014, we are cautiously optimistic that this system is stabilizing at an oligotrophic state conducive to maintenance of existing fisheries and to rehabilitation of depressed species, such as Lake Sturgeon, Cisco, and Bloater. This report in its entirety is reflective of the collaborative programs that underpin lakewide fishery management. We are truly grateful for this dedicated effort. No one can predict the future, and Lake Ontario cannot be tamed. Our goal simply is to follow its trajectory and to implement those measures with public input that reflect a scientific consensus aimed at avoiding the fishery losses of the past.

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LITERATURE CITED

Adkinson, A.C., and Morrison, B.J. [EDS.]. 2014. The state of Lake Ontario in 2008 [online]. Available from http://www.glfc.org/pubs/SpecialPubs/Sp14_01.pdf [accessed 09 September 2017].

Auer, M.T., Tomlinson, L.M., Higgins, S.N., Malkin, S.Y., Howell, E.T., and Bootsma, H.A. 2010. Great Lakes *Cladophora* in the 21st century: same algae—different ecosystem. J. Great Lakes Res. **36**: 248-255.

Barbiero, R.P., and Tuchman, M.L. 2004. The deep chlorophyll maximum in Lake Superior. J. Great Lakes Res. **30**: 256-268.

Barbiero, R.P., Lesht, B.M., and Warren, G.J. 2011. Evidence for bottom-up control of recent shifts in the pelagic food web of Lake Huron. J. Great Lakes Res. **37**: 78-85.

Barbiero, R.P., Lesht, B.M., and Warren, G.J. 2012. Convergence of trophic state and the lower food web in Lakes Huron, Michigan and Superior. J. Great Lakes Res. **38**: 368-380.

Barbiero, R.P., Lesht, B.M., and Warren, G.J. 2014. Recent changes in the crustacean zooplankton community of Lake Ontario. J. Great Lakes Res. **40**: 898-910.

Bergstrom, M.A., and Mensinger, A.F. 2009. Interspecific resource competition between the invasive Round Goby and three native species: Logperch, Slimy Sculpin, and Spoonhead Sculpin. Trans. Am. Fish. Soc. **138**: 1009-1017.

Biesinger, Z., Gorsky, D., Jacobs, G.R., Sweka, J.A., Webb, M.A.H., and Talbott, M. 2014. Population assessment of Lake Sturgeon in the lower Niagara River. *In* 2013 annual report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to the Great Lakes Fishery Commission's Lake Ontario Committee. Section 25. NY State Dept. Environ. Conserv., Cape Vincent, NY.

Birkett, K., Lozano, S., and Rudstam, L.G. 2015. Long-term trends in Lake Ontario's benthic macroinvertebrate community from 1994-2008. Aquat. Ecosyst. Health Manage. **18**: 76-85.

Bishop, D.L., and Penney-Sabia, M.E. 2005. 2004 Salmon River creel survey. *In* 2004 annual report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to the Great Lakes Fishery Commission's Lake Ontario Committee. Section 10. NY State Dept. Environ. Conserv., Cape Vincent, NY.

Bishop, D.L., Prindle, S.E., and Johnson, J.H. 2014. 2013 Salmon River wild young-of-year Chinook Salmon seining program. *In* 2013 annual report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to the Great Lakes Fishery Commission's Lake Ontario Committee. Section 8. NY State Dept. Environ. Conserv., Cape Vincent, NY.

Boscarino, B.T., Rudstam, L.G., Eillenberger, J.J., and O'Gorman, R. 2009. Importance of light, temperature, zooplankton and fish in predicting the nighttime vertical distribution of *Mysis diluviana* [online]. Available from http://www.int-res.com/articles/ab2009/5/b005p263.pdf [accessed 09 September February 2017].

Boscarino, B.T., Rudstam, L.G., Tirabassi, J., Janssen, J., and Loew, E.R. 2010. Light effects on alewife-mysid interactions in Lake Ontario: a combined sensory physiology, behavioral, and spatial approach [online]. Available from https://www.researchgate.net/publication/250392928_Light_effects_on_alewife-mysid_interactions_in_Lake_Ontario_A_combined_sensory_physiology_behavioral_and_spatial_approach [accessed 09 September 2017].

Bowlby, J.N., and Stanfield, L.W. 2001. Exploitation of wild rainbow trout populations in Wilmot Creek and the Ganaraska River. *In* Lake Ontario fish communities and fisheries: 2000 annual report of the Lake Ontario Management Unit, pp. 10.1-10.6. Ont. Min. Nat. Resour., Picton, ON, Canada.

Bowlby, J.N., Hoyle, J.A., Lantry, J.R., and Morrison, B.J. 2010. The status of walleye in Lake Ontario 1988-2006. *In* Status of walleye in the Great Lakes: proceedings of the 2006 symposium. *Edited by* E. Roseman, P. Kocovsky, and C. Vandergoot [online]. Available from http://www.glfc.org/pubs/TechReports/Tr69.pdf [accessed 09 September 2017].

Brandt, S.B. 1986. Food of salmon and trout in Lake Ontario. J. Great Lakes Res. **12**: 200-205.

Brenden, T.O., Bence, J.R., Lantry, B.F., Lantry, J.R., and Schaner, T. 2011. Population dynamics of Lake Ontario lake trout during 1985-2007. N. Am. J. Fish. Manage. **31**: 962-979.

Bunnell, D.B., Barbiero, R.P., Ludsin, S.A., Madenjian, C.P., Warren, G.J., Dolan, D.M., Brenden, T.O., Briland, R., Gorman, O.T., He, J.X., Johengen, T.H., Lantry, B.F., Lesht, B.M., Nalepa, T.F., Riley, S.C., Riseng, C.M., Treska, T.J., Tsehaye, I., Walsh, M.G., Warner, D.M., and Weidel, B.C. 2014. Changing ecosystem dynamics in the Laurentian Great Lakes: bottom-up and top-down regulation [online]. Available from http://bioscience.oxfordjournals.org/content/64/1/26.full [accessed 09 September 2017].

Carlson, R.E. 1977. A trophic state index for lakes. Limnol. Oceanogr. 22: 361-369. Available from http://aslo.net/lo/toc/vol_22/issue_2/0361.pdf [accessed 09 September 2017].

Casselman, J.M. 2002. Effects of temperature, global extremes, and climate change on year-class production of warmwater, coolwater, and coldwater fishes in the Great Lakes basin. *In* Fisheries in a changing climate. *Edited by* N.A. McGinn. Am. Fish. Soc. Symp. **32**: 39-59.

Casselman, J.M., and Scott, K.A. 1992. Fish community dynamics of the outlet basin of Lake Ontario. *In* Lake Ontario fisheries unit, 1991 annual report. Section 18. Ont. Min. Nat. Resour., Picton, ON, Canada.

Casselman, J.N., and Scott, K.A. 2003. Fish-community dynamics of Lake Ontario: long-term trends in fish populations of eastern Lake Ontario and the Bay of Quinte. *In* State of Lake Ontario: past, present and future. *Edited by* M. Munawar. Ecovision World Monograph Series, Aquatic Ecosystem Health and Management Society, Backhuys Publishers, Leiden, The Netherlands. pp. 349-384.

Casselman, J.M., and Marcogliese, L.A. 2014. Wild and stocked eel abundance in the upper St. Lawrence River and eastern Lake Ontario–index quantitative electrofishing, 2013. Conducted for Ontario Ministry of Natural Resources, Lake Ontario Management Unit, 41 Hatchery Lane, Picton, ON, Canada. 24 p.

Casselman, J.M., Brown, D.M., and Hoyle, J.A. 1996. Resurgence of lake whitefish, *Coregonus clupeaformis*, in Lake Ontario in the 1980s [online]. Available from http://www.esf.edu/glrc/documents/glrr96.pdf [accessed 09 September 2017].

Chalupnicki, M.A., Dittman, D.E., and Carlson, D.M. 2011. Distribution of Lake Sturgeon in New York: 11 Years of Restoration Management. Am. Midl. Nat. **165**: 364-371.

Christie, W.J. 1973. A review of the changes in the fish species composition of Lake Ontario [online]. Available from http://www.glfc.org/pubs/TechReports/Tr23.pdf [accessed 09 September 2017].

Christie, W.J. 1974. Changes in the fish species composition of the Great Lakes. J. Fish. Res. Board Can. **31**: 827-854.

Christie, W.J., Hurley, D.A, and Nepszy, S.J. 1989. Canadian fish stock survey during IFYGL (Section 11.A, pp. 185-208). *In* Status of the IFYGL biota of Lake Ontario during International Field Year for the Great Lakes, 1972-1973. *Edited by* N.A. Thomas, W.J. Christie, and S.A. Gannon. Available from http://www.glfc.org/pubs/misc/Status_of_IFYGL_biota_Lake_Ontario_72-73.pdf [accessed 09 September 2017].

Claramunt, R.M., Madenjian, C.P., and Clapp, D.F. 2012. Pacific salmonines in the Great Lakes basin. *In* Great Lakes fisheries policy and management: a binational perspective, 2nd edition. *Edited by* W.W. Taylor, A.J. Lynch, and N.J. Leonard. Mich. State Univ. Press, East Lansing, MI. pp. 609-650.

Connerton, M.J. 2014. New York Lake Ontario stocking program 2013. *In* 2013 annual report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to the Great Lakes Fishery Commission's Lake Ontario Committee. Section 1. NY State Dept. Environ. Conserv., Cape Vincent, NY.

Connerton, M.J., Holden, J., and Schaner, T. 2014a. Acoustic assessment of pelagic planktivores, 2013. *In* 2013 annual report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to the Great Lakes Fishery Commission's Lake Ontario Committee. Section 24. NY State Dept. Environ. Conserv., Cape Vincent, NY.

Connerton, M.J., Lantry, J.R., Walsh, M.G., Daniels, M.E., Hoyle, J.A., Bowlby, J.N., Johnson, J.H., Bishop, D.L., and Schaner, T. 2014b. Offshore pelagic fish community. *In* The state of Lake Ontario in 2008. *Edited by* A.C. Adkinson and B.J. Morrison [online]. Available from http://www.glfc.org/pubs/SpecialPubs/Sp14_01.pdf [accessed 09 September 2017].

Connerton, M.J., Balk, C.J., Prindle, S.E., Lantry, J.R., Daniels, M.E., Bowlby, J.N., Bronte, C.R., and Holey, M.E. 2014c. 2013 mass marking of Chinook Salmon in Lake Ontario. *In* 2013 annual report, Bureau of Fisheries Lake Ontario Unit and St Lawrence River Unit to the Great Lakes Fisheries Commission's Lake Ontario Committee. Section 3. NY State Dept. Environ. Conserv., Cape Vincent, NY.

Couillard, C.M., Verreault, G., Dumont, P., Stanley D., and Threader, R.W. 2014. Assessment of fat reserves adequacy in the first migrant silver American Eels of a large-scale stocking experiment. N. Am. J. Fish. Manage. **34**: 802-813.

Crane, D.P., Farrell, J.M., Einhouse, D.W., Lantry, J.R., and Markham, J.L. 2015. Trends in body condition of native piscivores following invasion of Lakes Erie and Ontario by the round goby. Freshwater Biol. **60**: 111-124.

Dermott, R.M. 2001. Sudden disappearance of the amphipod *Diporeia* from eastern Lake Ontario, 1993-1995. J. Great Lakes Res. **27**: 423-433.

Dietrich, J.P., Morrison, B.J., and Hoyle, J.A. 2006. Alternative ecological pathways in the Eastern Lake Ontario food web—Round Goby in the diet of lake trout. J. Great Lakes Res. **32**: 395-400.

Dietrich, J.P, Morrison, B.J., Ebener, M.P., Honeyfield, D.C., Noyes, A.D., Wright, G.M., and LaPan, S.R. 2007. Identifying potential impediments to the development of a restoration program for deepwater ciscoes. Gt. Lakes Fish. Comm. Proj. Compl. Rep. Ann Arbor, MI.

Dillon, P.J., and Rigler, F.H. 1974. The phosphorus-chlorophyll relationship in lakes [online]. Available from http://onlinelibrary.wiley.com/doi/10.4319/lo.1974.19.5.0767/abstract [accessed 09 September 2017].

Dittman, D.E., and Zollweg, E. 2006. Assessment of habitat use by experimentally stocked juvenile lake sturgeon. Final report submitted to U.S. EPA Great Lakes National Program Office by USGS Tunison Lab. Aquat. Sci., Cortland, NY. Interagency agreements DW-14-947993-01-0 & DW-14-947991-01-0 [online]. Available from http://www.fws.gov/midwest/sturgeon/documents/ddittman-genesee_sturgeon_03-05_final.pdf [accessed 09 September 2017].

Dolan, D.M., and Chapra, S.C. 2012. Great Lakes total phosphorus revisited: 1. Loading analysis and update (1994-2008). J. Great Lakes Res. **38**: 730-740.

Dove, A. 2009. Long-term trends in major ions and nutrients in Lake Ontario. Aquat. Ecosys. Health Manage. **12**: 281–295.

Dove, A., and Chapra, S.C. 2015. Long-term trends of nutrients and trophic response variables for the Great Lakes. Limnol. Oceanogr. **60**: 696-721.

Dunlop, E.S., and Riley, S.C. 2013. The contribution of cold winter temperatures to the 2003 alewife population collapse in Lake Huron. J. Great Lakes Res. **39**: 682-689.

Ebener, M.P., King, Jr., E.L., Edsall, T.A. 2006. Application of a dichotomous key to the classification of sea lamprey marks on Great Lakes fish [online]. Available from http://www.glfc.org/pubs/misc/2006-02.pdf [accessed 11 October 2017].

Eckert, T.H. 2002. Lake Ontario fishing boat census 2001. *In* 2001 annual report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to the Great Lakes Fishery Commission’s Lake Ontario Committee. Section 2. NY State Dept. Environ. Conserv., Cape Vincent, NY.

Elrod, J.H., O’Gorman, R., Schneider, C.P., Eckert, T.H., Schaner, T., Bowlby, J.N., and Schleen, L.P. 1995. Lake trout rehabilitation in Lake Ontario. J. Great Lakes Res. **21**(Suppl.1): 83-107.

Faisal, M., and Winters, A.D. 2011. Detection of viral hemorrhagic septicemia virus (VHSV) from *Diporeia* spp. (Pontoporeiidae, Amphipoda) in the Laurentian Great Lakes, USA [online]. Available from http://parasitesandvectors.biomedcentral.com/articles/10.1186/1756-3305-4-2 [accessed 09 September 2017].

Fave, M.J., and Turgeon, J. 2008. Patterns of genetic diversity in Great Lakes bloaters (*Coregonus hoyi*) with a view to future reintroduction in Lake Ontario. Conserv. Genet. **9**: 281-293.

Fitzsimons, J., and O'Gorman, R. 2004. Status and assessment, research, and restoration needs for lake herring in the Great Lakes. [online]. Available from http://www.glfc.org/pubs/pdfs/research/reports/Fitzsimons_Lakeherring.pdf [accessed 09 September 2017].

Fitzsimons, J., Lantry, B.F., and O'Gorman, R. 2003. A review of lake trout (*Salvelinus namaycush*) restoration in Lake Ontario from an early life history perspective. *In* State of Lake Ontario: past, present and future. *Edited by* M. Munawar. Ecovision World Monograph Series. Aquat. Ecosyst. Health Manage. Soc., Backhuys Publishers, Leiden, The Netherlands. pp. 493-516.

Fitzsimons, J.D., Dalton, A., MacVeigh, B., Heaton, M., Wilson, C., and Honeyfield, D.C. 2013. Use of stable isotopes to identify redds of putative hatchery and wild Atlantic salmon and evaluate their spawning habitat and egg thiamine status in a Lake Ontario tributary. North Am. J. Fish. Manage. **33**: 741-753.

Flint, W.R. 1986. Hypothesized carbon flow through the deepwater Lake Ontario foodweb. J. Great Lakes Res. **12**(4): 344-354.

French, III, J.R.P., and Jude, D.J. 2001. Diets and diet overlap of nonindigenous gobies and small benthic native fishes co-inhabiting the St. Clair River, Michigan. J. Great Lakes Res. **27**: 300-311.

Gal, G., Rudstam, L.G., Mills, E.L., Lantry, J.R., Johannsson, O.E., and Greene, C.H. 2006. Mysid and fish zooplanktivory in Lake Ontario: quantification of direct and indirect effects. Can. J. Fish. Aquat. Sci. **63**: 2734-2747.

GLFC (Great Lakes Fishery Commission). 2007. A joint strategic plan for management of Great Lakes fisheries [online]. Available from http://www.glfc.org/fishmgmt/jsp97.pdf [accessed 09 September 2017].

Grossnickle, N.E. 1982. Feeding habits of *Mysis relicta*—an overview. Hydrobiologia **93**: 101-107.

Halpin, K.E., Boscarino, B.T., Rudstam, L.G., Walsh, M.G., and Lantry, B.F. 2013. Effect of light, prey density, and prey type on the feeding rates of *Hemimysis anomala*. Hydrobiologia **720**: 101-110.

He, J.X., Bence, J.R., Madenjian, C.P., Pothoven, S.A., Dobiesz, N.E., Fielder, D.G., Johnson, J.E., Ebener, M.P., Cottrill, R.A., Mohr, L.C., and Koproski, S.R. 2015. Coupling age-structured stock assessment and fish bioenergetics models: a system of time-varying models for quantifying piscivory patterns during the rapid trophic shift in the main basin of Lake Huron. Can. J. Fish. Aquat. Sci. **72**: 7-23.

Hecky, R.E., Smith, R.E.H., Barton, D.R., Guildford, S.J., Taylor, W.D., Charlton, M.N., and Howell, T. 2004. The nearshore phosphorus shunt: a consequence of ecosystem engineering by dreissenids in the Laurentian Great Lakes. Can. J. Fish. Aquat. Sci. **61**: 1285-1293.

Hewson, I., Eaglesham, J.B., Hook, T.O., LaBarre, B.A., Sepulveda, M.S., Thompson, P.D., Watkins, J.M., and Rudstam, L.G. 2013. Investigation of viruses in *Diporeia* spp. from the Laurentian Great Lakes and Owasco Lake as potential stressors of declining populations. J. Great Lakes Res. **39**: 499-506.

Higgins, S.N., Pennuto, C.M., Howell, E.T., Lewis, T., and Makarewicz, J.C. 2012. Urban influences on *Cladophora* blooms in Lake Ontario. J. Great Lakes Res. **38**(Suppl. 4): 116-123.

Holeck, K.T., Watkins, J.M., Mills, E.L., Johannsson, O., Millard, S., Richardson, V., and Bowen, K. 2008. Spatial and long-term temporal assessment of Lake Ontario water clarity, nutrients, chlorophyll *a*, and zooplankton. Aquat. Ecosys. Health Manage. **11**: 377-391.

Holeck, K.T., Rudstam, L.G., Hotaling, C., Swan, J.W., Watkins, J.W., McCullough, R., Lemmon, D., Pearsall, W., Lantry, J., Connerton, M., LaPan, S., Trometer, B., Lantry, B., Walsh, M., and Weidel, B. 2013. 2012 status of the Lake Ontario lower trophic levels. Annual Report Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to Great Lakes Fishery Commission’s Lake Ontario Committee. March 2013. Section 16, 1-26.

Holeck, K., Rudstam, L.G., Hotaling, C., McCullough, R., Lemon, D., Pearsall, W., Lantry, J., Connerton, M., LaPan, S., Trometer, B., Lantry, B., Walsh, M., and Weidel, B. 2014. 2013 status of the Lake Ontario lower trophic levels. *In* 2014 annual report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to Great Lakes Fishery Commission's Lake Ontario Committee. Section 16. NY State Dept. Environ. Conserv., Cape Vincent, NY.

Holeck, K.T., Rudstam, L.G., Watkins, J.M., Luckey, F., Lantry, J.R., Lantry, B.F., Trometer, B., Koops, M., and Johnson, T. 2015a. Lake Ontario water quality during the 2003 and 2008 intensive field years and comparison with long-term trends. Aquat. Ecosys. Health Manage. **18**: 7-17.

Holeck, K.T., Rudstam, L.G., Hotaling, C., McCullough, R., Lemon, D., Pearsall, W., Lantry, J., Connerton, M., LaPan, S., Biesinger, Z., Lantry, B., Walsh, M., and Weidel, B. 2015b. 2014 status of the Lake Ontario lower trophic levels. *In* 2014 annual report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to the Great Lakes Fishery Commission's Lake Ontario Committee. Section 16. NY State Dept. Environ. Conserv., Cape Vincent, NY.

Honeyfield, D.C., Brown, S.B., Fitzsimons, J.D., and Tillitt, D.E. 2005. Early mortality syndrome in Great Lakes salmonines. J. Aquat. Anim. Health **17**: 1-3.

Howell, E.T., Chomicki, K.M., and Kaltenecker, G. 2012. Patterns in water quality on Canadian shores of Lake Ontario: correspondence with proximity to land and level of urbanization. J. Great Lakes Res. **38**(Suppl. 4): 32-46.

Hoyle, J.A. 2000. Bay of Quinte recreational fishery. *In* Lake Ontario fish communities and fisheries: 1999 annual report of the Lake Ontario Management Unit. Chapter 7. Ont. Min. Nat. Resour., Picton, On, Canada.

Hoyle, J.A. 2015. Fish species composition, distribution and abundance trends in the open coastal waters of northeastern Lake Ontario, 1992-2012. Aquat. Ecosyst. Health Manage. **18**: 89-100.

Hoyle, J.A., and Lake, C. 2011. First occurrence of Chain Pickerel (*Esox niger*) in Ontario: possible range expansion from New York waters of eastern Lake Ontario. Can. Field-Nat. **125**: 16-21.

Hoyle, J.A., and Yuille, M.J. 2016. Nearshore fish community assessment on Lake Ontario and the St. Lawrence River: a trap net-based index of biotic integrity. J. Great Lakes Res. **42**: 687-694.

Hoyle, J.A., Casselman, J.M., Dermott, R., and Schaner, T. 1999. Changes in lake whitefish (*Coregonus clupeaformis*) stocks in eastern Lake Ontario following *Dreissena* mussel invasion [online]. Available from http://www.esf.edu/glrc/documents/glrr99.pdf [accessed 09 September 2017].

Hoyle, J.A., Casselman, J.M., Dermott, R., and Schaner T. 2003. Resurgence and decline of lake whitefish (*Coregonus clupeaformis*) stocks in eastern Lake Ontario, 1972 to 1999. *In* State of Lake Ontario: past, present and future. *Edited by* M. Munawar. Ecovision World Monograph Series. Aquat. Ecosyst. Health Manage. Soc., Backhuys Publishers, Leiden, The Netherlands. pp. 475-491.

Hoyle, J.A., Bowlby, J.N., Mathers, A., Schaner, T., Eckert, T.H., Casselman, J.M. 2007. The nearshore fish community. *In* The state of Lake Ontario in 2003. *Edited by* B.J. Morrison and S.R. LaPan [online]. Available from http://www.glfc.org/pubs/SpecialPubs/Sp07_1.pdf [accessed 09 September 2017].

Hoyle, J.A., Bowlby, J.N., and Morrison, B.J. 2008. Lake whitefish and walleye population responses to dreissenid mussel invasion in eastern Lake Ontario. Aquat. Ecosyst. Health Manage. **11**: 403-411.

Hoyle, J.A., Bowlby, J.N., Brousseau, C.M., Johnson, T.B., Morrison, B.J., and Randall, R.G. 2012. Fish community structure in the Bay of Quinte, Lake Ontario: the influence of nutrient levels and invasive species. Aquat. Ecosyst. Health Manage. **15**: 370-384.

Isaac, E.J., Hrabik, T.R., Stockwell, J.D., and Gamble, A.E. 2012. Prey selection by the Lake Superior fish community. J. Great Lakes Res. **38**: 326-335.

Johannsson, O.E., Millard, E.S., Ralph, K.M., Myles, D.D., Graham, D.M., Taylor, W.D., Giles, B.G., and Allen, R.E. 1998. The changing pelagia of Lake Ontario (1981-1995): a report of the DFO long-term biomonitoring (Bioindex) program. Can. Tech. Rep. Fish. Aquat. Sci. No. 2243. 278 pp.

Johannsson, O.E., Rudstam, L.G., Gal, G., and Mills, E.L. 2003. *Mysis relicta* in Lake Ontario: population dynamics, trophic linkages and further questions. *In* State of Lake Ontario: past, present, and future. *Edited by* M. Munawar. Ecovision World Monograph Series. Aquat. Ecosyst. Health Manage. Soc., Backhuys Publishers, Leiden, The Netherlands. pp. 257-287.

Johannsson, O.E., Bowen, K.L., Holeck, K.T., and Walsh, M.G. 2011. *Mysis diluviana* population and cohort dynamics in Lake Ontario before and after the establishment of *Dreissena* spp., *Cercopagis pengoi*, and *Bythotrephes longimanus*. Can. J. Fish. Aquat. Sci. **68**: 795-811.

Johnson, T.B., Bunnell, D.B., and Knight, C.T. 2005. A potential new energy pathway in central Lake Erie: the round goby connection. J. Great Lakes Res. **31**: 238-251.

Johnson, J.H., Ross, R.M., McCullough, R.D., and Mathers, A. 2010. Diet shift of double-crested cormorants in eastern Lake Ontario associated with the expansion of the invasive round goby. J. Great Lakes Res. **36**: 242-247.

Johnson, J.H., McCullough, R.D., Mazzacchi, I.M. 2014. Double-crested cormorant studies at Little Galloo Island, Lake Ontario in 2013: diet composition, fish consumption and the efficacy of management activities in reducing fish predation. *In* 2013 annual report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to the Great Lakes Fishery Commission's Lake Ontario Committee. Section 14. NY State Dept. Environ. Conserv., Cape Vincent, NY.

Jones, M.L., Koonce, J.F., and O'Gorman, R. 1993. Sustainability of hatchery-dependent salmonine fisheries in Lake Ontario: the conflict between predator demand and prey supply. Trans. Am. Fish. Soc. **122**: 1002-1018.

Karatayev, V.A., Karatayev, A.Y., Burlakova, L.E., and Padilla, D.K. 2013. Lakewide dominance does not predict the potential for spread of dreissenids. J. Great Lakes Res. **39**: 622-629.

Kirk, J.T.O. 1994. Light and photosynthesis in aquatic ecosystems. 2nd edition. Cambridge University Press, Cambridge, UK. 509 pp.

Klindt, R.M., and Gordon, D.J. 2014. Lake Sturgeon tagging study 2013. *In* 2013 annual report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to the Great Lakes Fishery Commission's Lake Ontario Committee. Section 18. NY State Dept. Environ. Conserv., Cape Vincent, NY.

Koops, M.A., Munawar, M., and Rudstam, L.G. 2015. The Lake Ontario ecosystem: an overview of current status and future directions. Aquat. Ecosys. Health Manage. **18**: 101-104.

Kornis, M.S., Mercado-Silva, N., and Vander Zanden, M.J. 2012. Twenty years of invasion: a review of round goby *Neogobius melanostomus* biology, spread and ecological implications. J. Fish. Biol. **80**: 235-285.

Krueger, C.C., Perkins, D.L., Mills, E.L., and Marsden, J.E. 1995. Predation by alewives on lake trout fry in Lake Ontario: role of an exotic species in preventing restoration of a native species. J. Great Lakes Res. **21**: 458-469.

Lantry, B.F., and Stewart, D.J. 1993. Ecological energetics of rainbow smelt in the Laurentian Great Lakes: an interlake comparison. Trans. Am. Fish. Soc. **122**: 951-976.

Lantry, B.F., and Lantry, J.R. 2014. Lake trout rehabilitation in Lake Ontario, 2013. *In* 2013 annual report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to the Great Lakes Fishery Commission's Lake Ontario Committee. Section 5. NY State Dept. Environ. Conserv., Cape Vincent, NY.

Lantry, B.F., Eckert, T.H., Schneider, C.P, and Chrisman, J.R. 2002. The relationship between the abundance of smallmouth bass and double-crested cormorants in the eastern basin of Lake Ontario. J. Great Lakes Res. **28**: 193-201.

Lantry, B.F., O'Gorman, R., Walsh, M., Casselman, J., Hoyle, J., Keir, M., and Lantry, J.R. 2007. Reappearance of deepwater sculpin in Lake Ontario: resurgence or last gasp of a doomed population? J. Great Lakes Res. **33**(Suppl. 1): 34-45.

Lantry, B.F., Gumtow, C., Walsh, M.G., Weidel, B., Boscarino, B.T., and Rudstam, L.G. 2012. Seasonal consumption of *Hemimysis anomala* by fish in southeastern Lake Ontario, 2009-2010. J. Great Lakes Res. **38**(Suppl. 2): 73-78.

Lantry, J.R. 2001. Spatial and temporal dynamics of predation by Lake Ontario trout and salmon. M.Sc. thesis. College of Environ. Sci. and Forestry, State Univ. of New York, Syracuse, NY.

Lantry, J.R. 2012. Eastern basin of Lake Ontario warmwater fisheries assessment, 1976-2011. *In* 2011 annual report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to the Great Lakes Fishery Commission's Lake Ontario Committee. Section 4. NY State Dept. Environ. Conserv., Cape Vincent, NY.

Lantry, J.R. 2014. 2013 eastern basin of Lake Ontario warmwater fisheries assessment, 1976-2013. *In* 2013 annual report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to the Great Lakes Fishery Commission's Lake Ontario Committee. Section 4. NY State Dept. Environ. Conserv., Cape Vincent, NY.

Lantry, J.R., and Eckert, T.H. 2014. 2013 Lake Ontario fishing boat survey. *In* 2013 annual report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to the Great Lakes Fishery Commission's Lake Ontario Committee. Section 2. NY State Dept. Environ. Conserv., Cape Vincent, NY.

Lantry, B.F., Lantry, J.R., Weidel, B., Walsh, M., Hoyle, J., Schaner, T., Neaves, F., and Keir, M. 2014a. The offshore benthic fish community. *In* The state of Lake Ontario in 2008. *Edited by* A.C. Adkinson and B.J. Morrison [online]. Available from http://www.glfc.org/pubs/SpecialPubs/Sp14_01.pdf [accessed 09 September 2017].

Lantry, J.R., Hoyle, J.A., Mathers, A., McCullough, R.D., Walsh, M.G., Johnson, J.H., LaPan, S.R., and Weseloh, D.V. 2014b. Nearshore fish community. *In* The state of Lake Ontario in 2008. *Edited by* A.C. Adkinson and B.J. Morrison [online]. Available from http://www.glfc.org/pubs/SpecialPubs/Sp14_01.pdf [accessed 09 September 2017].

Lantry, J.R., Schaner, T., and Copeland T. 2014c. A management strategy for the restoration of lake trout in Lake Ontario, 2014 update [online]. Available from http://glfc.org/pubs/lake_committees/ontario/Lake%20Ontario_Lake_Trout_Strategy_Nov_2014.pdf [accessed 09 September 2017].

LaPan, S.R. 2014. Lake Ontario commercial fishery summary, 2000-2013. *In* 2013 annual report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to the Great Lakes Fishery Commission's Lake Ontario Committee. Section 20. NY State Dept. Environ. Conserv., Cape Vincent, NY.

Lehman, J.T., and Cáceres, C.E. 1993. Food-web responses to species invasion by a predatory invertebrate: *Bythotrephes* in Lake Michigan [online]. Available from http://onlinelibrary.wiley.com/doi/10.4319/lo.1993.38.4.0879/abstract [accessed 09 September 2017].

Lozano, S.J., Scharold, J.V., and Nalepa, T.F. 2001. Recent declines in benthic macroinvertebrate densities in Lake Ontario. Can. J. Fish. Aquat. Sci. **58**: 518-529.

Madenjian, C.P., O'Gorman, R., Bunnell, D.B., Argyle, R.L., Roseman, E.F., Warner, D.M., Stockwell, J.D., and Stapanian, M.A. 2008. Adverse effects of alewives on Laurentian Great Lakes fish communities. North Am. J. Fish. Manage. **28**: 263-28.

Madenjian, C.P., Bunnell, D.B., Desorcie, T.J., Kostich, M.J., Armenio, P.M., and Adams, J.V. 2014. Status and trends of prey fish populations in Lake Michigan, 2013. *In* Compiled reports to the Great Lakes Fishery Commission of the annual bottom trawl and acoustics surveys, 2013 [online]. Available from http://www.glfc.org/lakecom/common_docs/Compiled%20Reports%20from%20USGS%202014.pdf [accessed 09 September 2017].

Maity, S., Jannash, A., Adamec, J., Nalepa, T.F., Höök, T.O., and Sepúlveda, M.S. 2012. Starvation causes disturbance in amino acid and fatty acid metabolism in *Diporeia*. Comp. Biochem. Physiol. B Biochem. Mol. Biol. **161**: 348-355.

Makarewicz, J.C., and Howell, E.T. 2012. The Lake Ontario nearshore study: introduction and summary. J. Great Lakes Res. **38**(Suppl. 4): 2-9.

Makarewicz, J.C., Grigorovich, I.A., Mills, E., Damaske, E., Cristescu, M.E., Pearsall, W., LaVoie, M.J., Keats, R., Rudstam, L., Hebert, P., Halbritter, H., Kelly, T., Matkovich, C., and MacIsaac, H.J. 2001. Distribution, fecundity, and genetics of *Cercopagis pengoi* (Ostroumov) (Crustacea, Cladocera) in Lake Ontario. J. Great Lakes Res. **27**: 19-32.

Makarewicz, J.C., Lewis, T.W., Pennuto, C., Atkinson, J.F., Edwards, W.J., Boyer, G.L., Howell, T., and Thomas, G. 2012. Physical and chemical characteristics of the nearshore zone of Lake Ontario. J. Great Lakes Res. **38**(Suppl. 4): 21-31.

Mathers, A., and Pratt, T.C. 2011. 2010 update on the status and progress on management goals for American Eel in Ontario. Dept. Fish Oceans-Can. Sci. Advis. Sec. Res. Doc. 2011/046. vi + 18 p.

McCullough, R.D., and Mazzocchi, I.M. 2014. Cormorant management activities in Lake Ontario's eastern basin. *In* 2013 annual report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to the Great Lakes Fishery Commission's Lake Ontario Committee. Section 13. NY State Dept. Environ. Conserv., Cape Vincent, NY.

Mida, J.L., Scavia, D., Fahnenstiel, G.L., Pothoven, S.A., Vanderploeg, H.A., and Dolan, D.M. 2010. Long-term and recent changes in southern Lake Michigan water quality with implications for present trophic status. J. Great Lakes Res. **36**: 42-49.

Millard, E.S., Johannsson, O.E., Nielson, M.A., and El-Shaarawi, A.H. 2003. Long-term seasonal and spatial trends in nutrients, chlorophyll *a* and light attenuation in Lake Ontario. *In* State of Lake Ontario: past, present, and future. *Edited by* M. Munawar. Ecovision World Monograph Series. Aquat. Ecosyst. Health Manage. Soc., Backhuys Publishers, Leiden, The Netherlands. pp. 97-132.

Mills, E.L., Dermott, R.M., Roseman, E.F., Dustin, D., Mellina, E., Conn, D.B., and Spidle, A.P. 1993. Colonization, ecology, and population structure of the quagga mussel (Bivalvia, Dreissenidae) in the lower Great Lakes. Can. J. Fish. Aquat. Sci. **50**: 2305-2314.

Mills E.L., Casselman, J.M., Dermott, R., Fitzsimons, J.D., Gal, G., Holeck, K.T., Hoyle, J.A., Johannsson, O.E., Lantry, B.F., Makarewicz, J.C., Millard, E.S., Munawar, I.F., Munawar M., O'Gorman, R., Owens, R.W., Rudstam, L.G., Schaner, T., and Stewart, T.J. 2003. Lake Ontario: food web dynamics in a changing ecosystem (1970-2000). Can. J. Fish. Aquat. Sci. **60**: 471-490.

Mullet, K.M., Heinrich, J.W., Adams, J.V., Young, R.J., Henson, M.P., McDonald, R.B., and Foldale, M.F. 2003. Estimating lake-wide abundance of spawning-phase sea lampreys (*Petromyzon marinus*) in the Great Lakes: extrapolating from sampled streams using regression models. J. Great Lakes Res. **29**(Suppl. 1): 240-252.

Munawar, M., Munawar, I.F., Niblock, H., Fitzpatrick, M., and Lorimer, J. 2015a. Phytoplankton of Lake Ontario: changing structure, biodiversity and trophic status. Aquat. Ecosys. Health Manage. **18**: 28-42.

Munawar, M., Rudstam, L.G., and Koops, M.A. 2015b. Preface—special issue on the state of Lake Ontario in 2008. Aquat. Ecosys. Health Manage. **18**: 3-6.

Naddafi, R., and L.G. Rudstam. 2014. Predation on invasive zebra mussel, *Dreissena polymorpha*, by pumpkinseed sunfish, rusty crayfish, and round goby. Hydrobiologia **721**: 107-115.

Nalepa, T., Fanslow, D., and Lang, G. 2009. Transformation of the offshore benthic community in Lake Michigan: recent shift from the native amphipod *Diporeia* spp. to the invasive mussel *Dreissena rostriformis bugensis*. Freshwater Biol. **54**: 466-479.

Neave, F. 2012. Chapter 6: Five-year plan for Lake Ontario. *In* Lake-level, five-year plans for achieving sea lamprey control targets in each Great Lake. *Edited by* K. Mullett, J. Slade, P. Sullivan, and M. Steeves [online]. Available from http://glfc.org/pubs/slcp/LL_5YearPlan.pdf [accessed 09 September 2017].

New York State DEC (New York State Department of Environmental Conservation). 2013. Lake Sturgeon spawning beds habitat improvement project: 2012 monitoring activities at the Iroquois Dam and results. Final report to the New York Power Authority and the Technical Advisory Council for St. Lawrence-FDR Power Project: FERC NO. 2000. Prepared by: NYSDEC-St. Lawrence Habitat Management Project 1003, County Route 39, Chase Mills, NY.

O'Gorman, R., and Schneider, C.P. 1986. Dynamics of alewives in Lake Ontario following a mass mortality. Trans. Am. Fish. Soc. **115**: 1-14.

O'Gorman, R., and Stewart, T.J. 1999. Ascent, dominance, and decline of the alewife in the Great Lakes: food web interactions and management strategies. *In* Great Lakes policy and management: a binational perspective. *Edited by* W.W. Taylor and C.P. Ferreri. Mich. State Univ. Press, East Lansing, MI. pp. 489-513.

O'Gorman, R., and Burnett, J.A.D. 2001. Fish community dynamics in northeastern Lake Ontario with emphasis on the growth and reproductive success of yellow perch (*Perca flavescens*) and white perch (*Morone americana*), 1978 to 1997. J. Great Lakes Res. **27**: 367-383.

O'Gorman, R., and Owens, R.W. 2003. Establishment of dreissenids in Lake Ontario: implications for the endemic fish community. *In* Invasion of alien species in Holarctic. *Edited by* D.F. Pavlov and G. Kh. Scherbina. Proceedings of U.S.-Russia invasive species workshop. 27-31 August 2001. I.D. Papanin Institute of Biology of Inland Waters, Borok, Yaroslavl Region, Russia. pp. 546-553.

O'Gorman, R., Elrod, J.H., and Hartman, W.L. 1989. Survey of the fish stocks in U.S. waters of Lake Ontario during IFYGL, 1972 (Section 11.B, pp. 209-247). *In* Status of the IFYGL biota of Lake Ontario during International Field Year for the Great Lakes, 1972-1973. *Edited by* N.A. Thomas, W.J. Christie, and S.A. Gannon [online]. Available from http://www.glfc.org/pubs/misc/Status_of_IFYGL_biota_Lake_Ontario_72-73.pdf [accessed 09 September 2017].

O'Gorman, R., Elrod, J.H., and Schneider, C.P. 1998. Reproductive potential and fecundity of lake trout strains in southern and eastern waters of Lake Ontario, 1977-1994. J. Great Lakes Res. **24**: 131-144.

O'Gorman, R., Elrod, J.H., Owens, R.W., Schneider, C.P., Eckert, T.H., and Lantry, B.F. 2000. Shifts in depth distributions of alewives, rainbow smelt, and age-2 lake trout in southern Lake Ontario following establishment of dreissenids. Trans. Am. Fish. Soc. **129**: 1096-1106.

O'Gorman, R, Lantry, B.F., and Schneider, C.P. 2004. Effect of stock size, climate, predation, and trophic status on recruitment of alewives in Lake Ontario, 1978-2000. Trans. Am. Fish. Soc. **133**: 855-867.

O'Gorman, R., Prindle, S.E., Lantry, J.R., and Lantry, B.F. 2008. Disruption of the lower food web in Lake Ontario: did it affect alewife growth and condition? Aquat. Ecosys. Health Manage. **11**: 392-402.

O'Malley, B.P., and Bunnell, D.B. 2014. Diet of *Mysis diluviana* reveals seasonal patterns of omnivory and consumption of invasive species offshore Lake Michigan. J. Plankton Res. **36**: 989-1002.

OMNR (Ontario Ministry of Natural Resources). 2007. Lake Ontario fish communities and fisheries: 2006 annual report of the Lake Ontario Management Unit. Queen's Printer for Ontario, Picton, ON, Canada.

OMNR (Ontario Ministry of Natural Resources). 2009. Lake Ontario fish communities and fisheries: 2008 annual report of the Lake Ontario Management Unit. Queen's Printer for Ontario, Picton, ON, Canada.

OMNR (Ontario Ministry of Natural Resources). 2012. Lake Ontario fish communities and fisheries: 2011 annual report of the Lake Ontario Management Unit. Queen's Printer for Ontario, Picton, ON, Canada.

OMNR (Ontario Ministry of Natural Resources). 2013. Lake Ontario fish communities and fisheries: 2012 annual report of the Lake Ontario Management Unit. Queen's Printer for Ontario, Picton, ON, Canada.

OMNR (Ontario Ministry of Natural Resources). 2014. Lake Ontario fish communities and fisheries: 2013 annual report of the Lake Ontario Management Unit. Queen's Printer for Ontario, Picton, ON, Canada.

Owens, R.W., and Bergstedt, R.A. 1994. Response of slimy sculpins to predation by lake trout in southern Lake Ontario. Trans. Am. Fish. Soc. **123**: 28-36.

Owens, R.W., and Dittman, D.E. 2003. Shifts in the diets of slimy sculpin (*Cottus cognatus*) and lake whitefish (*Coregonus clupeaformis*) in Lake Ontario following the collapse of the burrowing amphipod, *Diporeia*. Aquat. Ecosys. Health Manage. **6**: 311-322.

Owens, R.W., O'Gorman, R., Eckert, T.H., and Lantry, B.F. 2003. The offshore fish community in southern Lake Ontario, 1972-1998. *In* State of Lake Ontario: past, present, and future. *Edited by* M. Munawar. Ecovision World Monograph Series. Aquat. Ecosyst. Health Manage. Soc., Backhuys Publishers, Leiden, The Netherlands. pp. 407-442.

Pangle, K.L., Peacor, S., and Johannsson, O.E. 2007. Large nonlethal effects of an invasive invertebrate predator on zooplankton population growth rate. Ecology **88**: 402-412.

Pearce, W.A., Braem, R.A., Dustin, S.M., and Tibbles, J.J. 1980. Sea lamprey (*Petromyzon marinus*) in the Lower Great Lakes. Can. J. Fish. Aquat. Sci. **37**: 1802-1810.

Pratt, T.C., and Threader, R.W. 2011. Preliminary evaluation of a large-scale American Eel conservation stocking experiment. N. Am. J. Fish. Manage. **31**: 619-628.

Pratt, T.C., O'Connor, L.M., and Stanley, D.R. 2015. American Eel stocking effectiveness monitoring on the upper St. Lawrence River and Lake Ontario. Report submitted to the Ontario Power Generation Action Plan Steering Committee.

Prindle, S.E., and Bishop, D.L. 2013. Lake Ontario tributary creel survey: fall 2011-spring 2012. *In* 2012 annual report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to the Great Lakes Fishery Commission’s Lake Ontario Committee. Section 11. NY State Dept. Environ. Conserv., Cape Vincent, NY.

Prindle, S.E., and Bishop, D.L. 2014. Population characteristics of Pacific salmonines collected at the Salmon River Fish Hatchery 2013. *In* 2013 annual report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to the Great Lakes Fishery Commission’s Lake Ontario Committee. Section 9. NY State Dept. Environ. Conserv., Cape Vincent, NY.

Rand, P.S., Stewart, D.J., Seelbach, P.W., Jones, M.L., and Wedge, L.R. 1993. Modeling steelhead population energetics in Lakes Michigan and Ontario. Trans. Am. Fish. Soc. **122**: 977-1001.

Rand, P.S., Lantry, B.F., O'Gorman, R., Owens, R.W., and Stewart, D.J. 1994. Energy density and size of pelagic prey fishes in Lake Ontario, 1978-1990: implications for salmonine energetics. Trans. Am. Fish. Soc. **123**: 519-534.

Reavie, E.D., Barbiero, R.P., Allinger, L.E., and Warren, G.J. 2014. Phytoplankton trends in the Great Lakes, 2001-2011. J. Great Lakes Res. **40**: 618-639.

Ricciardi, A., Avlijas, S., and Marty, J. 2012. Forecasting the ecological impacts of the *Hemimysis anomala* invasion in North America: Lessons from other freshwater mysid introductions. J. Great Lakes Res. **38**: 7-13.

Riley, S.C., Roseman, E.F., Nichols, S.J., O'Brien, T.P., Kiley, C.S., and Schaeffer, J.S. 2008. Deepwater demersal fish community collapse in Lake Huron. Trans. Am. Fish. Soc. **137**: 1879-1890.

Riveredge Associates. 2014. 2013 survey of American Eel in the tailwater of the international St. Lawrence Power Project. Final Report. Prepared for: New York Power Authority, 123 Main Street, White Plains, NY.

Riveredge Associates and Kleinschmidt Associates. 2014. 2013 monitoring of the eel passage facility at the R.H. Saunders Generating Station. Prepared for Ontario Power Generation, 2 Innovation Drive, Renfrew, ON, Canada.

Roseman, E.F., Chriscinske, M.A., Castle, D.K., and Bowser, D.A. 2015. Status and trends of the Lake Huron offshore demersal fish community, 1976-2014 [online]. Available from http://www.glfc.org/lakecom/common_docs/Compiled%20Reports%20from%20USGS%202015.pdf [accessed 09 September 2017].

Rudstam, L.G. [ED.]. 1996. A review of the current status of Lake Ontario's pelagic fish community. Report of the 1996 Lake Ontario technical panel [online]. Available from http://www.esf.edu/glrc/documents/glrr96.pdf [accessed 09 September 2017].

Rudstam, L.G., Schaner, T., Gal, G., Boscarino, B.T., O'Gorman, R., Warner, D.M., Johannsson, O.E., and Bowen, K. 2008. Hydroacoustic measures of *Mysis relicta* abundance and distribution in Lake Ontario. Aquatic Ecosys. Health Manage. **11**: 355-367.

Rudstam, L.G., Holeck, K.T., Bowen, K.L., Watkins, J.M., Weidel, B.C., and Luckey, F.J. 2015. Lake Ontario zooplankton in 2003 and 2008: community changes and vertical redistribution. Aquat. Ecosys. Health Manage. **18**: 43-62.

Rush, S.A., Paterson, G., Johnson, T.B., Drouillard, K.G., Haffner, G.D., Hebert, C.E., Arts, M.T., McGoldrick, D.J., Backus, S.M., Lantry, B.F., Lantry, J.R., Schaner, T., and Fisk, A.T. 2012. Long-term impacts of invasive species on a native top predator in a large lake system. Freshwater Biol. **57**: 2342-2355.

Sanderson, M.J. 2012. 2010-2011 warmwater fisheries assessment at Webster and Pultneyville, Lake Ontario. *In* 2011 annual report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to the Great Lakes Fishery Commission's Lake Ontario Committee. Section 24. NY State Dept. Environ. Conserv., Cape Vincent, NY.

Sanderson, M.J., and Lantry, J.R. 2014. Assessment of the Lake Ontario black bass fishery using cooperator angler diaries. *In* 2013 annual report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to the Great Lakes Fishery Commission's Lake Ontario Committee. Section 22. NY State Dept. Environ. Conserv., Cape Vincent, NY.

Scavia, D., Allan, J.D., Arend, K.K., Bartell, S., Beletsky, D., Bosch, N.S., Brandt, S.B., Briland, R.D., Daloglu, I., DePinto, J.V., Dolan, D.M., Evans, M.A., Farmer, T.M., Goto, D., Han, H., Hook, T.O., Knight, R., Ludsin, S.A., Mason, D., Michalak, A.M., Richards, R.P., Roberts, J.J., Rucinski, D.K., Rutherford, E., Schwab, D.J., Sesterhenn, T.M., Zhang, H., and Zhou, Y. 2014. Assessing and addressing the re-eutrophication of Lake Erie: central basin hypoxia. J. Great Lakes Res. **40**: 226-246.

Schelske, C.L., Stoermer, E.G., Fahnenstiel, G.L., and Haibach, M. 1986. Phosphorus enrichment, silica utilization, and biochemical silica depletion in the Great Lakes. Can. J. Fish. Aquat. Sci. **43**: 407-415.

Schneider, C.P., Kolenosky, D.P., and Goldthwaite, D.B. 1983. A joint plan for the rehabilitation of lake trout in Lake Ontario. Lake trout subcommittee of the Great Lakes Fishery Commission's Lake Ontario Committee [online]. Available from http://glfc.org/pubs/pdfs/research/reports/LakeOntLaketrout1983.pdf [accessed 09 September 2017].

Schneider, C.P., Owens, R.W., Bergstedt, R.A., and O'Gorman, R. 1996. Predation by sea lampreys (*Petromyzon marinus*) on lake trout (*Salvelinus namaycush*) in southern Lake Ontario, 1982-92. Can. J. Fish. Aquat. Sci. **53**: 1921-1932.

Smith, B.M., Farrell, J.M., Underwood, H.B., and Smith, S.J. 2007. Year-class formation of upper St. Lawrence River Northern Pike. N. Am. J. Fish. Manage. **27**: 481-491.

Smith, S.H. 1972. Factors of ecologic succession in oligotrophic fish communities of the Laurentian Great Lakes. J. Fish. Res. Board Can. **29**: 717-730.

Stanley, D. 2012. Research into trap and transport as a potential mitigation using traditional fisheries methods 2011. OPG action plan for offsetting turbine mortality of American Eel at the R.H. Saunders Generating Station (2006-2011) and OMNR/OPG Saunders ESA agreement monitoring requirements Part D. OPG Hydro Business, Environ. Div., Niagara-on-the-Lake, ON, Canada.

Stapanian, M.A., Madenjian, C.P., Bronte, C., Ebener, M., Lantry, B.F., and Stockwell, J. 2008. Status of burbot populations in the Laurentian Great Lakes: a synthesis. *In* Burbot: ecology, management, and culture. *Edited by* V.L. Paragamian and D.H. Bennett. Am. Fish. Soc. Symp. **59**: 111-130.

Stevens, R.J.J., and Neilson, M.A. 1987. Response of Lake Ontario to reductions in phosphorous load, 1967-82. Can. J. Fish. Aquat. Sci. **44**: 2059-2068.

Stewart, T.J., Lange, R.E., Orsatti, S.D., Schneider, C.P., Mathers, A., and Daniels, M.E. 1999. Fish-community objectives for Lake Ontario [online]. Available from http://www.glfc.org/pubs/SpecialPubs/Sp99_1.pdf [accessed 09 September 2017].

Stewart, T.J., Sprules, W.G., and O'Gorman, R. 2009. Shifts in the diet of Lake Ontario alewife in response to ecosystem change. J. Great Lakes Res. **35**: 241-249.

Stewart, T.J., Todd, A., and LaPan, S.R. 2013. Fish community objectives for Lake Ontario 2013 [online]. Available from http://www.glfc.org/pubs/lake_committees/ontario/LO-FCO-2013-Final.pdf [accessed 09 October 2017].

Stewart. T.J., Bowlby, J.N., and Wilson, C. [EDS.]. 2014a. Proceedings of the Lake Ontario Atlantic salmon restoration science workshop. 18-20 February 2014. Alliston, Ontario. Ont. Min. Nat. Resour. Forest. File Report 14.08.

Stewart, T.J., Dermott, R., Dittman, D.E., Holeck, K.T., Johnson, J.H., McCullough, R.D., Weseloh, D.V., and Weidel, B. 2014b. Ecological drivers of Lake Ontario fish abundance and distribution. *In* The state of Lake Ontario in 2008. *Edited by* A.C. Adkinson and B.J. Morrison [online]. Available from www.glfc.org/pubs/SpecialPubs/Sp14_01.pdf [accessed 09 September 2017].

Stewart, T.J., Rudstam, L.G., Watkins, J., Johnson, T.B., Weidel, B.C., and Koops, M. 2016. Research needs to better understand Lake Ontario ecosystem function: a workshop summary [online]. Available from http://www.sciencedirect.com/science/article/pii/S0380133015002154 [accessed 09 September 2017].

Stirling, M.R. 1999. Manual of instructions: nearshore community index netting (NSCIN) [online]. Available from https://www.ontario.ca/document/nearshore-community-index-netting-instructions [accessed 09 September 2017].

Stone. U.B. 1938. Growth, habits, and fecundity of the ciscoes of Irondequoit Bay, New York. Trans. Am. Fish. Soc. **67**: 234-245.

Sun, J., Rudstam, L.G., Boscarino, B.T., Walsh, M.G., and Lantry, B.F. 2013. Laboratory-derived temperature preference and effect on the feeding rate and survival of *Hemimysis anomala*. J. Great Lakes Res. **39**: 630-636.

Taraborelli, A.C., Fox, M.G., Johnson, T.B., and Schaner, T. 2010. Round Goby (*Neogobius melanostomus*) population structure, biomass, prey consumption, and mortality from predation in the Bay of Quinte, Lake Ontario. J. Great Lakes Res. **36**: 625-632.

Taylor, W.A. 2000. Change-point analysis: a powerful new tool for detecting changes [online]. Available from http://www.variation.com/cpa/tech/changepoint.html [accessed 11 October 2017].

Thomas, N.A., Robertson, A., and Sonzoni, W.C. 1980. Review of control objectives: new target loads and input controls. *In* Phosphorus management strategies for lakes. *Edited by* R.C. Loehr, C.S. Martin, and W. Rast. Ann Arbor Sci. Pub., Ann Arbor, MI. pp. 61-90.

Tilman, D. 1982. Resource competition and community structure. Princeton Univ. Press, Princeton, NJ. 296 pp.

Twiss, M.R., Ulrich, C., Zastepa, A., and Pick, F.R. 2012. On phytoplankton growth and loss rates in the epilimnion and metalimnion of Lake Ontario in mid-summer. J. Great Lakes Res. **38**(Suppl. 4): 146-153.

Vanderploeg, H.A., Liebig, J.R., Nalepa, T.F., Fahnenstiel, G.L., and Pothoven, S.A. 2010. *Dreissena* and the disappearance of the spring phytoplankton bloom in Lake Michigan. J. Great Lakes Res. **36**: 50-59.

Verreault, G., and Dumont, P. 2003. An estimation of American Eel escapement from the upper St. Lawrence River and Lake Ontario in 1996 and 1997. Amer. Fish. Soc. Symp. **33**: 243-251.

Verreault, G., Dumont, P., Dussureault, J., and Tardif, R. 2010. First record of migrating silver American eels (*Anguilla rostrata*) in the St. Lawrence estuary originating from a stocking program. J. Great Lakes Res. **36**: 794-797.

Walsh, M.G., and Connerton, M.J. 2014. Status of alewife in the U.S. waters of Lake Ontario, 2013. *In* 2013 annual report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to the Great Lakes Fishery Commission’s Lake Ontario Committee. Section 12, pp. 6-10. NY State Dept. Environ. Conserv., Cape Vincent, NY.

Walsh, M.G., O’Gorman, R., Lantry, B.F., Strang T., and Maloy, A.P. 2006. Status of sculpins and Round Goby in the U.S. waters of Lake Ontario, 2005. *In* 2005 annual report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to the Great Lakes Fishery Commission’s Lake Ontario Committee. Section 12. NY State Dept. Environ. Conserv., Cape Vincent, NY.

Walsh, M.G., Dittman, D.E., and O’Gorman, R. 2007. Occurrence and food habits of the Round Goby in the profundal zone of southwestern Lake Ontario. J. Great Lakes Res. **33**: 83-92.

Walsh, M.G., O'Gorman, R., Lantry, B.F., Strang, T., Golod, P., and Connerton, M.J. 2008a. Status of sculpins and Round Goby in the U.S. waters of Lake Ontario, 2007. *In* 2007 annual report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to the Great Lakes Fishery Commission’s Lake Ontario Committee. Section 12. NY State Dept. Environ. Conserv., Cape Vincent, NY.

Walsh, M.G., O'Gorman, R., Strang, T., Edwards, W.H., and Rudstam, L.G. 2008b. Fall diets of alewife, rainbow smelt, and slimy sculpin in the profundal zone of southern Lake Ontario during 1994-2005 with an emphasis on occurrence of *Mysis relicta*. Aquat. Ecosyst. Health Manage. **11**: 368-376.

Walsh, M.G., Strang, T., and Connerton, M.J. 2011. Status of alewife in the U.S. waters of Lake Ontario, 2010. *In* 2010 annual report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to the Great Lakes Fishery Commission's Lake Ontario Committee. Section 12, pp. 1-10. NY State Dept. Environ. Conserv., Cape Vincent, NY.

Walsh, M.G., Boscarino, B.T., Marty, J., and Johannsson, O.E. 2012. *Mysis diluviana* and *Hemimysis anomala*: reviewing the roles of a native and invasive mysid in the Laurentian Great Lakes region. J. Great Lakes Res. **38**(Suppl. 2): 1-6.

Walsh, M.G., Weidel, B.C., and Connerton, M.J. 2014. Lake Ontario prey fish assessments, 2013, introduction and methods. *In* 2013 annual report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to the Great Lakes Fishery Commission's Lake Ontario Committee. Section 12, pp. 1-5. NY State Dept. Environ. Conserv., Cape Vincent, NY.

Warner, D.M., Rudstam, L.G., Benoît, H., Johannsson, O.E., and Mills, E.L. 2006. Changes in seasonal nearshore zooplankton abundance patterns in Lake Ontario following establishment of the exotic predator *Cercopagis pengoi*. J. Great Lakes Res. **32**: 531-542.

Watkins, J.M., Dermott, R., Lozano, S.J., Mills, E.L., Rudstam, L.G., and Scharold, J.V. 2007. Evidence for remote effects of dreissenid mussels on the amphipod *Diporeia*: analysis of Lake Ontario benthic surveys, 1972-2003. J. Great Lakes Res. **33**: 642-657.

Watkins, J.M., Rudstam, L.G., and Holeck, K.T. 2011. Length-weight regressions for zooplankton biomass calculations—a review and a suggestion for standard equations [online]. Available from http://hdl.handle.net/1813/24566 [accessed 09 September 2017].

Watkins, J.M., Rudstam, L.G., Mills, E.L., and Teece, M.A. 2012. Coexistence of the native benthic amphipod *Diporeia* spp. and exotic dreissenid mussels in the New York Finger Lakes. J. Great Lakes Res. **38**: 226-235.

Watkins, J.M., Rudstam, L.G., Crabtree, D.L., and Walsh, M.G. 2013. Is reduced benthic flux related to the *Diporeia* decline? Analysis of spring blooms and whiting events in Lake Ontario. J. Great Lakes Res. **39**: 395-403.

Watkins, J.M., Rudstam, L.G., Connerton, M.J., Schaner, T., Rudstam, P.G., and Bowen, K.L. 2015a. Abundance and spatial distribution of *Mysis diluviana* in Lake Ontario in 2008 estimated with 120 kHz hydroacoustic surveys and net tows. Aquat. Ecosys. Health Manage. **18**: 63-75.

Watkins, J.M., Weidel, B., Rudstam, L.G., and Holeck, K.T. 2015b. Spatial extent and dissipation of the deep chlorophyll layer (DCL) in Lake Ontario during LOLA 2003 and 2008. Aquat. Ecosys. Health Manage. **18**: 18-27.

Weidel, B., and Connerton, M. 2014. Status of rainbow smelt in the U.S. waters of Lake Ontario, 2013. *In* 2013 annual report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to the Great Lakes Fishery Commission's Lake Ontario Committee. Section 12, pp. 11-15. NY State Dept. Environ. Conserv., Cape Vincent, NY.

Weidel, B.C., Walsh, M.G., and Connerton, M.J. 2014. Benthic prey fish assessment, Lake Ontario 2013. *In* 2013 annual report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to the Great Lakes Fishery Commission's Lake Ontario Committee. Section 12, pp. 16-24. NY State Dept. Environ. Conserv., Cape Vincent, NY.

Wells, L. 1969. Fishery survey of U.S. waters of Lake Ontario. *In* Limnological Survey of Lake Ontario, 1964 [online]. Available from: http://www.glfc.org/pubs/TechReports/Tr14.pdf [accessed 11 October 2017].

Wetzel, R.G. 2001. Limnology, lake and river ecosystems. 3rd ed. Academic Press, San Diego, CA. 1006 pp.

Yan, N.D., Blukacz, A., Sprules, W.G., Kindy, P.K., Hackett, D., Girard, R.E., and Clark, B.J. 2001. Changes in zooplankton and the phenology of the spiny water flea, *Bythotrephes*, following its invasion of Harp Lake, Ontario, Canada. Can. J. Fish. Aquat. Sci. **58**: 2341-2350.

Yan, N.D., Leung, B., Lewis, M.A., and Peacor, S.D. 2011. The spread, establishment and impacts of the spiny water flea, *Bythotrephes longimanus*, in temperate North America: a synopsis of the special issue. Biol. Invasions **13**: 2423-2432.

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