THE STATE OF LAKE SUPERIOR IN 2017

Great Lakes Fishery Commission

SPECIAL PUBLICATION 2021-02

The Great Lakes Fishery Commission was established by the Convention on Great Lakes Fisheries between Canada and the United States, which was ratified on October 11, 1955. It was organized in April 1956 and assumed its duties as set forth in the Convention on July 1, 1956. The Commission has two major responsibilities: first, develop coordinated programs of research in the Great Lakes, and, on the basis of the findings, recommend measures that will permit the maximum sustained productivity of stocks of fish of common concern; second, formulate and implement a program to eradicate or minimize Sea Lamprey populations in the Great Lakes.

The Commission is also required to publish or authorize the publication of scientific or other information obtained in the performance of its duties. In fulfillment of this requirement the Commission publishes two types of documents, those that are reviewed and edited for citation indexing and printing and those intended for hosting on the Commission's website without indexing or printing. Those intended for citation indexing include three series: Technical Reports—suitable for either interdisciplinary review and synthesis papers of general interest to Great Lakes fisheries researchers, managers, and administrators, or more narrowly focused material with special relevance to a single but important aspect of the Commission's program (requires outside peer review); Special Publications—suitable for reports produced by working committees of the Commission; and Miscellaneous Publications—suitable for specialized topics or lengthy reports not necessarily endorsed by a working committee of the Commission. One series, Fishery Management Documents, is not suited for citation indexing. It is intended to provide a web-based outlet for fishery-management agencies to document plans or reviews of plans while forgoing technical review and style editing by Commission staff. Those series intended for citation indexing follow the style of the Canadian Journal of Fisheries and Aquatic Sciences. The style for Fishery Management Documents is at the discretion of the authors. Sponsorship of publications does not necessarily imply that the findings or conclusions contained therein are endorsed by the Commission.

Great Lakes Fishery Commission
2200 Commonwealth Blvd., Suite 100
Ann Arbor, MI 48105

THE STATE OF LAKE SUPERIOR IN 2017

Edited by

Mark P. Ebener[1] and Thomas C. Pratt[2]

Citation (entire volume) (online): Ebener, M.P., and Pratt, T.C. [EDS]. 2021. The state of Lake Superior in 2017 [online]. Available from http://www.glfc.org/pubs/SpecialPubs/Sp21_02.pdf [accessed 04 April 2021].

Citation (individual chapter) (online): Gorman, O.T., Vinson, M.R., and Yule, D.L. 2021. Status of Prey Fish in Lake Superior in 2017. *In* The state of Lake Superior in 2017. *Edited by* M.P. Ebener and T.C. Pratt [online]. Available from http://www.glfc.org/pubs/SpecialPubs/Sp21_02.pdf [accessed 24 April 2021].

May 2021

ISSN 2159-6581 (online)

[1]**M.P. Ebener**. Fresh Lake Whitefish Company, 4234 I75 Business Spur, #250, Sault Ste. Marie, MI 49783, USA (e-mail: tflwc@yahoo.com).
[2]**T.C. Pratt**. Fisheries and Oceans Canada, Great Lakes Laboratory for Fisheries and Aquatic Sciences, 1219 Queen Street East, Sault Ste Marie, ON P6A 2E5, Canada.

Frontispiece. Map of Lake Superior showing major geographical features and management units. Treaty-ceded waters are shown by bold lines and include all US waters of Lake Superior.

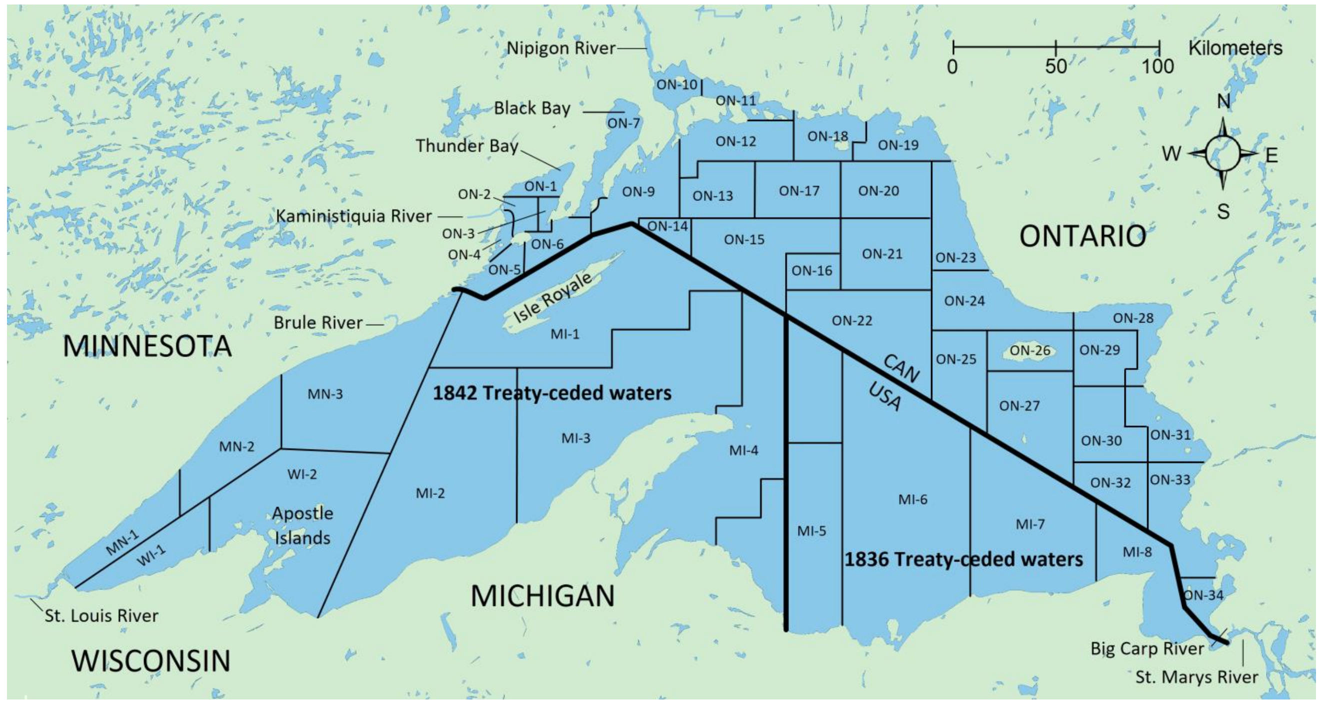


TABLE OF CONTENTS

Abstract **1**

Introduction to the State of Lake Superior in 2017 .... **3**

The State of Fish Habitat in Lake Superior in 2017 .... **7**

Progress/Status 9
Physical and Climate Variables and Climate Change 12
Conclusions 14

Status of the Lower Food Web in Lake Superior in 2017 .... **15**

Status of Prey Fish in Lake Superior in 2017 .... **17**

Biomass of Nearshore Prey Fish 21
Biomass of Offshore Prey Fish 26
Summary 27

Status of Cisco in Lake Superior in 2017 .... **29**

Population Status 29
Management and Current Fisheries 30

Status of Lake Whitefish in Lake Superior in 2017 .... **33**

Commercial-Fishery Yield 34
Management 36
Summary 37

Status of Lake Trout in Lake Superior in 2017 .... **38**

Status of Siscowet Lake Trout in Lake Superior in 2017 .... **46**

State of the Lake Superior Ecosystem in 2017 .... **55**

Status of Pacific Salmon, Rainbow Trout (Steelhead), and Brown Trout in Lake Superior in 2017 .... **61**

Status of Walleye in Lake Superior in 2017 .... **70**

Population Status 71

Status of Brook Trout Rehabilitation in Lake Superior in 2017 .... **76**

Conclusions and Recommendations 80

Status of Lake Sturgeon in Lake Superior in 2017 .... **81**

State of Lake Superior in 2017: Native-Species Diversity **87**

Status of Sea Lamprey in Lake Superior in 2017 .... **93**

Control Measures 94
Lentic Areas 95
Barriers 96
Conclusions and Recommendations 96

State of Lake Superior In 2017: Aquatic Nuisance Species **98**

Overview of Progress in Fishery Management on Lake Superior as of 2017 .... **105**

Literature Cited **112**

ABSTRACT[3]

This report describes the status of fish species and their habitat in Lake Superior during the reporting period of 2012-2016 in response to achievement of fish community objectives (FCOs) established by fishery managers for the lake. The overarching goal for the FCOs continued to be met as the fish community remained diverse, self-regulating, dominated by indigenous species, and able to support sustainable fisheries, although further rehabilitation of certain fish is required. The Lake Superior Lakewide Action and Management Plan classified all habitat indicators for Lake Superior as good. Primary production and zooplankton abundance were stable during the reporting period and unchanged from the two previous reporting periods, indicating the lower food web is healthy. Abundance of the invertebrates *Mysis diluviana* and *Diporeia* spp. were stable during the reporting period, and *Diporeia* spp. density exceeded target levels defined in the Great Lakes Water Quality Agreement. Lake Whitefish (*Coregonus clupeaformis*) abundance was lower than during the previous reporting period but was within the FCO target. Abundance of lean, siscowet, and humper forms of Lake Trout (*Salvelinus namaycush*) remained stable at levels seen in previous reporting periods. The FCO for non-indigenous salmonids was met as Chinook Salmon (*Oncorhynchus tshawytscha*), Coho Salmon (*O. kisutch*), and steelhead/Rainbow Trout (*O. mykiss*) were being sustained by natural reproduction, and their abundance remained stable or increased from previous reporting periods. The FCO for Walleye (*Sander vitreus*) was not

---

[3]Complete publication including maps of place names, abstract, other chapters, scientific fish names, and references is available at http://www.glfc.org/pubs/SpecialPubs/Sp21_02.pdf.

met, although populations showed signs of improvement since the previous reporting period. The fish community in littoral areas and embayments continued to be diverse and composed mostly of indigenous species. No new invasive species were found in Lake Superior during the reporting period. Degraded embayment and tributary habitats continued to prevent achievement of the FCOs for Brook Trout (*S. fontinalis*) and Lake Sturgeon (*Acipenser fulvescens*). Barriers created for hydroelectric generation either blocked Lake Sturgeon from historically important spawning grounds or reduced stream flows necessary for its reproduction. In tributaries without man-made barriers, Lake Sturgeon was relatively abundant and appeared healthy. Attainment of the FCOs for Brook Trout and Lake Sturgeon will be challenging and can only be attained through development of large-scale management actions like those implemented for Lake Trout rehabilitation and Sea Lamprey (*Petromyzon marinus*) control. Sea Lamprey-control expenditures doubled in 2016 from past levels and should result in suppression of the population closer to its FCO after 2016. The prey-fish FCO appears to have been met, but biomass of nearly all prey-fish species declined from that reported for the previous reporting period and has been on a downward trajectory since 2000. Predation by Lake Trout is probably to blame for the declining biomass of prey fish. Poor recruitment by Cisco (*C. artedi*) over the last 15 years is exacerbating the declines in prey-fish biomass because Lake Trout must compensate for the loss of Cisco by consuming other, less-abundant prey fish.

INTRODUCTION TO THE STATE OF LAKE SUPERIOR IN 2017[4]

Mark P. Ebener[5]

Lake Superior is the largest of the Laurentian Great Lakes in both volume and surface area and is probably the least impacted by human activities (see Bronte et al. 2003; Horns et al. 2003). The terrestrial habitat surrounding the lake is largely forested and undeveloped while the aquatic habitat and the fish community more closely resemble their historical state than any other Great Lake (Bronte et al. 2003). That is not to say that Lake Superior is immune to invasions by non-indigenous species (Griffiths et al. 1991; Grigorovich et al. 2008), or that it is not affected by climate change (Austin and Colman 2007, 2008), or that human activities have not destroyed aquatic habitat and overharvested fish populations (Lawrie and Rahrer 1972; Selgeby 1982).

Federal, state, and Native American governments have banded together to prevent and counteract the effects of invasive species, habitat loss, and overharvest in the Great Lakes ecosystem and its fisheries. The Great Lakes Fishery Commission (GLFC) was created in 1955 by a treaty between Canada and the U.S. to eradicate Sea Lamprey, to coordinate inter-jurisdictional management, and to disseminate information useful for management of the fisheries (Fetterolf 1980). Lake committees (composed of an upper-level fishery manager from each state, Province of Ontario, and Native American political jurisdiction) were established to coordinate fishery management on each of the Great Lakes, and a Council of Lake Committees coordinates basinwide management. Lake technical committees composed of fishery biologists from each state, Province of Ontario, Native

---

[4]Complete publication including maps of place names, abstract, other chapters, and references is available at http://www.glfc.org/pubs/SpecialPubs/Sp21_02.pdf.

[5]**M.P. Ebener**. Fresh Lake Whitefish Company, 4234 I75 Business Spur, #250, Sault Ste. Marie, MI 49783, USA (e-mail: tflwc@yahoo.com).

American organizations, and other natural-resource organizations advise the lake committees on the status of fish communities, conduct research, and recommend specific management actions.

The 1998 revision to *A Joint Strategic Plan for the Management of Great Lakes Fisheries* (GLFC 2007) requires that the lake committees periodically produce a state of the lake report in support of fish community objectives (FCOs). The FCOs describe the future desired state of the fish community and its habitat as envisioned jointly by the states, Province of Ontario, and tribes with jurisdiction over the fisheries on a lake. By describing the status of individual fish species, or groups of them, and their habitat, state of the lake reports measure progress being made to achieve the FCOs (see Table 1 in Pratt et al. 2016). The Lake Superior Committee (LSC) drafted their first FCOs in 1990 (Busiahn 1990) and modified them to be more habitat oriented in 2003 (Horns et al. 2003). The Lake Superior Technical Committee typically produces the state of the lake report for the LSC in compliance with the GLFC (GLFC 2007).

The overall FCO (Horns et al. 2003) was considered to be mostly met in the previous state of the lake report, which covered 2006-2011 (Pratt et al. 2016). The overall FCO is

> *To rehabilitate and maintain a diverse, healthy, and self-regulating fish community, dominated by indigenous species and supporting sustainable fisheries.*

There are 12 specific objectives, and Pratt et al. (2016) considered that the objectives were met for prey fish, Lake Trout, Lake Whitefish, and non-native salmonines during the previous state of the lake reporting period. Pratt et al. (2016) considered objectives for habitat, Walleye, Lake Sturgeon, and Brook Trout to have been partially met. Only the objective that calls for suppression of Sea Lamprey was not met in the previous state of the lake report (Pratt et al. 2016).

This state of the lake report describes the status of portions of the fish community and the progress made to achieve the FCO during 2012-2016. We compare the status of each FCO during the current reporting period with that of previous state of the lake reports (Hansen 1990, 1994; Ebener 2007; Gorman et al. 2010; Pratt et al. 2016); evaluate progress at achieving the FCO; and, in some cases, make recommendations for research or management that will help to achieve the objective. We describe the status of only 28 fish species in this report (Table 1) of the 88 species that are known to inhabit Lake Superior (http://www.seagrant.umn.edu/fisheries/superior_fish_species#:~:text=Minnesota%20Sea%20Grant-,Lake%20Superior%27s%20Fish%20Species,can%20be%20sorted%20by%20column). The species we evaluate are specifically identified in the FCOs, and they are important to the recreational, commercial, and subsistence fisheries. While we only consider the status of 32% of the fish community, these species are mostly native, are indicators of a healthy ecosystem, and compose a large portion of the total fish biomass in Lake Superior.

Table 1. Common names, scientific names, and origin (native or non-native) of Lake Superior fish species referenced in this report. Non-native fish with asterisks introduced by management agencies.

Common Name	Scientific Name	Origin
Bloater	*Coregonus hoyi*	Native
Brook Trout	*Salvelinus fontinalis*	Native
Brown Trout	*Salmo trutta*	Non-native
Burbot	*Lota lota*	Native
Chinook Salmon*	*Oncorhynchus tshawytscha*	Non-native
Cisco	*Coregonus artedi*	Native
Coho Salmon*	*Oncorhynchus kisutch*	Non-native
Deepwater Sculpin	*Myoxocephalus thompsonii*	Native
Kiyi	*Coregonus kiyi*	Native
Lake Sturgeon	*Acipenser fulvescens*	Native
Lake Trout	*Salvelinus namaycush*	Native
Lake Whitefish	*Coregonus clupeaformis*	Native

Common Name	Scientific Name	Origin
Longnose Sucker	*Catostomus catostomus*	Native
Ninespine Stickleback	*Pungitius pungitius*	Native
Northern Pike	*Esox lucius*	Native
Pygmy Whitefish	*Prosopium coulterii*	Native
Rainbow Smelt	*Osmerus mordax*	Non-native
Rainbow Trout (steelhead)*	*Oncorhyncus mykiss*	Non-native
Sea Lamprey	*Petromyzon marinus*	Non-native
Shortjaw Cisco	*Coregonus zenthicus*	Native
Siscowet	*Salvelinus namaycush siscowet*	Native
Slimy Sculpin	*Cottus cognatus*	Native
Splake	*Salvelinus fontinalis x* S. *namaycush*	Non-native
Spoonhead Sculpin	*Cottus recei*	Native
Trout-Perch	*Percopsis omiscomaycus*	Native
Walleye	*Sander vitreus*	Native
White Bass	*Morone chrysops*	Non-native
Yellow Perch	*Perca flavescens*	Native

THE STATE OF FISH HABITAT IN LAKE SUPERIOR IN 2017[6]

Steve Hewett[7] and William Mattes

This chapter provides progress during 2012-2016 on meeting the fish community objectives (FCOs) below for the fish habitat of Lake Superior. These objectives were promulgated by Horns et al. (2003) as one part of a series of objectives for the whole lake.

> *Achieve no net loss of the productive capacity of habitat supporting Lake Superior fishes. Where feasible, restore habitats that have been degraded and have lost their capacity for fish production. Reduce contaminants so that all fish are safe to eat. Develop comprehensive and detailed inventories of fish habitats.*

In addition to the above objectives for the whole lake, more specific habitat-focused objectives in Horns et al. (2003) were associated with certain fish species or groups of species. The objective for prey fish mentions habitat degradation as having an impact on Rainbow Smelt populations and on localized Lake Herring (now Cisco) populations. Too, habitat degradation in the lake proper and in tributaries was identified as an impediment to achievement of the objective for Lake Trout. For Lake Whitefish, habitat degradation in nearshore areas and embayments (particularly deposition of woody debris) and above dams on tributaries also was implicated as an

---

[6]Complete publication including maps of place names, abstract, other chapters, scientific fish names, and references is available at http://www.glfc.org/pubs/SpecialPubs/Sp21_02.pdf.

S. Hewett. Great Lakes Fishery Commission, 2200 Commonwealth Boulevard., Suite 100, Ann Arbor, MI 48105, USA.

W. Mattes. Great Lakes Indian Fish and Wildlife Commission, P.O. Box 9, 72682 Maple Street, Odanah, WI 54861, USA.

[7]Corresponding author (e-mail: swhewett@lycos.com).

impediment despite the ability of Lake Whitefish to rebound to higher abundances since the 1990s (see Bronte et al. 2003; Ebener et al. 2008). The FCO for Walleye, in particular, devotes considerable space to discussion of habitat impediments to recovery of Walleye populations (Horns et al. 2003). Although commercial harvest and bycatch was a major factor in reducing Lake Sturgeon populations, habitat destruction in tributaries, including industrial development and the building of hydropower dams, had major negative impacts on Lake Sturgeon spawning and rearing habitat. Suppression of the Sea Lamprey population, another objective, and the associated treatment of streams with lampricides or the blocking of adults from accessing their spawning habitat in streams, affects tributary habitats. Lastly, protection and restoration of degraded nearshore and tributary habitats are keys to maintaining diversity of indigenous species.

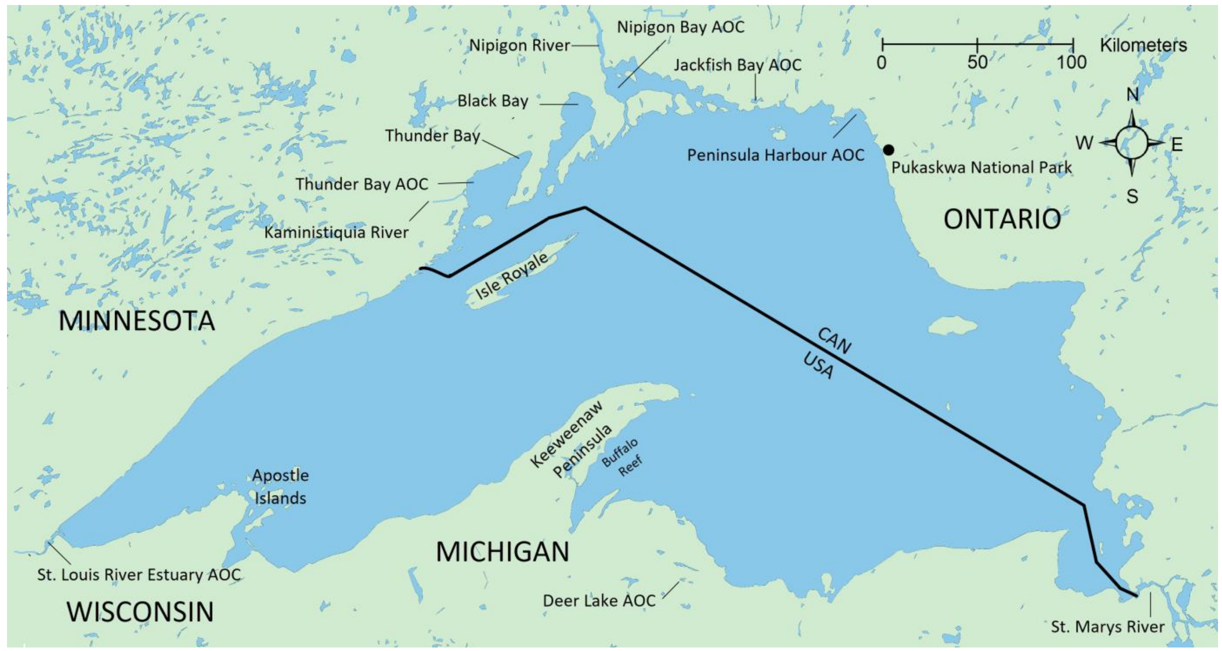
Reducing habitat impediments is critical for achieving the FCOs for Lake Superior, and most of these concerns relate to nearshore waters, embayments, and tributaries of all sizes. Summaries of progress on addressing habitat issues in state of the Great Lakes reports (EC and USEPA 2014) and in previous state of the lake reports (Hansen 1994; Schreiner 1994; Ebener 2007; Pratt 2007; Gorman et al. 2010; Pratt et al. 2016) have highlighted a continuing need for improvements to tributary, nearshore, and watershed habitats. For example, improved habitats in 17 tributaries were identified as critical to restoration of Lake Sturgeon. Degradation of tributary habitat from logging and damming has reduced the number of streams with spawning populations from more than 100 historically to just a handful. Offshore habitat in Lake Superior has been impacted little, with the exception of contaminant inputs, as compared to nearshore habitat. Fish species most impacted by habitat degradation are those that rely on nearshore waters or tributaries for all or part of their life history. Contaminants in fish flesh have been identified by Horns et al. (2003) as a use impairment owing to fish consumption advisories, making them a habitat issue in a broad sense. Moreover, additional contaminants have become important since the initial FOCs were developed, as discussed below.

Progress/Status

The Great Lakes Water Quality Agreement between Canada and the United States (IJC 2012) aims to protect and restore the waters of the Great Lakes. First signed in 1972 and amended in 2012, the agreement has focused action on habitat and contaminant issues across the lakes. The plan designates 43 Areas of Concern (AOCs) as specific areas showing severe environmental degradation and having at least one of 14 Beneficial Use Impairments (BUIs), most of which relate to fish and wildlife impairments, including habitat, or to contaminant impacts on fish, wildlife, or humans. Remedial Action Plans (RAPs) were developed for each AOC to direct efforts to eliminate the impairments and to allow the AOCs to be delisted. Seven of the AOCs are within the Lake Superior basin: two inland lakes in Michigan impacted by mining (Torch and Deer Lakes) that have outlets flowing into Lake Superior; the St. Louis River Estuary AOC (Fig. 1) between Minnesota and Wisconsin; and Peninsula Harbour, Jackfish Bay, Nipigon Bay, and Thunder Bay AOCs in Ontario (Fig. 1). RAPs have been the means for stakeholders to work together to restore beneficial uses to the AOCs. Across all Great Lakes, as of 2016, seven AOCs have been delisted and two have been designated Areas of Concern in Recovery (AOCiR) (Hartig et al. 2018).

The Deer Lake AOC in Michigan (Fig. 1) was delisted in 2014 and was the first to be delisted in the Lake Superior basin. Delisting resulted from mercury cleanup efforts that began prior to 2014. Next in importance, Jackfish Bay, Ontario (Fig. 1), was designated in 2011 as an AOCiR. Of the nine BUIs listed for the St. Louis River Estuary AOC (Fig. 1), the aesthetics BUI along the waterfront has been delisted, and progress has been made on the other impairments. The current status of restoration of impairments and progress toward delisting AOCs for the U.S. can be found at (https://www.epa.gov/great-lakes-aocs) and for Canada at (https://www.canada.ca/en/environment-climate-change/services/great-lakes-protection/areas-concern.html).

Fig. 1. Lake Superior showing locations of sites mentioned in the text.



The Lake Superior Committee of the Great Lakes Fishery Commission (GLFC) and its technical committee, in addition to other agencies, tribal groups, and public partnerships, have been instrumental in achieving progress toward habitat restoration in and outside of the AOC process. Specific to the AOCs in the U.S., a joint effort of the Great Lakes Commission and the National Oceanic and Atmospheric Administration, acting through regional partnerships, funds key habitat projects. Funded projects have primarily been in Lakes Huron, Michigan, and Erie. We note that these regional partnerships are an underutilized source of funding for Lake Superior projects. Two other funding sources that have been underutilized in Lake Superior are the GLFC partnerships with the Great Lakes Fishery & Environmental Restoration Program of the U.S. Army Corps of Engineers (https://www.lrd.usace.army.mil/Home/Great-Lakes-Fishery-Ecosystem-Restoration-Program) and the Great Lakes Fish and Wildlife Restoration Act (https://www.fws.gov/midwest/fisheries/glfwra-grants.html) of the U.S. Fish and Wildlife Service. Both funding programs have advisory or approval panels consisting of fisheries agency representatives from the Great Lakes, and they are an obvious source for funding Lake Superior habitat projects. The Great Lakes Restoration Initiative also provides funding for projects through the U.S. Environmental Protection Agency and its partner agencies (https://www.glri.us).

Environmental and fishery-management agencies have been making progress on restoration and inventory initiatives, but much remains to be done and many impediments remain to be overcome to achieve the habitat objectives specified in Horns et al. (2003). Remaining impediments include hydrological modification of regulated and unregulated tributary flows through the modification of water-management plans and land-conservation measures; long-term mitigation of legacy-mining waste on Buffalo Reef (Fig. 1) (Kerfoot et al. 2017); and additional restoration of estuaries, including coastal wetlands and floodplains. Buffalo Reef is an important Lake Whitefish and Lake Trout spawning area located offshore along the eastern side of the Keweenaw Peninsula that is threatened by the movement of 100-year-old copper mining waste (stamp sands), which threatens to completely cover the reef. These stamp sands contain high concentrations of mercury and copper that are highly inimical to plant and animal life (LAMP 2017).

The Lake Superior Lakewide Action and Management Plan (LAMP) classifies all habitat indicators for Lake Superior as good except for "maintain tributaries and watersheds in good ecological condition", which is listed as fair (LAMP 2016). In the preceding state of Lake Superior report, Pratt et al. (2016) list many FCOs as mostly achieved or achieved, with the exception of habitat, which is listed as partially achieved along with goals for Walleye, Lake Sturgeon, and Brook Trout.

Fish consumption advisories for Lake Superior remain in place as toxic chemicals continue to accumulate in fish. Legacy chemicals have decreased significantly over a 30-year period, but further declines have slowed (McGoldrick and Murphy 2016). The zero discharge by 2020 initiative (https://www.epa.gov/sites/production/files/2015-11/documents/lake-superior-zero-discharge-demonstration-program-2012-8pp.pdf) of the Lake Superior LAMP is likely unachievable. During this reporting period (2012-2016), Canada and the U.S. have identified hexabromocyclododecane (HBCD), long-chain perfluorinated carboxylic acids (LC-PFCAs), perfluorooctanoic acid (PFOA), polybrominated diphenyl ethers (PBDEs), polychlorinated biphenyls (PCBs), short-chain chlorinated paraffins (SCCPs), and mercury as Chemicals of Mutual Concern (https://binational.net/annexes/a3-2/). Microplastics, too, are of increasing concern, and studies of their effects on the aquatic community of Lake Superior are few. The first analyses of microplastics in the Great Lakes (Hoffman and Hittinger 2017) and in their tributaries (Baldwin et al. 2016) show that microplastic concentrations in Lake Superior are low in comparison with the lower Great Lakes, but microplastics remain an issue of concern.

Physical and Climate Variables and Climate Change

Water temperature, length of the stratified period, ice cover, and water level show significant interannual variation (www.glerl.noaa.gov). As an example, the annual maximum ice cover for Lake Superior ranged from a low of 11.9% (2002-2003) to a high of 94.7% (1979) during 1973-2016. During this reporting period (2012-2016), annual maximum ice cover ranged from a low of 12.9% (2012) to a high of 92.5% (2014). The ice cover during 2012-2016 is nearly the maximum range for the entire 45-year period, which is consistent with the prediction that climate variables are becoming more extreme. Water levels just prior to this current reporting period were among the lowest recorded since the drought of the 1920s, and they were a concern in Pratt et al. (2016). Since Pratt et al. (2016) was published, water levels have quickly rebounded to move above the long-term average in 2014. The average Lake Superior water temperature at the Great Lakes Environmental Research Laboratory (GLERL) monitoring station in 2014 (4.86^{o} C) was the lowest recorded since 1996 (4.39^{o} C) (GLERL, unpublished data).

Annual variation in water temperature, length of the stratified period, ice cover, and water level are expected to affect fish habitat and show correlated patterns through time in lakes separated by wide geographic distances across the planet (O'Reilly et al. 2015). That variation should be accounted for in the future when objectives for the fish community are modified. Even more challenging, these variables are likely to be affected by climate change, creating more uncertainty for fishery managers.

The Superior Work Group of the Lake Superior LAMP organized an initial effort to project the potential for climate-change impacts on Lake Superior (Huff and Thomas 2014). These projected climate-change impacts include, by the end of the 21st century, an increase in annual average air temperatures in the range of 3.0-4.5^{o} C; a slight increase in annual precipitation with decreased summer precipitation and increased winter precipitation; an increase in frequency and intensity of storms; an increase in average annual water temperatures of approximately 5-7^{o} C; a decrease in the extent and duration of ice cover by perhaps 1-2 months; only a slight effect on lake levels, which will continue likely to be variable; and earlier springs and summers and later first frost in fall, such that the length of the growing season at Pukaskwa National Park in Ontario (Fig. 1) may increase by 22.6 days.

The prediction of an increase in the frequency and intensity of storms is highlighted, perhaps, by events in the summer of 2016. In July 2016, a storm event deposited 20-30 cm of rain over an 8-hour period, causing extreme flooding in Wisconsin's tributaries to Lake Superior. The flooding caused numerous evacuations and damaged hundreds of kilometers of roads. Large plumes of sediment-rich water stretched across the southern coast of Lake Superior (https://wim.usgs.gov/geonarrative/badriver2016flood/).

Conclusions

Tributary and nearshore habitats have been the most-impacted fish habitats in Lake Superior. Many of these impacts have been highlighted in the AOCs, but many others also exist, such as the stamp sands threatening Buffalo Reef. Contaminants remain a major issue even as lower concentrations have been observed, and the list of new contaminants of concern grows longer. A variety of funding sources exists to assist agencies, local governments, and concerned citizen groups to address habitat improvement and protection projects. Both physical and climate variables impact fish habitat in both positive and negative ways. Potential climate and man-made effects should be accounted for in future modifications to Horns et al. (2003) and documented in reports such as this one.

STATUS OF THE LOWER FOOD WEB IN LAKE SUPERIOR IN 2017[8]

Michael E. Seizen[9]

We used U.S. Environmental Protection Agency (EPA) data on lakewide abundance and biomass of phytoplankton and invertebrates to evaluate the status of Lake Superior's lower food web and potential changes in lower trophic levels to support fisheries. Data were collected through the EPA's Cooperative Science and Monitoring Initiative (CSMI) (https://www.epa.gov/great-lakes-monitoring/cooperative-science-and-monitoring-initiative-csmi) in 2011 and 2016, Lake Superior lower-food-web sampling in 2006, and annual data from the Great Lakes National Program Office biology monitoring program. Lake Superior CSMI data are collected every five years, and they are spatially extensive (54 stations). Biology monitoring data have less spatial distribution (23 stations) but greater temporal detail because samples are collected twice each year. Thus the two programs offer complementary information.

There was general agreement on the status of the lower food web among CSMI and biology monitoring data. Primary production estimated by epilimnetic chlorophyll *a* and epilimnetic phytoplankton biovolume was variable among years but showed no overall increases or declines from 2001 to 2016. During those 16 years, the mean of the summer epilimnetic phytoplankton biovolume was 163.2 $\mu m^3 \bullet \mu L^{-1}$ (standard error (SE) = 13.1). The 1997-2016 pooled CSMI and annual summer zooplankton abundance

---

[8]Complete publication including maps of place names, abstract, other chapters, scientific fish names, and references is available at http://www.glfc.org/pubs/SpecialPubs/Sp21_02.pdf.

[9]**M.E. Sierszen**. U.S. Environmental Protection Agency, Center for Computational Toxicology and Ecology, Great Lakes Toxicology and Ecology Division, 6201 Congdon Boulevard, Duluth, MN 55804, USA (e-mail: sierszen.michael@epa.gov).

exhibited periodicity with peaks approximately every 7-9 years starting in 2000, but abundance did not increase or decline significantly.

Zooplankton abundance was 3217.6 animals•m^{-3} (SE = 183.5), and biomass was 23.1 mg•m^{-3} (SE = 0.87). *Mysis diluviana* (hereafter, *Mysis*) was most abundant in offshore waters >100 m and was rarely collected at stations <30 m. Summer abundance of *Mysis* increased significantly (N = 130, P < 0.0001, R^2 = 0.37) from about 100•m^{-2} in 2007 to 300•m^{-2} during 2013-2016. *Mysis* biomass increased significantly (N = 130, P < 0.0001, R^2 = 0.28) from 100-200 mg•m^{-2} in 2007 to 800 mg•m^{-2} in 2012 and then decreased slightly to 200-400 mg•m^{-2} during 2013-2016 (Jude et al. 2018).

Abundance and biomass of the benthic amphipod *Diporeia* spp. peaked in waters 31-100 m deep at 1,200-1,500 animals•m^{-2} and 250-300 mg•m^{-2} in CSMI data from 2006 to 2016. *Diporeia* spp. abundances have been consistent since 1994 in Lake Superior and are higher than ecosystem-health indicators proposed in the Great Lakes Water Quality Agreement of 1978 (UN 1978), which called for at least 220-320 *Diporeia* spp. m^{-2} in waters <100 m and 30-160 m^{-2} in waters >100 m. Contemporary abundances are also greater than those in the 1970s (Cook 1975), likely due to declines in benthivorous fish after Lake Trout recovery (see Status of Prey Fish in Lake Superior in 2017 chapter).

Overall, Lake Superior's lower food web appears to be in good condition and stable over decadal time frames with no apparent decline in the capacity of lower trophic levels to support fisheries. Thus the status during the current reporting period was the same as in the previous reporting period.

Status of Prey Fish in Lake Superior in 2017[10]

Owen T. Gorman[11], Mark R. Vinson, and Daniel L. Yule

The fish community objective (FCO) for prey fish (Horns et al. 2003) in Lake Superior is to establish

> *A self-sustaining assemblage of prey dominated by indigenous species at population levels capable of supporting desired populations of predators and a managed commercial fishery.*

The prey fish assemblage of Lake Superior includes Cisco; Bloater; Shortjaw Cisco; Kiyi; Lake Whitefish; Rainbow Smelt; Ninespine Stickleback; Trout-Perch; Pygmy Whitefish; Longnose Sucker; and Slimy, Spoonhead, and Deepwater Sculpins (Gorman 2012; Vinson et al. 2016). In this chapter, we examine the status and trends of the principal species of the prey-fish assemblage except for Shortjaw Cisco, Longnose Sucker, and Lake Whitefish. The status and trends of Lake Whitefish are addressed in a separate chapter (see Status of Lake Whitefish in Lake Superior in 2017 chapter). However, when overall biomass estimates of prey fish are given in this chapter, they are included.

Our lakewide assessment data come from annual spring daytime cross-contour bottom-trawl surveys that sample nearshore waters of 15-80 m depths (nearshore surveys) at 52-87 stations distributed throughout the lake, and annual summer daytime along-contour bottom-trawl surveys that sample

---

[10]Complete publication including maps of place names, abstract, other chapters, scientific fish names, and references is available at http://www.glfc.org/pubs/SpecialPubs/Sp21_02.pdf.

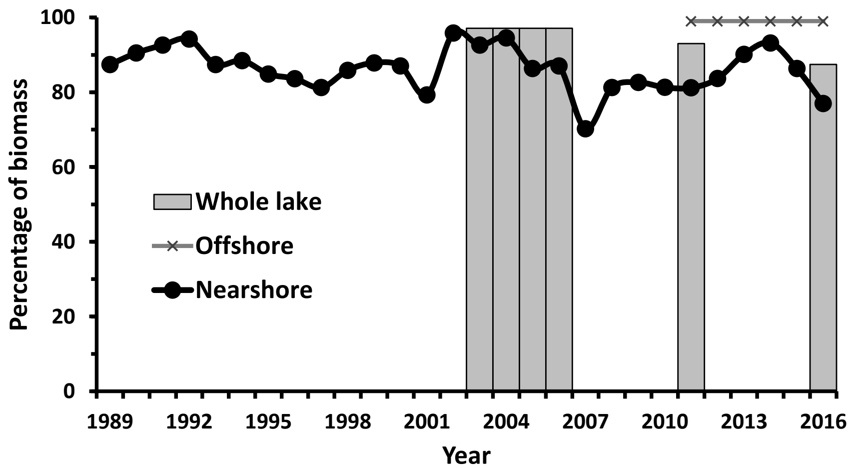
O.T. Gorman, M.R. Vinson, and D.L. Yule. U.S. Geological Survey, Great Lakes Science Center, Lake Superior Biological Station, 2800 Lake Shore Drive East, Ashland, WI 54806, USA.

[11]Corresponding author (e-mail: otgorman@usgs.gov).

offshore waters >80 m depth (offshore surveys) at 30-35 stations (Vinson et al. 2016). Summer whole-lake surveys were conducted during 2003-2006, in 2011, and in 2016 as part of the Cooperative Science and Monitoring Initiative (CSMI) (https://www.epa.gov/great-lakes-monitoring/cooperative-science-and-monitoring-initiative-csmi) using cross- and along-contour daytime bottom-trawl surveys and nighttime acoustic surveys that sampled depths of 15 to 200 m. Whole-lake surveys during 2003-2006 included a mixture of 52-86 nearshore stations and 8-21 offshore stations. Whole-lake surveys in 2011 and 2016 included 51 and 53 stations, respectively, from a mixture of nearshore and offshore sites. We will focus on changes in the prey-fish assemblage during the current state of the lake reporting period (2012-2016) relative to the previous reporting period (2006-2011), but we will also review some trends dating back to 1989. We will address the FCO for the prey-fish assemblage stepwise by addressing the proportion of indigenous species, population trends in principal prey species, and whether or not the prey-fish assemblage has adequate biomass to support populations of Lake Trout—the principal predator. Addressing whether or not current prey-fish populations can support a managed commercial fishery is addressed in chapters on the status of Cisco and Lake Whitefish.

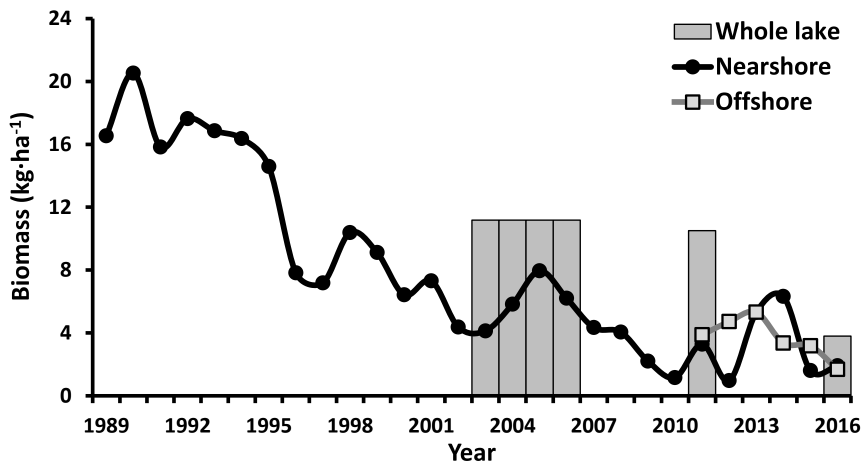
Biomass of indigenous nearshore prey fish was greater than that of non-native species during the current reporting period. For the purposes of this report, the only non-native species included in the prey-fish assemblage is Rainbow Smelt because other non-native species are rare and taken infrequently during surveys. Indigenous species dominated the prey-fish community biomass in nearshore waters, remaining at or above 80% during 1989-2016 except in 2007 and 2016 (Fig. 2). The trend in whole-lake prey-fish biomass from CSMI surveys in 2003-2006, 2011, and 2016 CSMI was congruent with this pattern. From 1989 to 2016, the nearshore prey-fish assemblage was dominated by indigenous species, which represented on average more than 86% of prey-fish biomass. The nearshore prey-fish assemblage was dominated by Rainbow Smelt, Cisco, Bloater, and Lake Whitefish. These four species accounted for 87% of total prey-fish biomass during 1989-2016; when Rainbow Smelt are omitted, the proportion drops to 73%. Indigenous species consistently represented >99% of prey-fish biomass in offshore waters as Rainbow Smelt is largely restricted to nearshore waters.

Fig. 2. Percentage of biomass of indigenous prey fish from nearshore, offshore, and whole-lake surveys in Lake Superior, 1989-2016. Nearshore biomass is based on annual spring daytime cross-contour bottom-trawl surveys, offshore biomass is based on summer daytime on-contour bottom-trawl surveys, and whole-lake biomass is based on both cross- and along-contour daytime bottom-trawl surveys and nighttime acoustic surveys.



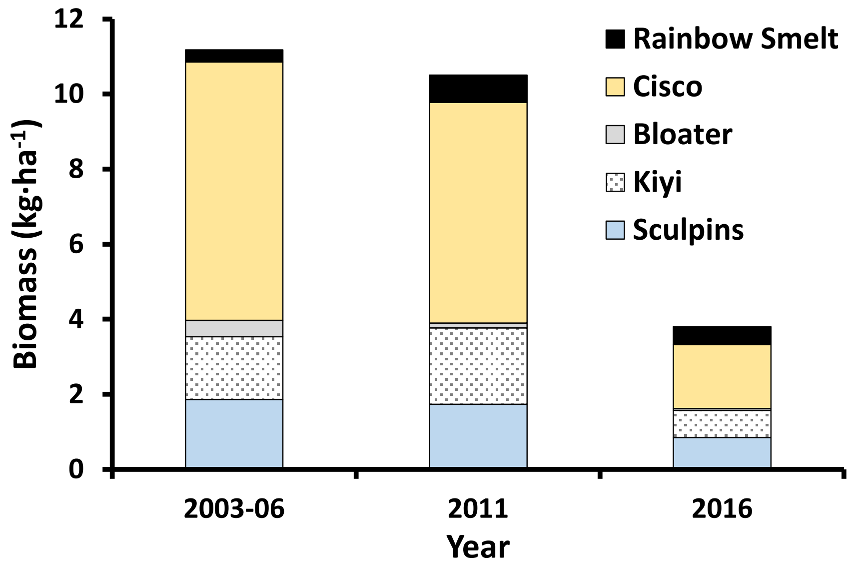
Prey-fish biomass declined 42% in nearshore surveys, 57% in offshore surveys, and 64% in whole-lake surveys from the end of the previous reporting period (2011) to the end of the current reporting period (2016) (Fig. 3). The increase in nearshore biomass in 2013 and 2014 of the current reporting period was attributed in part to large catches of adult Lake Whitefish at two stations in the Apostle Islands that accounted for 27% and 51%, respectively, of the mean total prey-fish biomass in those years. If those outliers are omitted from annual biomass estimates, the average prey-fish biomass for the current reporting period is 35% lower than the previous period; otherwise, there would be only a 9% decline. The concordant declining trends among nearshore, offshore, and whole-lake surveys indicate that prey-fish biomass available for Lake Superior predator populations was lower during the current reporting period than all other previous reporting periods.

Fig. 3**.** Mean prey-fish biomass in whole-lake, nearshore, and offshore surveys conducted in Lake Superior, 1989-2016.



Whole-lake prey-fish biomass provides a more accurate picture of the entire prey-fish assemblage in Lake Superior because it uses both bottom-trawl and acoustic sampling and is area weighted by depth (Fig. 4). In the whole-lake CSMI surveys, prey-fish biomass was dominated by Cisco during 2003-2006 and 2011; while Cisco was still the dominant species in 2016, its abundance was reduced 71% and 75% compared to previous whole-lake surveys in 2003-2006 and 2011, respectively. Similarly, other species underwent substantial reductions in abundance in the whole-lake survey: Bloater (62-89%), Kiyi (57-65%), and sculpins (51-55%). Deepwater Sculpin accounted for >90% of the whole-lake biomass of all sculpin species during the surveys. Rainbow Smelt biomass increased 48% in 2016 compared to biomass during 2003-2006, in contrast to the biomass of native prey fish.

Fig. 4. Whole-lake mean prey-fish biomass observed in the Cooperative Survey and Monitoring Initiative in Lake Superior, 2003-2006, 2011, and 2016. Sculpins include Slimy, Spoonhead, and Deepwater species.



Biomass of Nearshore Prey Fish

Nearshore biomass of Cisco and Bloater was stable but low during the current reporting period, declining on average by 50% and 32%, respectively, compared to the previous reporting period (Figs. 5, 6). Cisco and Bloater biomass varied considerably up until the early 2000s and became stable and low after 2007 for Cisco and after 2009 for Bloater. Peaks in Cisco and Bloater biomass until 2006 coincided with the maturation of strong to moderate year-classes that appeared as yearlings in 1989-1991, 1999, 2004, and 2006 (Pratt et al. 2016, Fig. 22). Moderate year-classes of Bloater that appeared as yearlings in 2015 and 2016 did not coincide with similar moderate year-classes of Cisco. Ray et al. (2007) showed that selection of coregonines by both the lean and siscowet forms of Lake Trout increased after 1991 based on an increasing proportion of coregonines in their diet. This increase suggests that predation by Lake Trout on Cisco and Bloater has contributed to declines in their biomass in combination with weak and intermittent recruitment.

Fig. 5. Mean annual density and biomass of age-1 Cisco from spring lakewide bottom-trawl surveys conducted in nearshore areas of Lake Superior, 1989-2016.

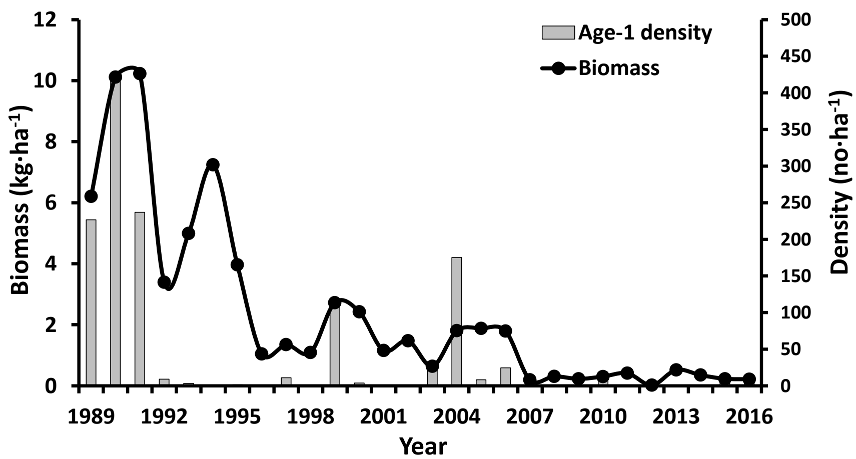
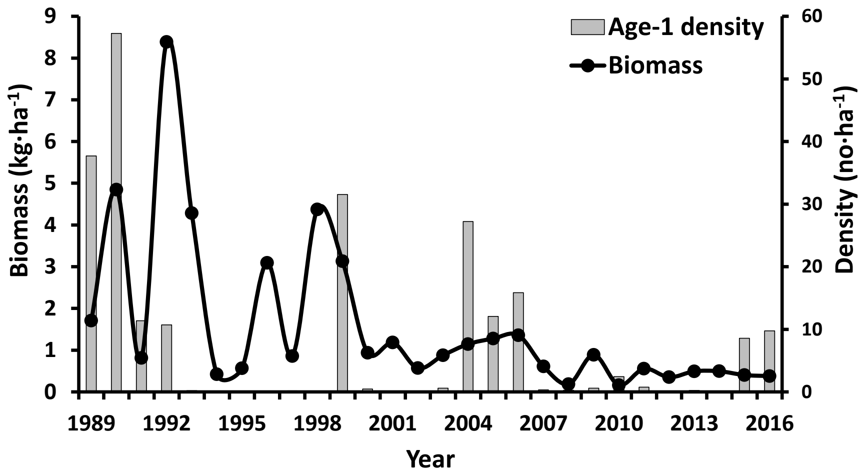
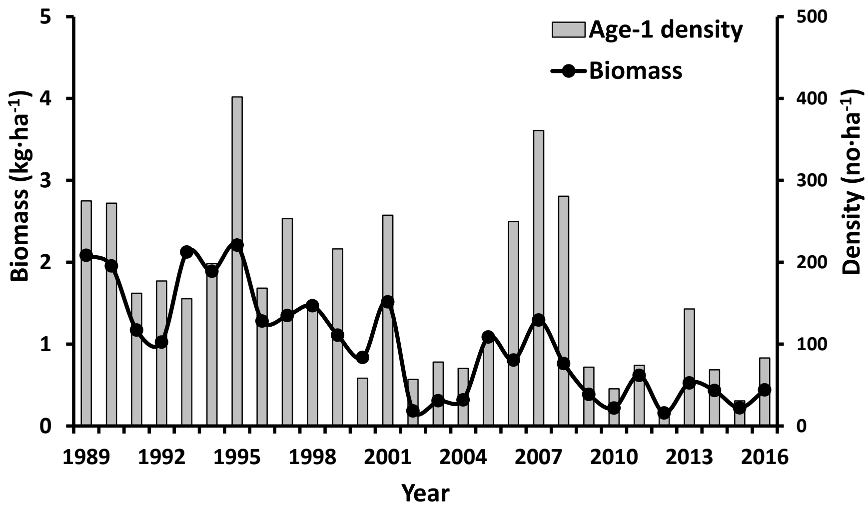


Fig. 6. Mean annual density and biomass of age-1 Bloater from spring lakewide bottom-trawl surveys conducted in nearshore areas of Lake Superior, 1989-2016.



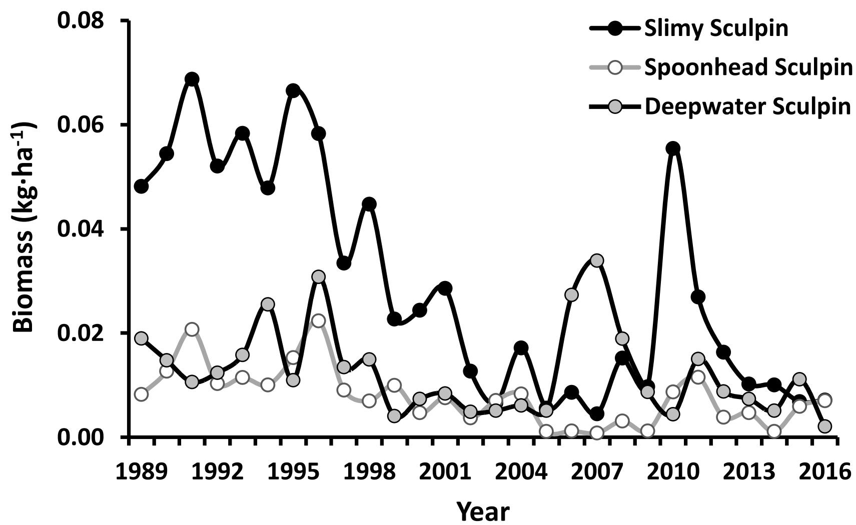
Biomass of Rainbow Smelt in nearshore areas was stable during the current reporting period but was 48% lower on average than during the previous period. Since 2009, Rainbow Smelt biomass averaged 30% less than from 1989-2008 (Fig. 7). Much of the annual variation in biomass was driven by variable year-class strength because the population was dominated by age-1 and age-2 fish (Pratt et al. 2016, Fig. 20). Rainbow Smelt is an important prey of Lake Trout in Lake Superior (Conner et al. 1993; Ray et al. 2007), and these trends are consistent with strong predation (Gorman 2007, 2012). Ray et al. (2007) showed that there was strong selection of Rainbow Smelt by both the lean and siscowet forms of Lake Trout, and selection by siscowets increased after 1998.

Fig. 7. Mean annual biomass density and biomass of Rainbow Smelt from spring lakewide bottom-trawl surveys conducted in nearshore areas of Lake Superior, 1989-2016.



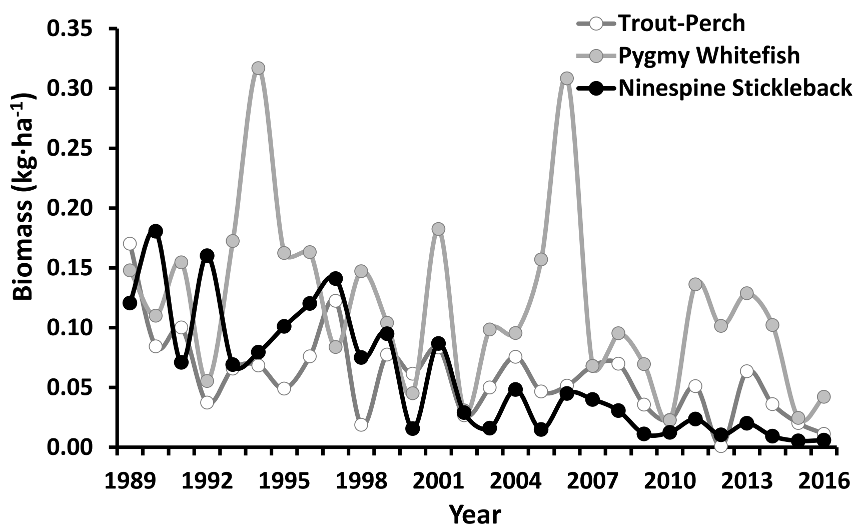
Nearshore biomass of Slimy, Spoonhead, and Deepwater Sculpins has trended downward since 1989, especially after 1996, and that trend continued during the current reporting period (Fig. 8). The downward trend in Slimy Sculpin biomass was interrupted in 2010-2011 due to large catches in Whitefish Bay. A comparison of sculpin biomass during 1989-1996 with the current reporting period shows that Slimy Sculpin biomass declined the most (82%) while Spoonhead and Deepwater Sculpin biomass declined 64% and 59%, respectively. In the current reporting period, Slimy and Deepwater Sculpin biomass declined on average 50% and 62%, respectively, compared to the previous period while Spoonhead Sculpin biomass remained unchanged. As with other prey fish, these trends are consistent with strong predation pressure by Lake Trout, especially after 1996. Siscowets showed selection for sculpins as prey in Lake Superior during 1986-2001 (Ray et al. 2007).

Fig. 8. Mean annual biomass of Slimy, Spoonhead, and Deepwater Sculpins from spring lakewide bottom-trawl surveys conducted in nearshore areas of Lake Superior, 1989-2016.



Nearshore biomass of Pygmy Whitefish, Ninespine Stickleback, and Trout-Perch has trended downward since 1989 and is especially evident for Ninespine Stickleback (Fig. 9). Biomass of Ninespine Stickleback and Trout-Perch was at its lowest levels during both the current and previous reporting periods. The synchronous downward trends in Ninespine Stickleback and Trout-Perch biomass are driven likely by Lake Trout predation because they are a common prey of both leans and siscowets (Ray et al. 2007). The trend in Pygmy Whitefish biomass was irregular and likely driven by variation in recruitment rather than predation since it is seldom observed in the diet of Lake Trout (Conner et al. 1993; Ray et al. 2007).

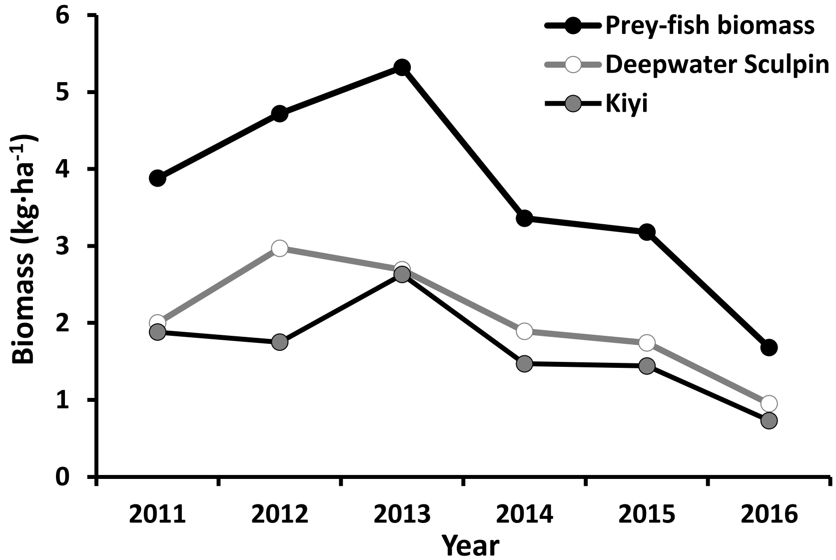
Fig. 9. Mean annual biomass of Trout-Perch, Pygmy Whitefish, and Ninespine Stickleback, and captured from spring lakewide bottom-trawl surveys conducted in nearshore areas of Lake Superior, 1989-2016.



Biomass of Offshore Prey Fish

Biomass of prey fish in offshore waters, based on summer bottom-trawl surveys, consisted almost entirely of Kiyi and Deepwater Sculpin and declined 41% from an average of 4.6 kg•ha^{-1} during 2011-2013 to 2.7 kg•ha^{-1} during 2014-2016 (Fig. 10). Kiyi biomass declined 42% from an average of 2.1 kg•ha^{-1} during 2011-2013 to 1.2 kg•ha^{-1} during 2014-2016. A lack of regular recruitment combined with strong predation pressure underlie this trend because Kiyi is the primary prey of large siscowets (Ray et al. 2007; Sitar et al. 2008; Gamble et al. 2011a). The decline in biomass of Kiyi was paralleled by that of Deepwater Sculpin, which declined 40% from an average of 2.6 kg•ha^{-1} during 2011-2013 to 1.5 kg•ha^{-1} during 2014-2016. Deepwater Sculpin is a common prey of siscowets (Sitar et al. 2008; Gamble et al. 2011a; Isaac et al. 2012), and its decline may also be the result of increased predation.

Fig. 10. Total prey-fish biomass and mean annual biomass of Kiyi and Deepwater Sculpin from summer bottom-trawl surveys conducted in offshore waters of Lake Superior, 2011-2016.



Summary

Prey-fish biomass during the current reporting period declined compared to the previous reporting period and both periods were dominated by indigenous species. Biomass of prey fish in nearshore areas of Lake Superior during the current reporting period declined 35% overall compared to the previous reporting period and was 76% lower than during 1989-2000. Except for Spoonhead Sculpin, biomass of individual prey fish declined 11% to 63% in nearshore waters from the previous reporting period to the present reporting period. These trends are consistent with a lack of consistent recruitment in Cisco, Bloater, and Kiyi populations combined with strong predation pressure on the prey-fish community by both lean and siscowet Lake Trout (Gorman and Hoff 2009; Gorman 2012; Gorman and Selgeby 2020).

STATUS OF CISCO IN LAKE SUPERIOR IN 2017[12]

Cory A. Goldsworthy[13] and Daniel L. Yule

Population Status

The fish community objectives (FCOs) for Lake Superior do not specifically address Cisco (Horns et al. 2003) but rather they are grouped with the prey-species objective to establish

> *A self-sustaining assemblage of prey dominated by indigenous species at population levels capable of supporting desired populations of predators and a managed commercial fishery.*

The prey-fish FCO recognizes that Cisco was historically (pre-1970s) the dominant prey fish, which served as prey for Lake Trout populations and supported a large commercial fishery (Horns et al. 2003). During more-recent times, lakewide biomass peaked during 1986-1990 and has since declined from one reporting period to the next (Pratt et al. 2016).

The decline in lakewide biomass of Cisco continued during the current reporting period, based on bottom-trawl and acoustic- and midwater-trawl surveys. Recruitment, as measured by the catch of age-1 fish in the U.S. Geological Survey (USGS) spring bottom-trawl survey, has been sporadic and in decline with only two strong year-classes (1998 and 2003) recruiting

---

[12]Complete publication including maps of place names, abstract, other chapters, scientific fish names, and references is available at http://www.glfc.org/pubs/SpecialPubs/Sp21_02.pdf.

C.A. Goldsworthy. Minnesota Department of Natural Resources, Lake Superior Area Fisheries Program, 5351 North Shore Drive, Duluth, MN 55804, USA.

D.L. Yule. U.S. Geological Survey, Great Lakes Science Center, Lake Superior Biological Station, 2800 Lake Shore Drive East, Ashland, WI 54806, USA.

[13]Corresponding author (e-mail: cory.goldsworthy@state.mn.us).

since the early 1990s (USGS 2017). Modest recruitment events were documented for the 2005, 2009, and 2014 year-classes (USGS 2017). Catch rates of Cisco >250-mm total length (adults) in lakewide midwater-trawl surveys conducted by the USGS averaged 5.4 fish•km^{-1} (SE = 1.1; N = 76 trawl samples) during 2003-2006, but subsequent catches averaged 2.0 fish•km^{-1} (SE = 0.4; N = 90) in 2011 and 1.9 fish•km^{-1} in 2016 (SE = 0.5; N = 64) (USGS 2019). This decline in adults coincides with low recruitment and the loss of the strong 1984 and 1988-1990 year-classes to senescence. Lakewide biomass, estimated using acoustic and trawl apportionment methods described by Yule et al. (2013), was estimated at 55,400 metric tons in 2003-2006, 47,300 metric tons in 2011, and 14,600 metric tons in 2016. (Matthias and Yule 2020).

Fishery agencies in Minnesota, Wisconsin, and Ontario now conduct late-autumn acoustic surveys (Yule et al. 2006, 2009, 2012) to estimate abundance of pre-spawn Cisco at sites where commercial fisheries operate. Some of these surveys are being combined with commercial-fishery yield and sex- and age-composition data in statistical catch-at-age models described by Fisch et al. (2019a, 2019b). These models will provide insight into population dynamics and can be used to forecast how populations may respond to alternate management policies. At present, agencies that manage Cisco roe fisheries have representatives working as a team to advance models for different jurisdictions.

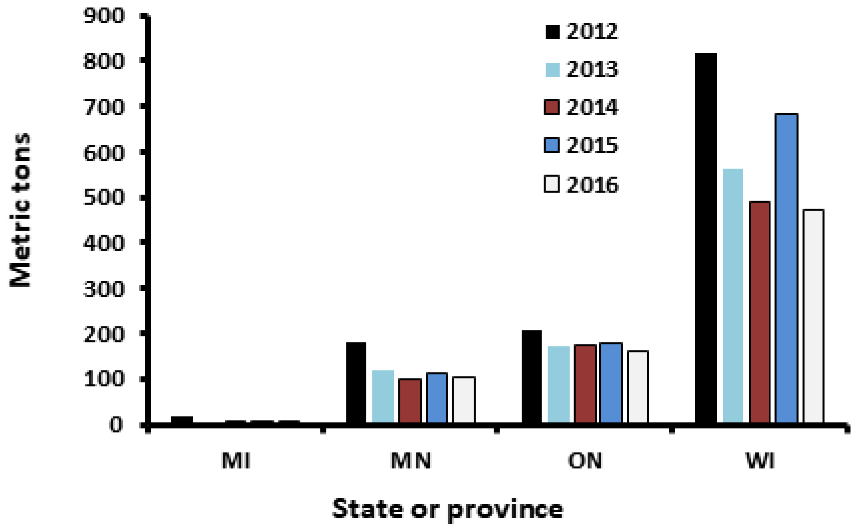
Management and Current Fisheries

Cisco populations are managed differently among political jurisdictions. The state-licensed fishery in Michigan is prohibited from targeting Cisco; instead, it is limited to bycatch allowances in the chub (i.e., Bloater and Kiyi) fishery. Consequently, nearly the entire harvest of Cisco in Michigan waters is taken by the tribal commercial fishery in 1836 and 1842 Treaty-ceded waters. In Minnesota and Ontario, a harvest-control rule was established that permitted the commercial fishery to harvest no more than 10% of the spawning-stock biomass estimated during the annual hydroacoustic surveys in each jurisdiction. In Wisconsin, there were ongoing discussions during the reporting period to institute a control policy allowing harvest of no more than 15% of the spawning-stock biomass. A range of 10-

15% harvest of mature females >250 mm total length was recommended by Stockwell et al. (2009).

Commercial-fishery yield declined in all jurisdictions during the reporting period. The harvest from Michigan waters was the lowest of all political jurisdictions during the reporting period whereas the harvest from Wisconsin was the largest (Fig. 11). A large portion of the yield since 2012 was used to supply caviar to European countries. The supply of Cisco caviar from Lake Superior exceeded market demand in Europe during the latter part of the reporting period, which subsequently reduced the harvest. From 2012 to 2016, the average harvest in Minnesota and Ontario declined 18% and 19%, respectively, compared to the previous 5-year average. The average harvest in Wisconsin waters increased 42% compared to the previous 5-year average, but the harvest from Wisconsin declined from more than 800 metric tons in 2012 to about 500 metric tons in 2016 (Fig. 11). The currently low market demand for Cisco caviar should not be viewed as an effective tool to ensure sustainability of the populations given continued low levels of Cisco recruitment (see Status of Prey Fish in Lake Superior in 2017 chapter). In Minnesota and Wisconsin, where similar gillnet-mesh sizes (70-76 mm stretch mesh) are used to harvest Cisco, the 2009 year-class comprised approximately half of the total harvest in 2014. Based on the USGS year-class strength index (see Status of Prey Fish in Lake Superior in 2017 chapter), the 2005 and 2009 year-classes were of similar abundance; however, contribution of the 2005 year-class to the 2014 roe fishery was only 3% in Minnesota and 1% in Wisconsin, indicating longevity of year-classes of similar magnitude may be relatively short given current levels of exploitation.

Fig. 11. Annual commercial-fishery yield of Cisco from political jurisdictions on Lake Superior, 2012-2016.



Cisco meets the prey-fish objective of a self-sustaining population that currently meets ecosystem needs and supports a managed commercial fishery (Horns et al. 2003); however, weak and sporadic recruitment and the subsequent decline in its lakewide biomass during the reporting period make the continued achievement of this objective tenuous. Progress has been made by all management agencies to respond to the recommendations of Pratt et al. (2016) to collaboratively evaluate the long-term sustainability of current harvest rates. Continuation of these efforts will be critical to ensure fishery managers have the tools needed to achieve sustainable harvests. Future revisions to the FCOs should consider creating a specific objective for Cisco.

STATUS OF LAKE WHITEFISH IN LAKE SUPERIOR IN 2017[14]

S. Ben Michaels[15] and Owen T. Gorman

The fish community objective (FCO) for Lake Whitefish (Horns et al. 2003) in Lake Superior is to

> *Maintain self-sustaining populations of lake whitefish within the range of abundance observed during 1990-1999.*

The magnitude of commercial yields from Lake Superior has varied substantially since the nineteenth century (Fig. 12). Yields peaked during the late 1800s, but lax regulation of effort and harvest quickly drove Lake Whitefish yield to low levels into the beginning of the twentieth century (Lawrie and Rahrer 1972). Commercial yields thereafter remained at relatively low levels, generally increasing throughout the first half of the twentieth century then decreasing during the 1950s as the number of Sea Lamprey increased. Commercial yields subsequently increased through the second half of the 1990s before stabilizing at roughly 1,500 metric tons.

---

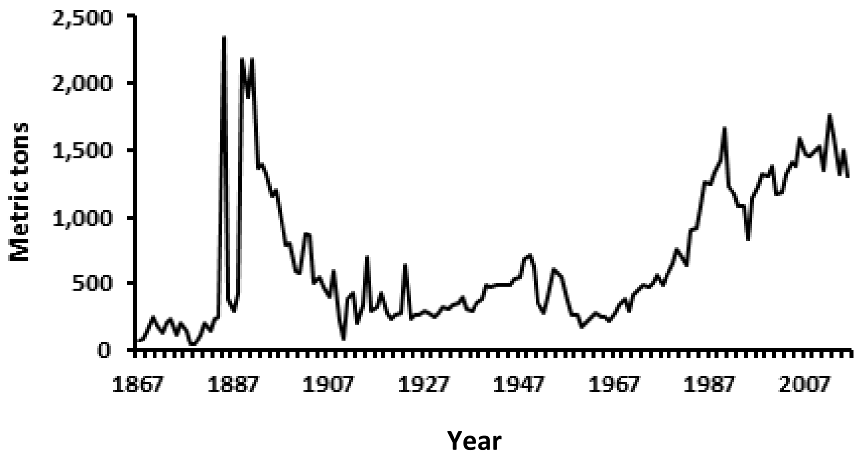
[14]Complete publication including maps of place names, abstract, other chapters, scientific fish names, and references is available at http://www.glfc.org/pubs/SpecialPubs/Sp21_02.pdf.

S.B. Michaels. Great Lakes Indian Fish and Wildlife Commission, P.O. Box 9, 72682 Maple Street, Odanah, WI 54861, USA.

O.T. Gorman. U.S. Geological Survey, Great Lakes Science Center, Lake Superior Biological Station, 2800 Lake Shore Drive East, Ashland, WI 54806, USA.

[15]Corresponding author (e-mail: smichaels@glifwc.org).

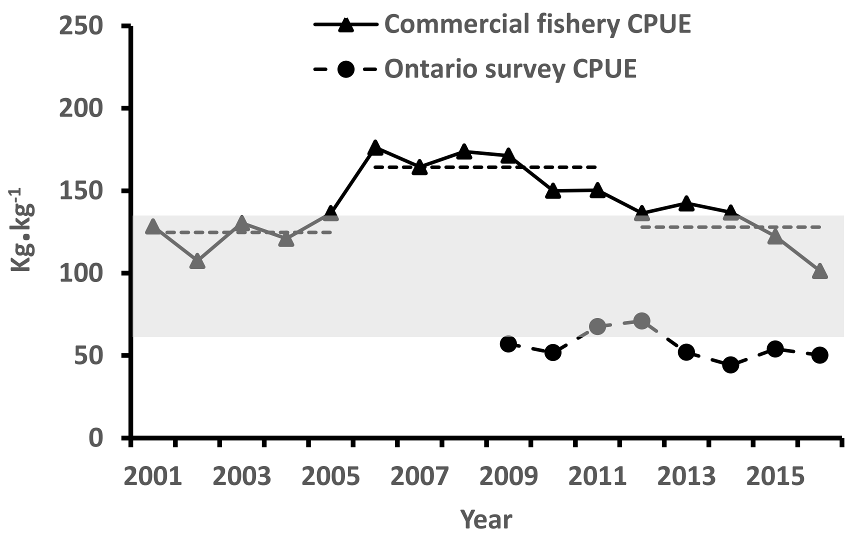
Fig. 12. Annual commercial yield of Lake Whitefish from Lake Superior, 1867-2016.



Commercial-Fishery Yield

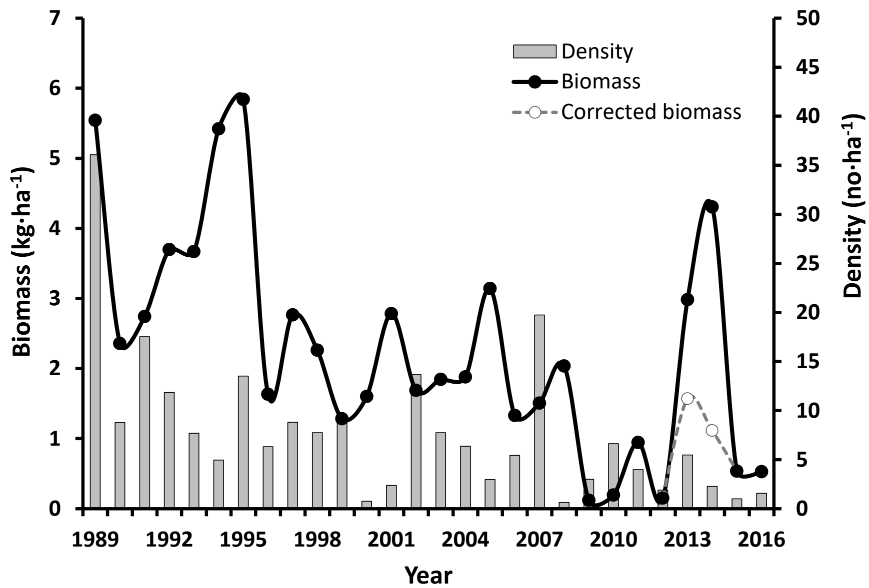
Commercial-fishery yield during the current reporting period (2012-2016) ranged from 1,300 to 1,700 metric tons and was nearly identical to levels observed during the previous reporting period (1,354 to 1,586 metric tons); however, lakewide commercial yield has generally declined from 2006 to 2016 as a consequence of reduced abundance. The annual commercial gillnet catch-per-unit effort (CPUE) declined from 150-176 kg•km^{-1} in the previous reporting period to 101-142 kg•km^{-1} in the current reporting period (Fig. 13), representing a 22% decline in average CPUE between the two time periods. The CPUE of Lake Whitefish captured during surveys in Ontario waters declined 7% from the previous reporting period to the current reporting period (Fig. 13). Although the average commercial gillnet CPUE during the reporting period was at its lowest level since 2001, CPUE was still within the target range specified by the FCO (65-136 kg•km^{-1} during 1990-1999).

Fig. 13. Commercial-fishery and survey gillnet catch-per-unit effort (CPUE) of Lake Whitefish in Lake Superior, 2001-2016. Horizontal dashed lines represent the average commercial gillnet CPUE, 2001-2005, 2006-2011, and 2012-2016. Shaded area represents the fish community objective relative abundance level during 1990-1999 (65 to 136 kg•km^{-1}).



The declines in commercial-fishery yield and CPUE of Lake Whitefish during the last two reporting periods may be attributed to reduced lakewide biomass and low recruitment, particularly for the 2007 to 2015 year-classes. Nearshore biomass of Lake Whitefish, based on lakewide spring nearshore bottom-trawl surveys, was highly variable during the reporting period and increased 64% on average compared to the previous reporting period (Fig. 14). The abrupt increase in biomass in 2013 and 2014 was attributed to large catches of adult Lake Whitefish at two Apostle Islands stations, accounting for 47% and 74% of lakewide Lake Whitefish biomass for 2013 and 2014, respectively. Without these large catches, biomass in the current reporting period declined 24% compared to the previous period. Peaks in biomass prior to 2009 are tied to the maturation of strong and moderate year-classes, which appeared as yearlings between 1989 and 2007 (Pratt et al. 2016, Fig. 20). Smaller year-classes that appeared after 2007 have not translated into sustained levels of biomass comparable to previous reporting periods, and the exceptional biomass peaks in 2013 and 2014 appear unconnected with requisite strong antecedent year-classes.

Fig. 14. Density and annual mean biomass of age-1 Lake Whitefish from spring lakewide bottom-trawl surveys in nearshore areas of Lake Superior, 1989-2016. Open circles show corrected biomass estimates without large catches from two Apostle Islands stations in 2013 and 2014.



Management

Harvest management of Lake Whitefish varies among political jurisdictions around Lake Superior. The commercial fishery in Wisconsin waters and the adjacent 1842 Treaty-ceded waters of Michigan is limited by quotas for Lake Trout, observed CPUE of Lake Trout, seasonal closures, and limited entry (Ebener et al. 2008). In comparison, commercial fisheries in Michigan waters of the 1836 Treaty-ceded area are limited by harvest quotas for Lake Whitefish established by statistical catch-at-age models (Ebener et al. 2005). In Ontario waters, each fisher is issued an individual transferrable quota (ITQ), which is developed for each management unit. These ITQs are evaluated on an annual basis and may be adjusted by generally no more than 10 or 15% based on the biological status of Lake Whitefish populations.

Summary

The FCO for Lake Whitefish in Lake Superior is currently being met; however, commercial gillnet CPUE and yield have declined during the current reporting period due to relatively low levels of recruitment during the last two reporting periods. The development and continuation of fishery-independent surveys will inform stock assessment models to better characterize Lake Whitefish populations in Lake Superior. Pratt et al. (2016) had recommended that agencies develop fishery-independent surveys of abundance to assess estimates that are based on fishery-dependent data. In response, the U.S. Geological Survey evaluated a multi-gear approach to estimate abundance of adult Lake Whitefish in Wisconsin waters using existing data from a combination of gillnets, trawls, and hydroacoustic surveys. This multi-gear sampling approach for estimating abundance may be reasonable and applicable to other areas of Lake Superior. Additionally, statistical catch-at-age analysis models are under development within the Michigan 1842 Treaty-ceded waters. If the trend in declining abundance continues into the next reporting period, management strategies may need to be revised to stabilize population abundances.

STATUS OF LAKE TROUT IN LAKE SUPERIOR IN 2017[16]

Shawn P. Sitar[17]

The fish community objective (FCO) for Lake Trout (Horns et al. 2003) in Lake Superior is to

> *Achieve and maintain genetically diverse self-sustaining populations of lake trout that are similar to those found in the lake prior to 1940, with lean lake trout being the dominant form in nearshore waters, siscowet lake trout the dominant form in offshore waters, and humper lake trout a common form in eastern waters and around Isle Royale.*

Lean Lake Trout populations were considered largely rehabilitated in Lake Superior in 2006, when stocking of hatchery-reared fish was halted in Michigan waters and half of Wisconsin waters because wild fish were common, and their abundance levels had reached milestones established for guiding rehabilitation (see Hansen et al. 1995; Hansen 1996). This state of the lake report chapter describes the status of lean Lake Trout in Lake Superior during the current reporting period (2012-2016) and compares the status to previous assessments (Sitar et al. 2010; Pratt et al. 2016).

Lean Lake Trout populations during the current reporting period declined slightly in most areas of Michigan, increased in Wisconsin, remained about at the same level in Minnesota, increased in western Ontario, and declined in eastern Ontario compared to the previous reporting period (2006-2011) (Fig.

---

[16]Complete publication including maps of place names, abstract, other chapters, scientific fish names, and references is available at http://www.glfc.org/pubs/SpecialPubs/Sp21_02.pdf.

[17]**S.P. Sitar**. Michigan Department of Natural Resources, 484 Cherry Creek Road, Marquette, MI 49855, U.S.A (e-mail: sitars@michigan.gov).

15). Some of the declines were driven by lower recruitment, which is most apparent in Michigan waters of Lake Superior (Fig. 16). However, high fishing mortality has caused stock declines in eastern Wisconsin, western Michigan, and eastern Ontario waters (Fig. 17). Overall, commercial yield generally declined or remained stable in most areas of Lake Superior. There were no major trends in recreational harvest of Lake Trout since 2011, except in WI-2 where harvest declined due to recent restrictive regulations (Fig. 18). Sea Lamprey predation continues to be a major source of mortality for Lake Trout in Lake Superior, as marking rates continue to be above target levels in many areas (Fig. 19). In MN-1, MN-3, MI-6, and MI-7 (see Frontispiece), marking rates have been above target in most years since 1993. Declines in marking rates have been observed in MN-2, Wisconsin, and in MI-5 in recent years. For stocks with statistical catch-at-age models, estimates of total annual mortality have been below management target maximum levels, except in WI-2 during 2015 (Fig. 20). In general, total mortality has been very similar to the average rates of the previous reporting period.

Presently, Lake Trout populations are sustained by wild fish with leans the dominant form in nearshore waters and the siscowet form dominant in offshore waters; the humper form is present in offshore sea mounts and island areas. Except in southeastern and some areas of west-central Lake Superior, exploitation of Lake Trout is generally low or at sustainable levels. Sea Lamprey predation and commercial fishing continue to be key threats to Lake Trout populations, but co-management by fishery agencies has been generally effective. Although research has indicated reduced genetic diversity in Lake Superior Lake Trout (Guinand et al. 2012; Bailie et al. 2016), the persistence of river-run Lake Trout in eastern Lake Superior and the recent documentation of a fourth form, the redfin (Hansen et al. 2016), highlights the existing genetic diversity. In summary, the FCO for Lake Trout is being met.

Fig. 15. Relative abundance of adult hatchery-reared (dashed black line) and wild (solid black line) lean Lake Trout expressed as the geometric mean catch-per-unit effort (GMCPUE, fish•km^{-1}•night^{-1}) in management units of Lake Superior, 1993-2016. Horizontal straight blue line represents average GMCPUE during 1993-2016 for wild fish. Vertical straight line is 2012, which delineates the current state of the lake reporting period from previous reporting periods. Relative abundance data is based on catches made during standardized spring gillnet surveys using 11.4 cm stretch mesh.

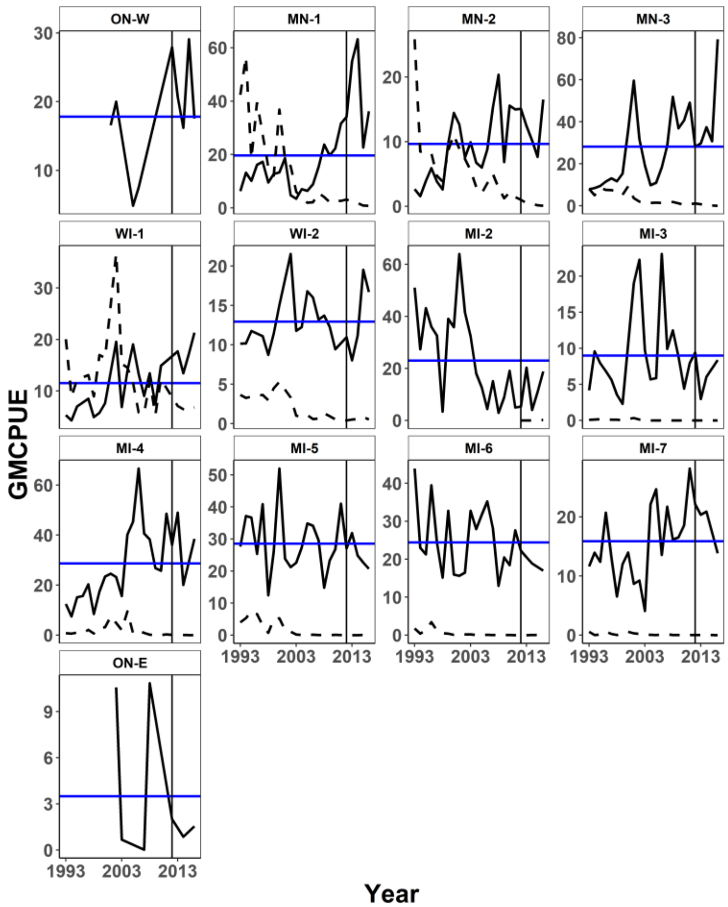


Fig. 16. Relative abundance of juvenile hatchery-reared (dashed black line) and wild (solid black line) lean Lake Trout expressed as the geometric mean catch-per-unit effort (GMCPUE, fish•km^{-1}•night^{-1}) in management units of Lake Superior, 1993-2016. Horizontal straight blue line represents average GMCPUE during 1993-2016 for wild fish. Vertical straight line is 2012, which delineates the current state of the lake reporting period from previous reporting periods. Relative abundance data is based on catches made during standardized spring gillnet surveys using 11.4 cm stretch mesh.

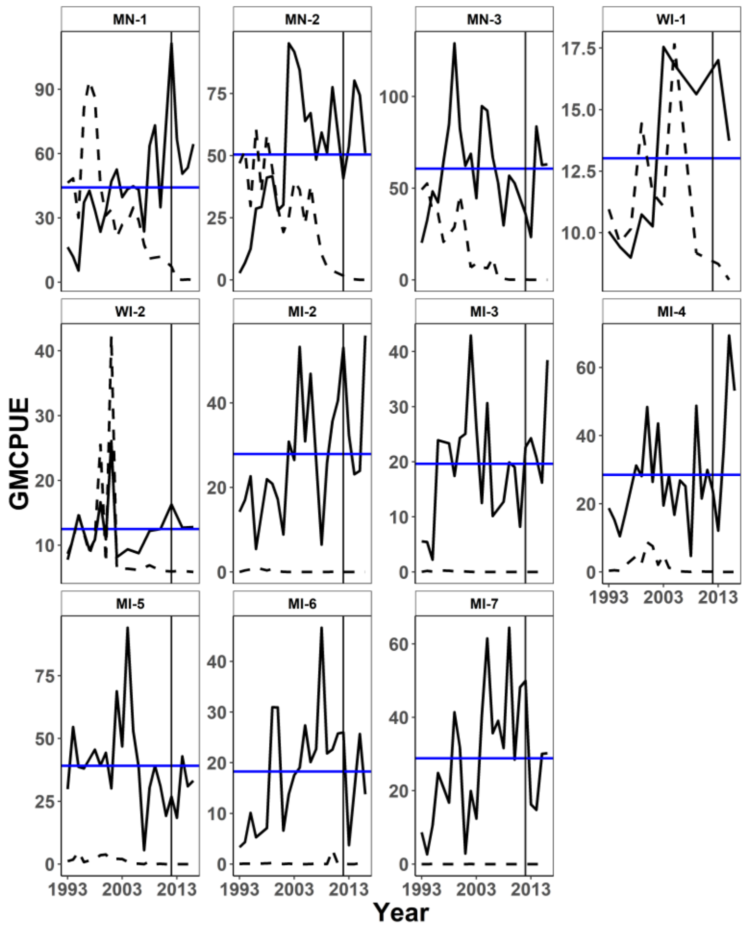


Fig. 17. Commercial-fishery gillnet effort (blue line) and yield (bars) of Lake Trout in management units of Lake Superior, 1993-2016. Horizontal straight line represents the average yield, 1993-2016.

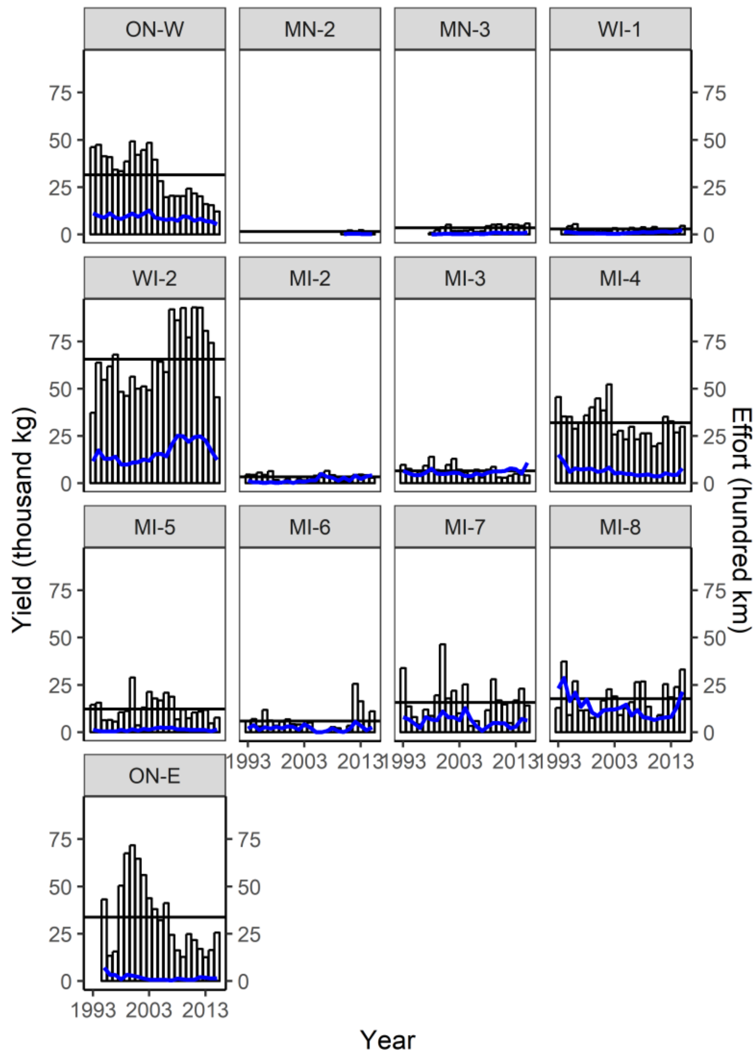


Fig. 18. Recreational-fishery effort (blue line) and harvest of hatchery (gray bars) and wild (white bars) Lake Trout in management units of Lake Superior, 1993-2016. Horizontal gray line represents the average yield, 1993-2016.

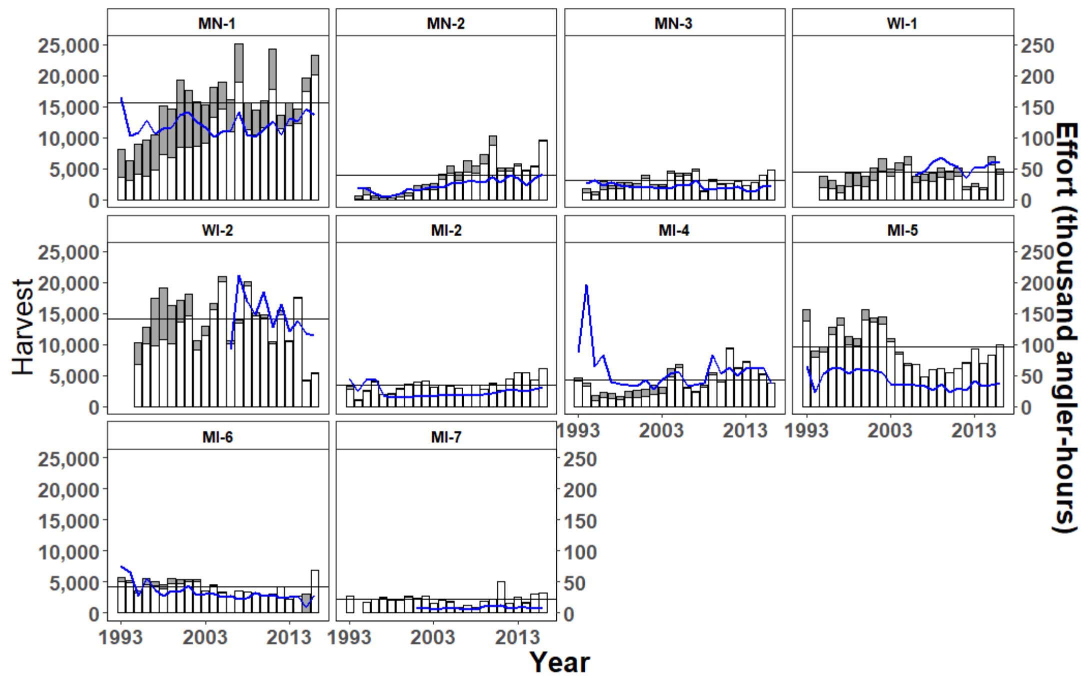


Fig. 19. Number of Sea Lamprey marks per 100 Lake Trout 532-mm total length and larger observed in management units of U.S. waters of Lake Superior, 1993-2016. Horizontal straight blue line represents the target maximum rate of 5 marks per 100 fish. Vertical straight line is 2012, which delineates the current state of the lake reporting period from the previous reporting periods. Marking data were collected during annual spring gillnet surveys using 11.4 cm stretch mesh.

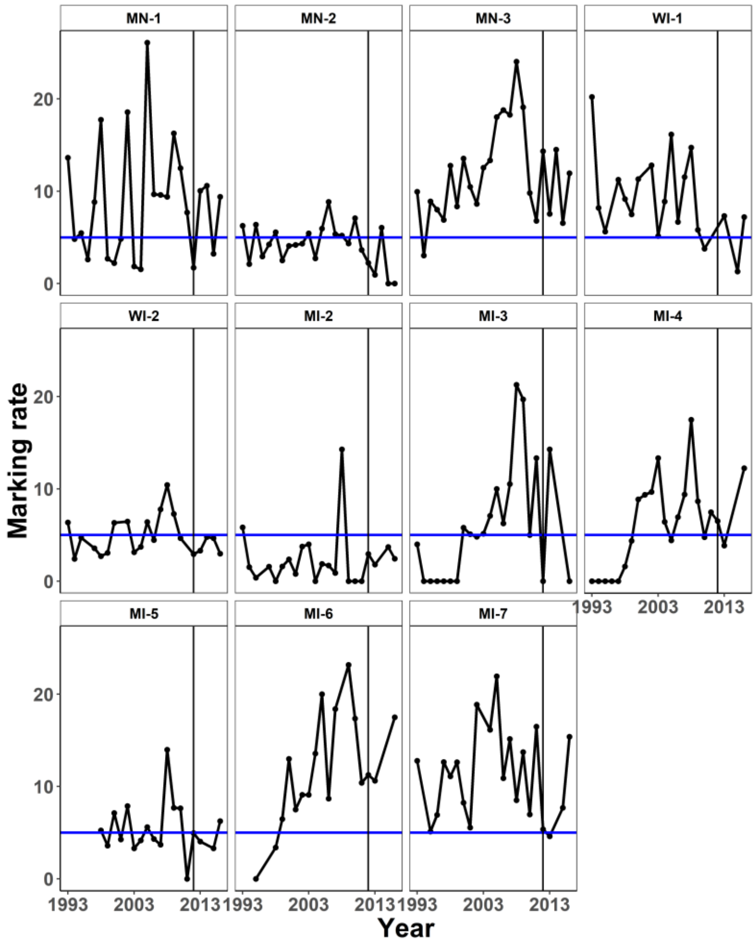
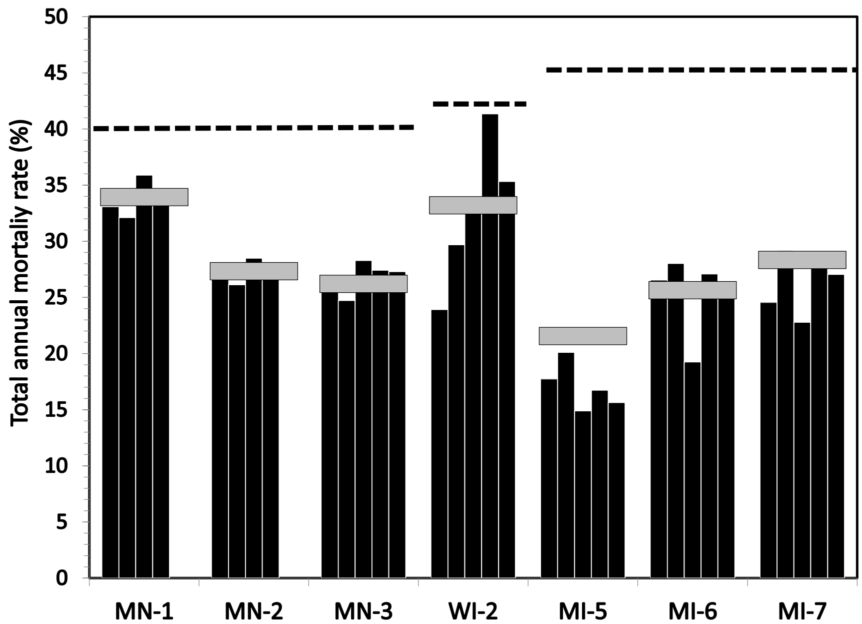


Fig. 20. Average total annual mortality rates (*A*) for ages-6-11 Lake Trout in Lake Superior during 2006-2016 based on statistical catch-at-age stock assessments. Data for Minnesota management units (MN-1, 2, 3) are for 2012-2015. Black bars represent the annual estimate of *A* from 2012 to 2016 (chronologically left to right). Gray horizontal bars represent the average *A* during the previous reporting period (2006-2011). Dashed lines represent the target maximum total annual mortality rates for each management unit.



STATUS OF SISCOWET LAKE TROUT IN LAKE SUPERIOR IN 2017[18]

Michael J. Seider[19], Shawn P. Sitar, and Mark R. Vinson

The fish community objectives (FCOs) envision the siscowet form of Lake Trout (hereafter, siscowet) to be the dominant form of Lake Trout in offshore waters of Lake Superior (Horns et al. 2003). Siscowets have always been an important component of the fish community, primarily in offshore waters where they are the dominant predator (Eschmeyer 1955; Bronte and Moore 2007; Bronte and Sitar 2008). There has been increased emphasis on understanding the ecology of the siscowet form during the last two decades because, in the Great Lakes, siscowets are unique to Superior at present and little was known about them (see Pratt et al. 2016). Herein, we compare the status of the siscowet during the current reporting period (2012-2016) with previous reporting periods.

The FCO for the siscowet remains achieved since the last state of the lake report (Pratt et al. 2016). Siscowets are the most-abundant form of Lake Trout, and they are self-sustaining. Siscowets principally occur in waters deeper than 70 m and are most abundant at depths of 110-219 m (Pratt et al. 2016). Siscowet abundance was generally stable between 2012 and 2016 and the same as during the previous reporting period (2006-2011). Mean catch-

---

[18]Complete publication including maps of place names, abstract, other chapters, scientific fish names, and references is available at http://www.glfc.org/pubs/SpecialPubs/Sp21_02.pdf.

M.J. Seider. U.S. Fish and Wildlife Service, Ashland Fish and Wildlife Conservation Office, 2800 Lakeshore Drive East, Ashland, WI 54806, USA.

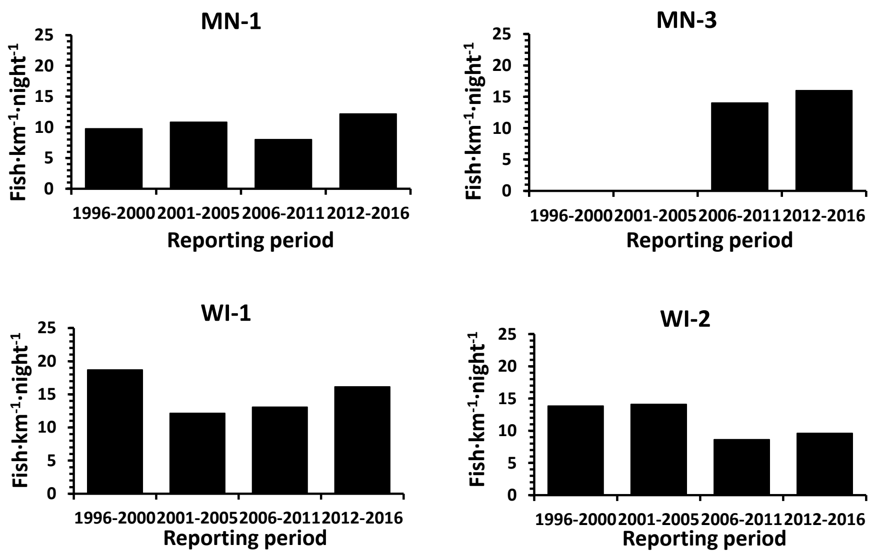
S.P. Sitar. Michigan Department of Natural Resources, 484 Cherry Creek Road, Marquette, MI 49855, U.S.A.

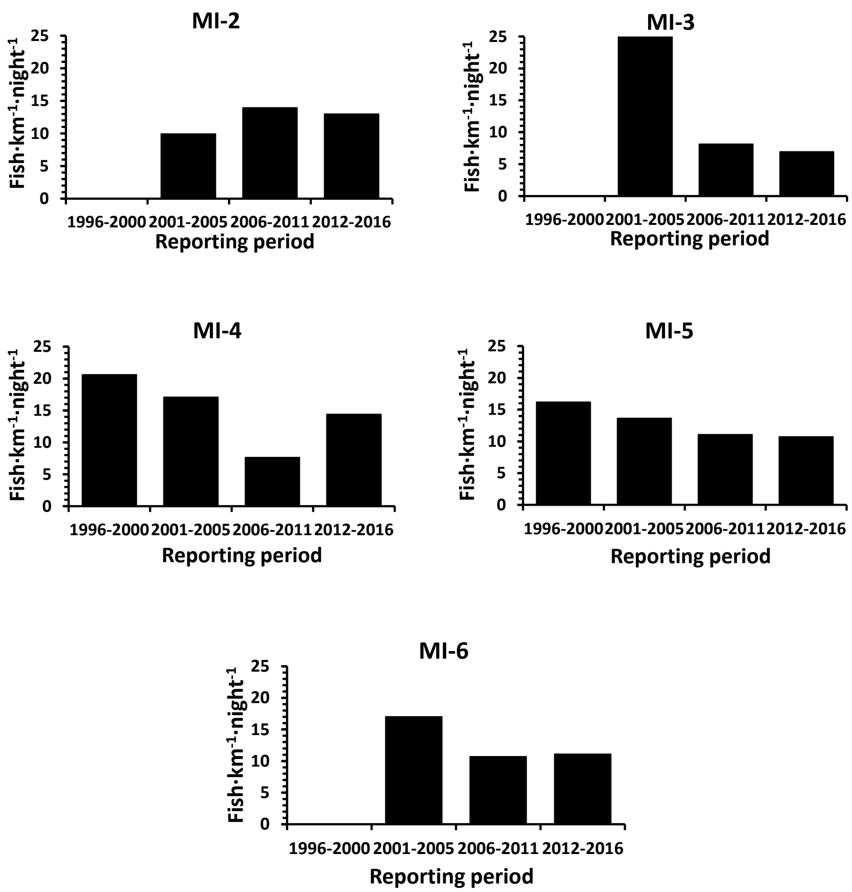
M.R. Vinson. U.S. Geological Survey, Great Lakes Science Center, Lake Superior Biological Station, 2800 Lake Shore Drive East, Ashland, WI 54806, USA.

[19]Corresponding author (e-mail: mike_seider@fws.gov).

per-unit effort (fish•km^{-1}•night^{-1}) of siscowets in coordinated gillnet surveys during the reporting period was generally the same as during the previous reporting period in most management units (Fig. 21). The U.S. Geological Survey's annual lakewide offshore bottom-trawl surveys found that abundance of siscowet <400-mm total length was stable during the reporting period with an average of 4.0 fish•ha^{-1} (range 4.0-5.9 fish•ha^{-1}).

Fig. 21. Catch-per-unit effort (fish•km^{-1}•night^{-1}) of siscowets caught in coordinated gillnet surveys in management units of Lake Superior during each state of the lake reporting period.




MI-2
MI-3
MI-4
MI-5
MI-6
Fish·km⁻¹·night⁻¹
0
5
10
15
20
25
1996-2000
2001-2005
2006-2011
2012-2016
Reporting period

Sport and commercial yields of siscowets remain low because they are mostly caught incidentally by fisheries targeting other species. Mean annual commercial yield of siscowet was 13% higher during the current reporting period than during the previous reporting period. Although siscowet abundance appears high, its sustainable level of harvest is unknown.

The age distribution of siscowets appeared to shift toward younger fish in most areas of Lake Superior after the last reporting period (Fig. 22). Prior to the current reporting period, the age distribution had been gradually shifting toward older fish. The proportion of age-20 and older siscowets increased from 5% in 1996 to 26% in 2006 but then declined to 14% during the current reporting period. Growth of siscowets (expressed as mean length at age 15) has not changed appreciably since the last reporting period (Fig. 23), despite declining prey populations in the offshore waters (see Status of Prey Fish in Lake Superior in 2017 chapter).

Fig. 22. Age distribution of siscowets caught in coordinated gillnet surveys in management units of Lake Superior during each state of the lake reporting period.

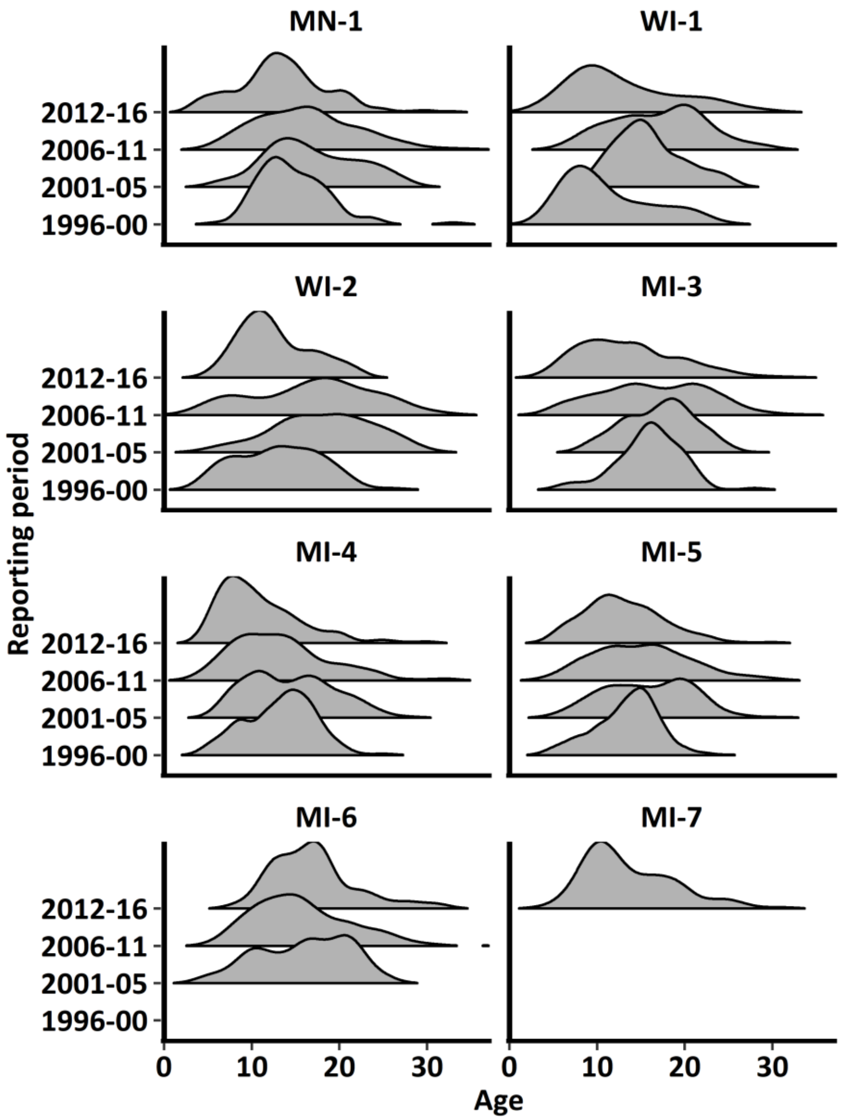
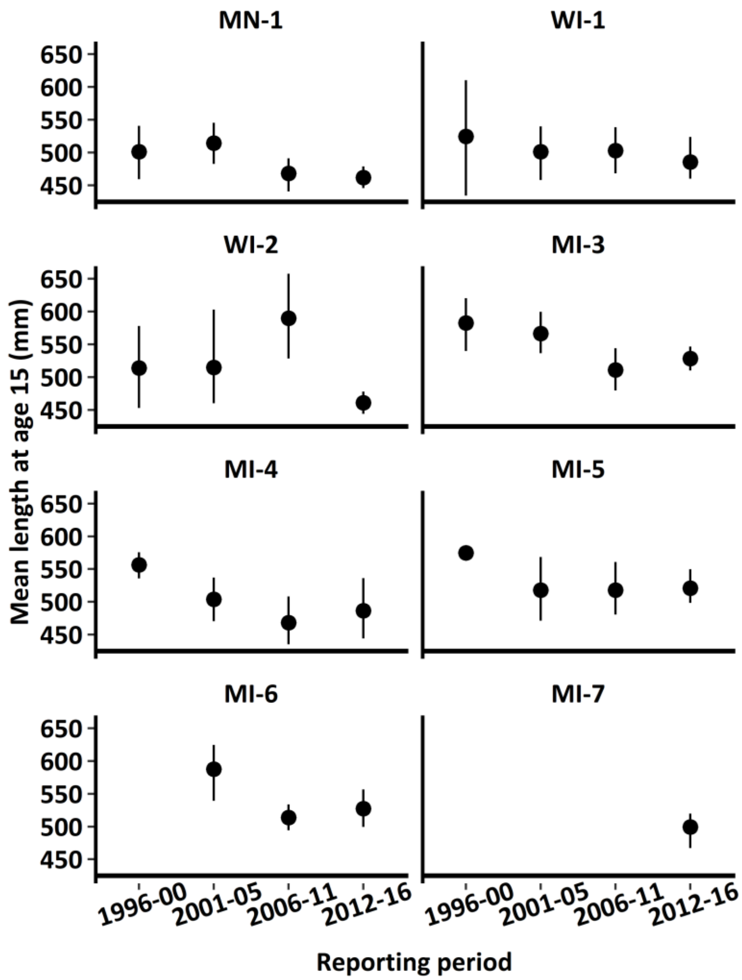
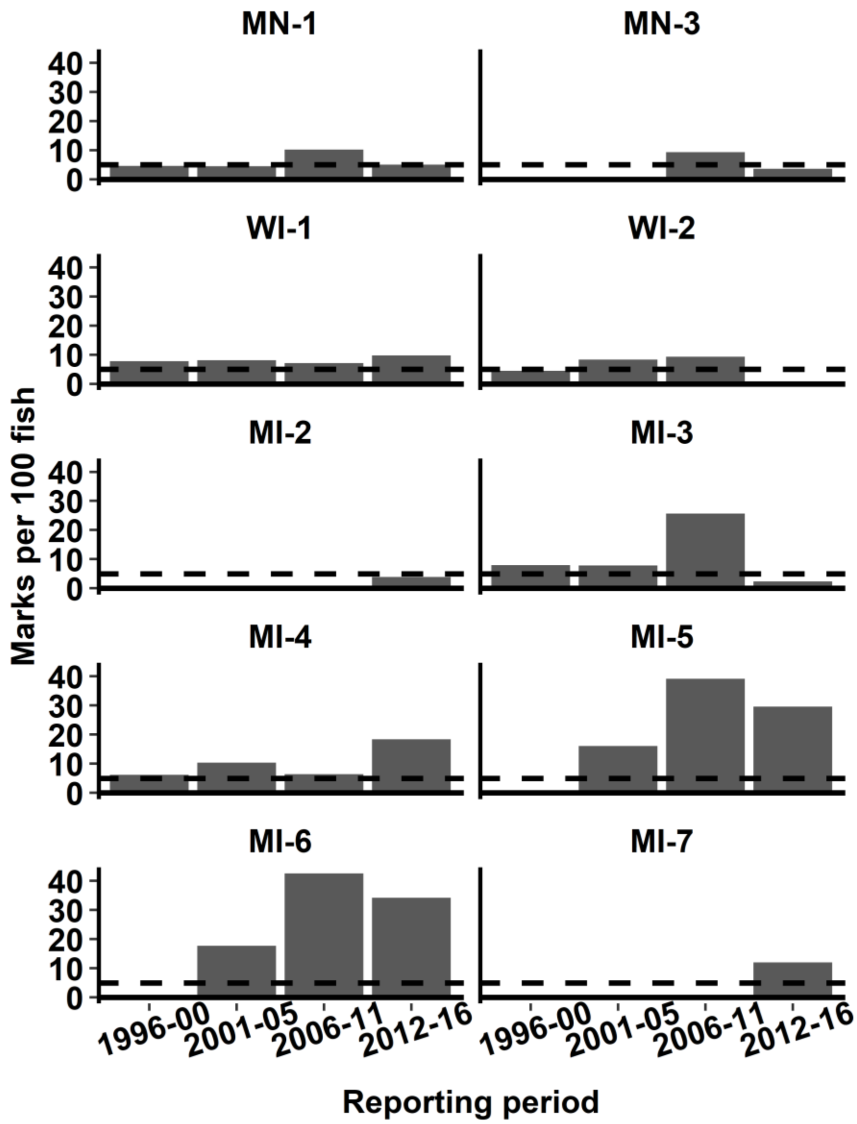

MN-1
WI-1
WI-2
MI-3
MI-4
MI-5
MI-6
MI-7
2012-16
2006-11
2001-05
1996-00
Reporting period
0
10
20
30
Age

Fig. 23. Average length of age-15 siscowets caught in coordinated gillnet surveys in management units of Lake Superior during each state of the lake reporting period. Vertical bars represent the 95% confidence interval.



Sea Lamprey wounding of siscowets was generally lower during the current reporting period than during the previous reporting period (Fig. 24). The Sea Lamprey marking rate on siscowets was higher than that for lean Lake Trout in most areas of Lake Superior. This rate is consistent with findings of Smith et al. (2016), who showed siscowets were significantly more likely to be wounded than leans. The lethality of Sea Lamprey attacks may be lower for siscowets than leans (Moody et al. 2011), which could give the impression of greater frequency of attacks with age. However, several lines of evidence suggest that Sea Lamprey may preferentially attack siscowets over leans (Smith et al. 2016), confirming that siscowets play a critical role in buffering the effects of Sea Lamprey predation on leans and other fish. The mechanism of how siscowets survive a Sea Lamprey attack remains unknown and is an important gap in our knowledge of both siscowet dynamics and Sea Lamprey management.

Fig. 24. Sea Lamprey marking rates on siscowets >532 mm total length caught during coordinated gillnet surveys in management units of Lake Superior during each state of the lake reporting period. Marking rates are the total number of Type A, Stages I-III, marks per 100 Lake Trout. Dashed horizontal line represents the target maximum (5 marks•100^{-1} lean Lake Trout) used to measure efficacy of the Sea Lamprey control program.



MN-1
MN-3
WI-1
WI-2
MI-2
MI-3
MI-4
MI-5
MI-6
MI-7
Marks per 100 fish
40
30
20
10
0
1996-00
2001-05
2006-11
2012-16
Reporting period

Recent studies have further described how Lake Trout forms differ in life-history traits, morphology, lipid content, and bathymetric distribution (Muir et al. 2014; Hansen et al. 2016). The Lake Trout forms were weakly differentiated via morphometric analyses in some areas of Lake Superior (e.g., Isle Royale), which is consistent with recent genetic research. There has been a substantial loss of genetic diversity for the lean and siscowet forms since their populations collapsed in the 1950s (Guinand et al. 2012; Bailie et al. 2016). Previous investigations of historical data suggest the Lake Trout forms were genetically distinguishable, but Bailie et al. (2016) detected a 60% reduction in genetic distance among the forms since the 1990s. Their work further suggested introgression has increased among Lake Trout forms since the 1950s. The reproductive barriers that once existed between Lake Trout forms have apparently been altered. The loss of genetic diversity is likely due to past population bottlenecks and the subsequent stocking programs of lean Lake Trout during the last 65 years.

Since the last state of the lake report, our collective knowledge of siscowet reproductive biology in Lake Superior has improved. Research by Goetz et al. (2011) supported earlier assumptions that the reproductive timing of siscowets was generally the same as that of leans. Siscowets near Isle Royale were found to reproduce in the fall (like leans, humpers, and redfins), but siscowets also spawn in the spring and likely at other times of the year (Goetz et al. 2017). This information is consistent with historical reports that suggest some populations might also spawn at other times of the year (Eschmeyer 1955; Bronte 1993). This alternative reproductive strategy may be advantageous because it could decrease competition with the offspring of the fall spawning form or avoid the perils of long winter incubation (Goetz et al. 2017). The characteristics of siscowet spawning habitat and early life history remain significant knowledge gaps. Sitar et al. (2014) reported that skipped spawning was more prevalent across a wider range of sizes (ages) in siscowets than in leans. About 58% of siscowets exhibited skipped spawning, likely as a density-dependent response to limited food resources (Sitar et al. 2014).

STATE OF THE LAKE SUPERIOR ECOSYSTEM IN 2017[20]

Bryan G. Matthias[21], Thomas R. Hrabik, Joel C. Hoffman, Owen T. Gorman, Michael J. Seider, Michael E. Sierszen, Mark R. Vinson, Dan L. Yule, and Peder M. Yurista

The Lake Superior ecosystem, near pristine in comparison to the other Laurentian Great Lakes, has seen major biological changes during the past two decades. Starting in the late 1990s, pelagic prey-fish biomass has been declining in both nearshore and offshore waters (Pratt et al. 2016; Vinson et al. 2016). Declines have been observed in native coregonines, including Cisco, Bloater, and Kiyi along with Deepwater Sculpin and non-native Rainbow Smelt (Gorman 2012; Pratt et al. 2016; Vinson et al. 2016). These species comprise a substantial proportion of the diets of native predators like the lean and siscowet forms of Lake Trout (hereafter, siscowet) and Burbot and introduced migratory salmonines (15-80% of total diets; Matthias and

---

[20]Complete publication including maps of place names, abstract, other chapters, scientific fish names, and references is available at http://www.glfc.org/pubs/SpecialPubs/Sp21_02.pdf.

B.G. Matthias. U.S. Fish and Wildlife Service, 850 South Guild Avenue, Suite 105, Lodi, CA 95240, USA.

T.R. Hrabik. University of Minnesota Duluth, 207 Swenson Science Building, 1035 Kirby Drive, Duluth, MN 55812, USA.

J.C. Hoffman, M.E. Sierszen, and P.M Yurista. U.S. Environmental Protection Agency, Center for Computational Toxicology and Ecology, Great Lakes Toxicology and Ecology Division, 6201 Congdon Boulevard, Duluth, MN 55804, USA.

O.T. Gorman, M.R. Vinson, and D.L. Yule. U.S. Geological Survey, Great Lakes Science Center, Lake Superior Biological Station, 2800 Lake Shore Drive East, Ashland, WI 54806, USA.

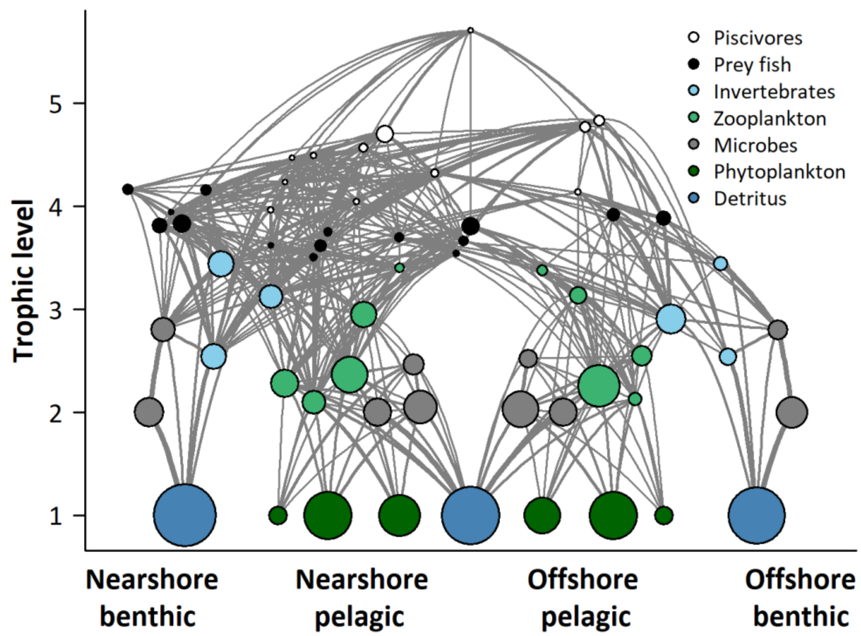
M.J. Seider. U.S. Fish and Wildlife Service, Ashland Fish and Wildlife Conservation Office, 2800 Lakeshore Drive East, Ashland, WI 54806, USA.

[21]Corresponding author (e-mail: bryan.matthias@fws.gov).

Yule 2020; also see Kitchell et al. 2000; Negus et al. 2007; Gamble et al. 2011a, 2011b; Isaac et al. 2012). The declines in prey resources are troubling given lean and siscowet Lake Trout populations have remained relatively stable during this time.

We built an EcoPath with EcoSim (EwE) model to quantify how the Lake Superior ecosystem changed from 2005 to 2016 and to predict how the ecosystem might change if 2016 commercial and recreational harvest levels on all targeted species are sustained until 2055. The EcoPath model was parameterized to the first lakewide Cooperative Science and Monitoring Initiative (CSMI), a binational intensive monitoring and assessment program conducted in 2005-2006 (https://www.epa.gov/great-lakes-monitoring/cooperative-science-and-monitoring-initiative-csmi). The model includes nearshore and offshore food webs, including 59 groups of producers and consumers and 3 detrital groups (Fig. 25; for model details and input data see Matthias and Yule 2020). The model represents a significant increase in the breadth of lower trophic levels when compared to past Lake Superior models (i.e., Kitchell et al. 2000; Cox and Kitchell 2004) and recent models of Lakes Michigan and Huron (Langseth et al. 2012; Rogers et al. 2014; but see Kao et al. 2016). We incorporated multiple levels in the microbial loops representing significant sources of biomass and carbon cycling from detrital sources. This model includes greater detail in the offshore fish communities and all zooplankton communities than in prior ecosystem models.

Fig. 25. Configuration of the Lake Superior EcoPath model representing both nearshore (generally left side) and offshore zones (generally right side), benthic-pelagic coupling, and nearshore-offshore coupling. Node size is proportional to total biomass, and line thickness represents biomass flow between groups.



The EcoSim model was fit to 2005-2016 data from the CSMI (e.g., Yurista et al. 2009; Isaac 2010; Yule et al. 2013; Pratt et al. 2016), U.S. Environmental Protection Agency's Great Lakes National Program Office (e.g., Barbiero et al. 2019), U.S. Geological Survey trawl survey (see Vinson et al. 2016), coordinated siscowet surveys (see Status of Siscowet Lake Trout in Lake Superior in 2017 chapter), Minnesota and Wisconsin DNR gillnet and acoustics surveys (C. Goldsworthy, unpublished data; B. Ray, unpublished data), acoustics and fish community surveys in Ontario (Fisch et al. 2019a; E. Berglund, unpublished data), and statistical catch-at-age models from the Michigan, Minnesota, and Wisconsin DNRs (see Modeling Subcommittee, Technical Fisheries Committee 2018). This model represented data from across Lake Superior (Fig. 26) and encompassed all trophic levels. Agency surveys indicate declines in biomass across the prey-fish community (Cisco, Bloater, Kiyi, and Deepwater Sculpin); relatively stable populations of Lake Whitefish, Rainbow Smelt, and nearshore Slimy and Spoonhead Sculpins; lean and siscowet forms of Lake Trout; and Burbot. The EcoSim model for 2005-2016 estimated large declines (>20% since 2005) for siscowet, Bloater, Kiyi, and sculpins. Unlike the survey trends, Cisco biomass was estimated to remain stable along with that of Lake Whitefish and lean Lake Trout (Fig. 27). Biomass of Burbot and Rainbow Smelt was estimated to increase (see Fig. 27).

Fig. 26. Map showing political jurisdictions and spatial areas where EcoSim model fitting procedures occurred.

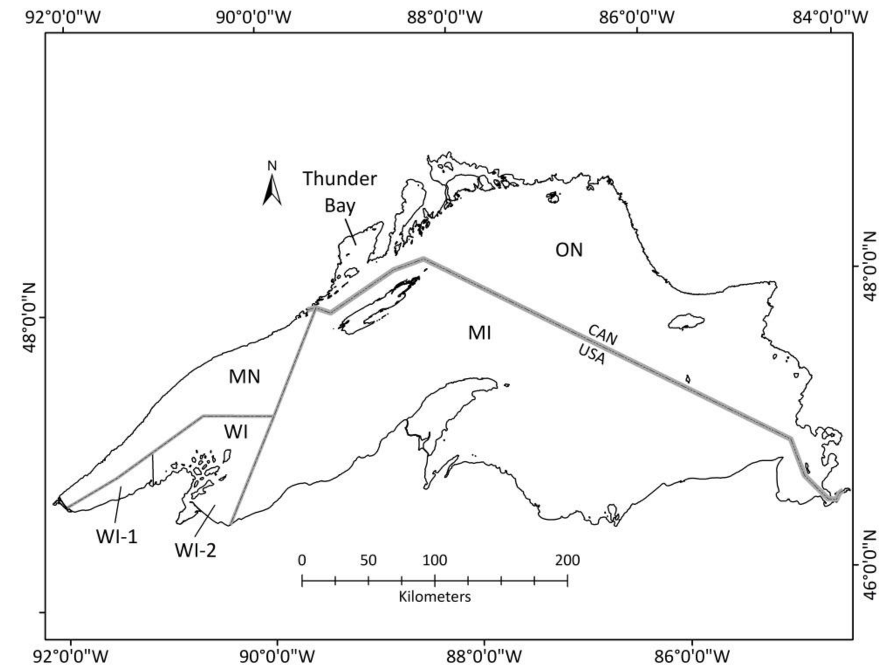
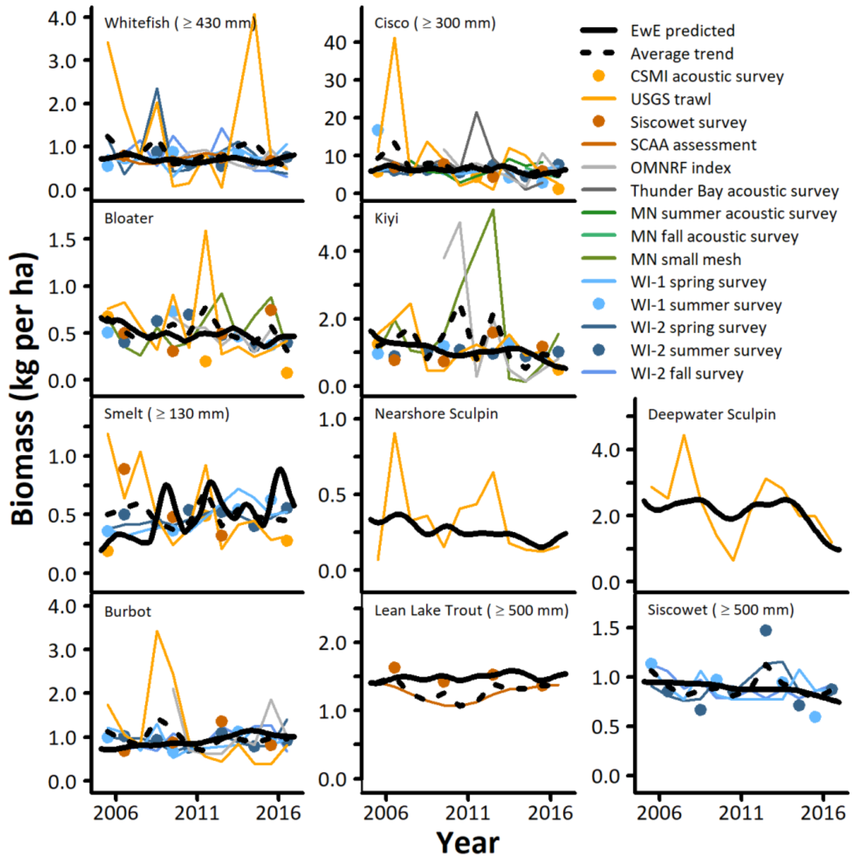


Fig. 27. Relative biomass trends for the Lake Superior fish community (points and thin lines) and trends averaged over all surveys (thick dashed black line), 2005 to 2016 for management units or surveys. Model predicted biomass from EcoSim (thick solid black line) for major fish species or groups. Nearshore sculpin includes Slimy and Spoonhead Sculpins (USGS = U.S. Geological Survey; SCAA = statistical catch-at-age analysis; OMNRF = Ontario Ministry of Natural Resources and Forestry).



Predicted long-term trends (i.e., 2005-2055) appear consistent with the estimated 2005-2016 EwE trends, provided harvest remains at the 2016 level. Biomass is predicted to decline for most coregonines, sculpins, and Burbot; increase for Rainbow Smelt; and remain stable for Cisco and both forms of Lake Trout. The prediction that Cisco will remain stable is contrary to data provided for this species in this reporting period (see Status of Prey Fish in Lake Superior in 2017 chapter). Cisco appears to decline in most surveys (Fig. 27), but there is high variability within these trends. In addition, we have not yet been able to account for the high variability observed in Cisco recruitment, which influenced biomass trends. Future work should seek to assess the drivers of Cisco recruitment and incorporate recruitment variability in EcoSim. Model development will continue into future reporting periods, and we will be able to utilize future CSMI efforts and agency surveys to better inform the model and test predictions of population trajectories over time. For example, there are concerns by Lake Superior biologists that the biomass of large-sized (≥500 mm total length) siscowets and leans generated from the bottom-trawl surveys are misleading because the trawl itself does a poor job of capturing these large-sized fish. The bottom-trawl biomass inputs to the EwE were downweighted relative to other data sources because of these concerns. Studies of the selectivity and catchability of large-sized Lake Trout forms and other species to the bottom trawls would better inform future EwE simulations. The long-term goal is to provide a reliable forecasting tool that can be used to predict outcomes of management actions on various fish community objectives, given observed trends in the Lake Superior ecosystem (*sensu* Kitchell et al. 2000).

STATUS OF PACIFIC SALMON, RAINBOW TROUT (STEELHEAD), AND BROWN TROUT IN LAKE SUPERIOR IN 2017[22]

Kyle Rogers[23]

The fish community objective (FCO) for non-native salmonines (Horns et al. 2003) in Lake Superior is to

> *Manage populations of Pacific salmon, rainbow trout, and brown trout that are predominantly self-sustaining but that may be supplemented by stocking that is compatible with restoration and management goals established for indigenous fish species.*

Since their introductions into Lake Superior, non-indigenous salmonines have provided recreational anglers with additional nearshore and tributary angling opportunities. Natural reproduction by Chinook Salmon, Rainbow Trout (steelhead), and Coho Salmon has allowed agencies to significantly reduce stocking of these species during the current reporting period (2012-2016) (Fig. 28) while maintaining supplemental stocking rates of the Kamloops strain of Rainbow Trout in Minnesota, Brown Trout in Wisconsin, and Splake in Wisconsin/Michigan for localized fisheries (Fig. 29). The number of non-native salmonines stocked in the future will be reduced even further such that, in 2018, the only stocking of Chinook Salmon will be made by the Thunder Bay Salmon Association in Thunder Bay, Ontario. Minnesota has also developed a framework to phase out

---

[22]Complete publication including maps of place names, abstract, other chapters, scientific fish names, and references is available at http://www.glfc.org/pubs/SpecialPubs/Sp21_02.pdf.

[23]**K. Rogers**. Ontario Ministry of Natural Resources and Forestry, Upper Great Lakes Management Unit, 435 James Street South, Suite 221e, Thunder Bay, ON P7E-6S8, Canada (e-mail: kyle.rogers@ontario.ca).

stocking of the Kamloops strain of Rainbow Trout and the stocking of its fry.

Fig. 28. Number of non-native salmonines stocked into Lake Superior, 1987-2016. Rainbow Trout includes steelhead.

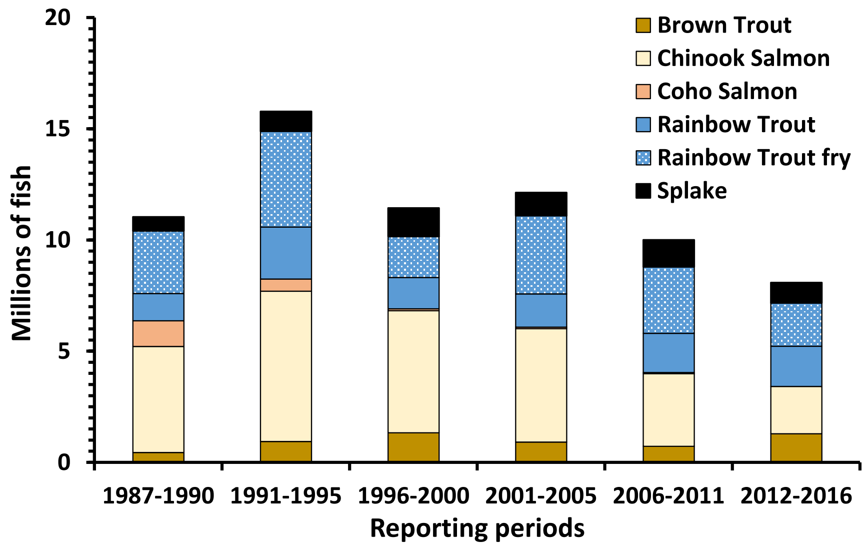
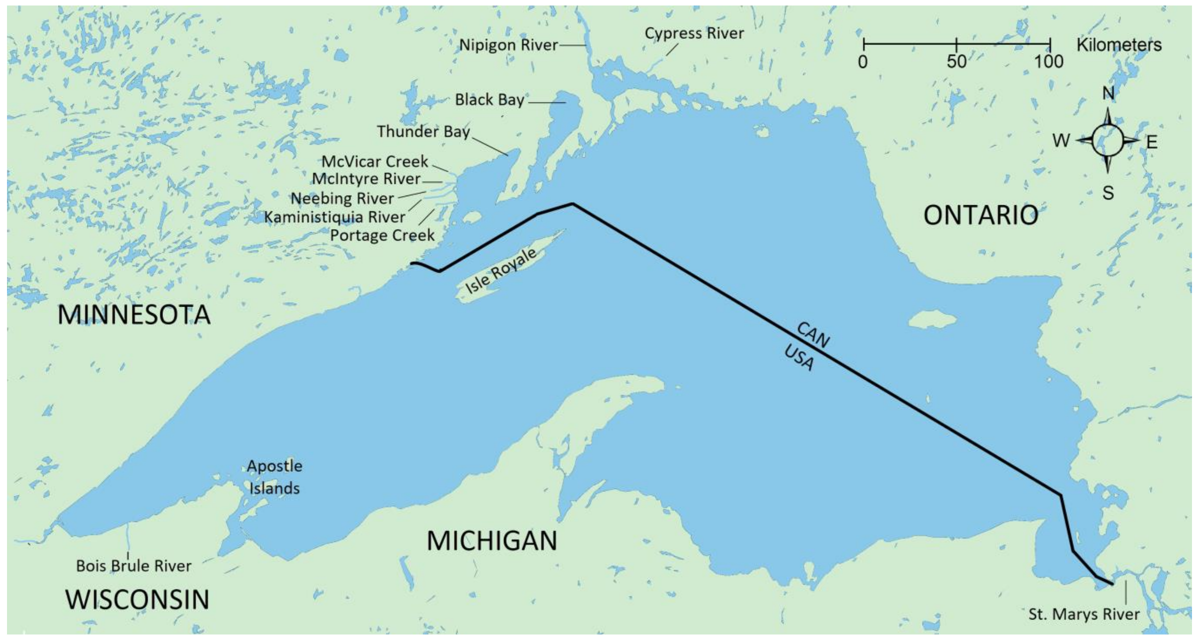
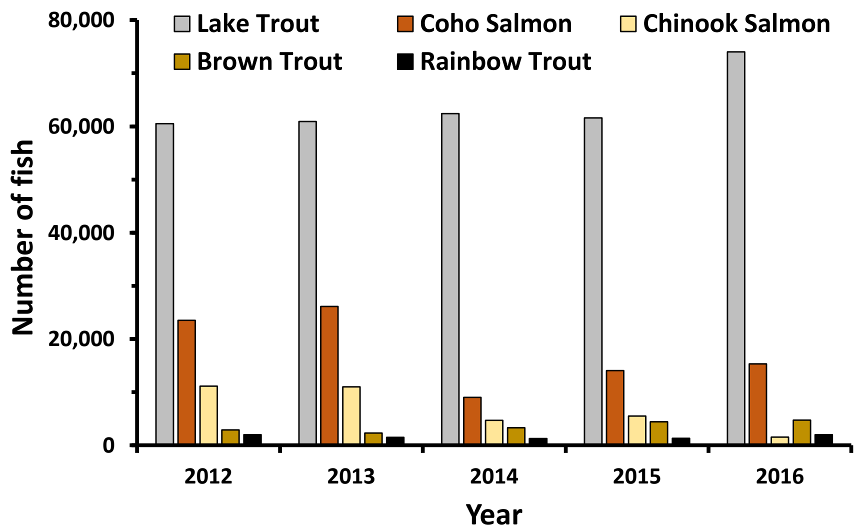


Fig. 29. Lake Superior showing locations of sites mentioned in the text.



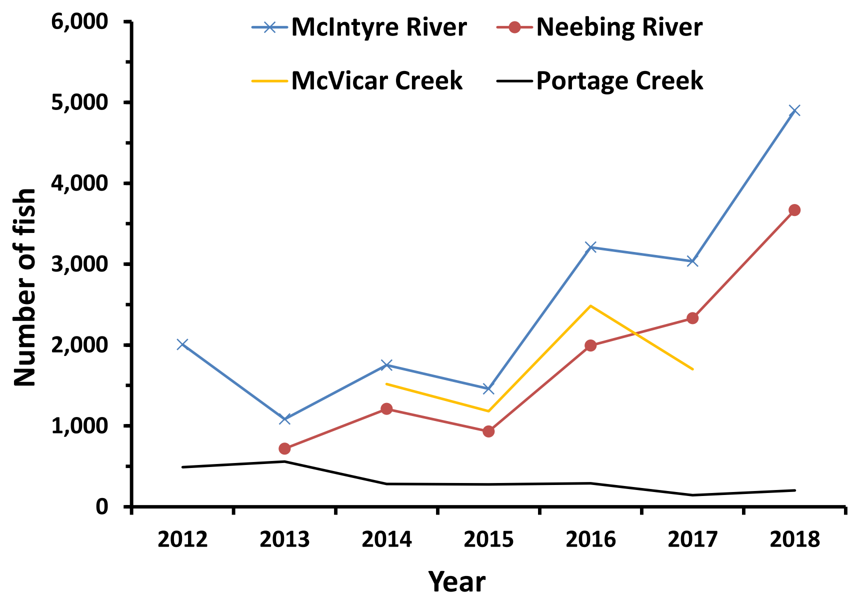
The states of Minnesota, Wisconsin, and Michigan monitor the harvest of native and non-native salmonines in the recreational fishery by conducting open-water creel surveys. Non-native salmonines play an important role in the recreational fishery on Lake Superior, although lean Lake Trout are the most sought-after species. Non-native salmonines accounted for 32% of the total harvest by the recreational fishery during the reporting period, and Lake Trout accounted for the remainder. Coho Salmon accounted for 19% of the total recreational harvest during the reporting period and nearly 60% of the non-native salmonine harvest while Chinook Salmon were next in importance at 7% of the total harvest and 23% of the harvest of non-native salmonines (Fig. 30).

Fig. 30. Harvest of non-native salmonines from U.S. waters of Lake Superior, 2012-2016. Rainbow Trout includes steelhead.



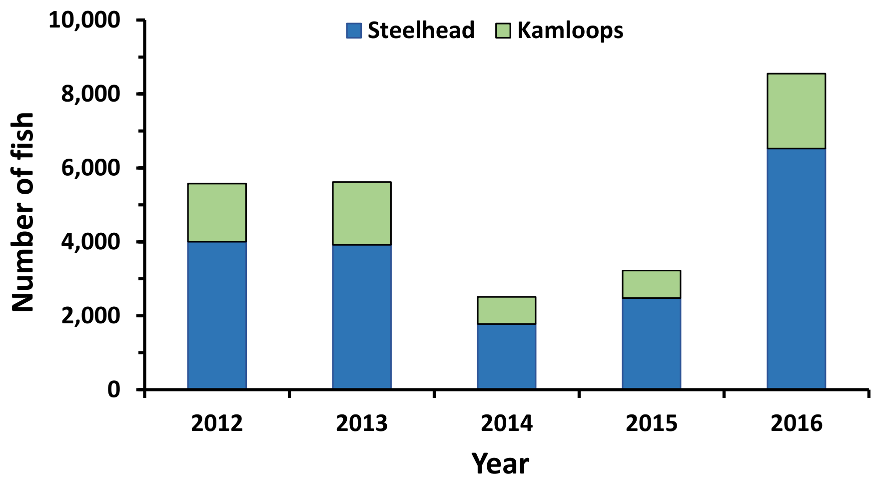
A cooperative angler sampling program has been used by the Ontario Ministry of Natural Resources and Forestry to monitor the recreational harvest of steelhead from Ontario tributaries since the early 2000s. This program allows anglers to participate in collecting biological data during the tributary fishery in the spring. The cooperative sampling program also conducted Peterson-type mark-recapture studies on the McIntyre, Neebing, and Cypress Rivers and McVicar and Portage Creeks during the reporting period (Fig. 31). This program indicates that steelhead ascending tributaries in Thunder Bay, Ontario, have increased during the past two years largely due to an abundant 2013 year-class, which made up about 50% of the harvest in 2016.

Fig. 31. Population estimates of steelhead in selected tributaries to Ontario waters of Lake Superior, 2012-2016. Population estimates were made based on a Peterson-type mark-recapture study conducted cooperatively between recreational anglers and the Ontario Ministry of Natural Resources and Forestry.



The state of Minnesota conducts a spring creel survey on its tributaries to monitor steelhead populations. The surveys show that most fish caught during the reporting period were of wild origin. The abundant 2013 year-class found in Ontario tributaries may also have been produced in Minnesota tributaries as angler catches increased nearly fourfold from 2014 to 2016 (Fig. 32).

Fig. 32. Catches of steelhead and Kamloops Rainbow Trout from Minnesota's spring creel surveys in tributaries to Lake Superior, 2012-2016.



The Wisconsin DNR monitors the upstream migration of salmonines in the Bois Brule River (WI) using digital recording equipment at the Sea Lamprey barrier and companion fishway located about 9.6 km (6 miles) upstream from Lake Superior. Steelhead, Brown Trout, and Coho Salmon are the predominant species that migrate up the river to spawn, and their numbers varied annually from 2011 through 2016 (Fig. 33). Chinook Salmon, Splake, and Brook Trout also migrate up the Bois Brule River, although in much lower numbers. Bois Brule River salmonines are self-sustaining, except for the few dozen observed Kamloops Rainbow Trout (stocked by the Minnesota DNR) and Splake and Brown Trout (stocked by the Wisconsin DNR). Migration timing varied by species during the reporting period as Brown Trout peaked in late-summer, Coho Salmon in early fall, and steelhead in mid-fall (Fig. 34).

Fig. 33. Number of adult non-native salmonines observed at the Sea Lamprey barrier and fishway migrating up the Bois Brule River, WI, from Lake Superior, 2011-2016. Rainbow Trout includes steelhead.

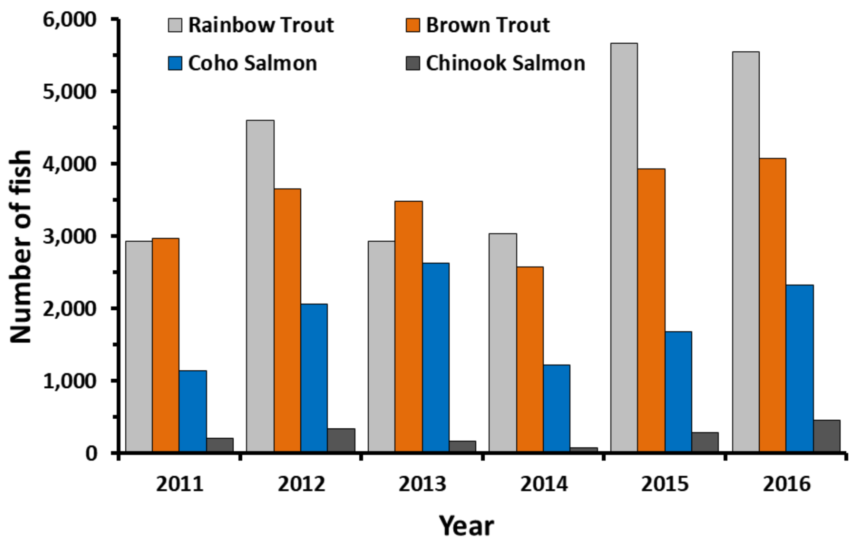
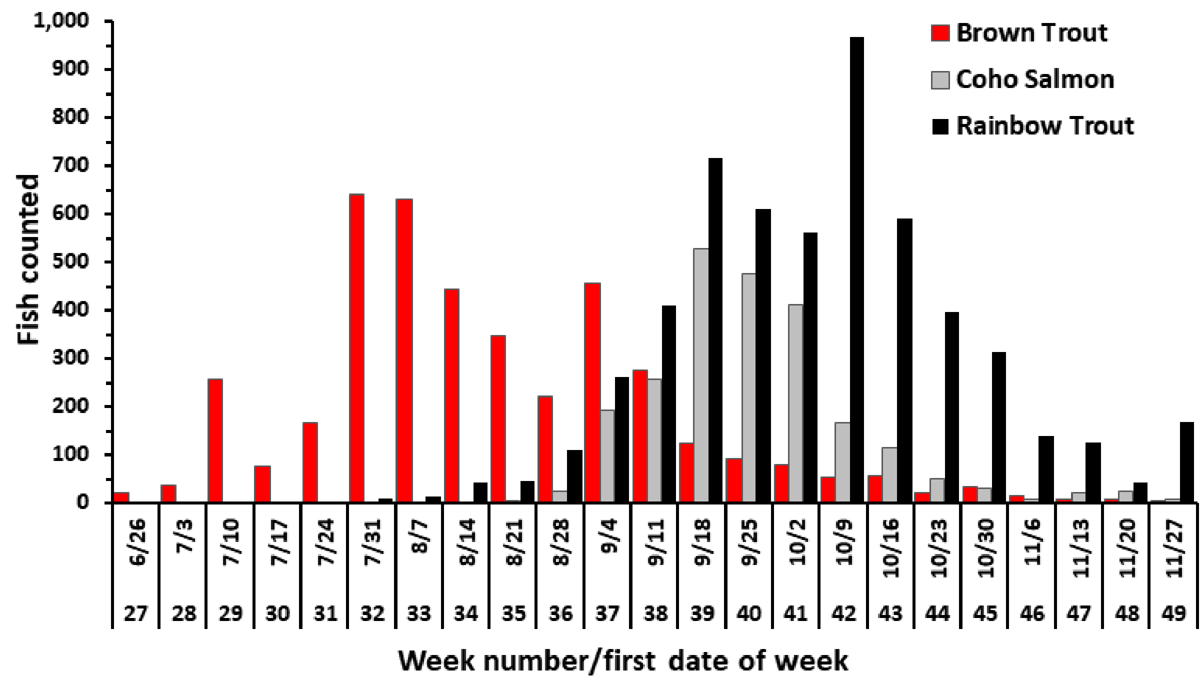


Fig. 34. Number of Brown Trout, Coho Salmon, and Rainbow Trout (includes steelhead) migrating up the Bois Brule River Sea Lamprey barrier and fishway weekly during 2016.



The FCO for non-indigenous salmonids in Lake Superior is being met. Populations of Chinook Salmon, Coho Salmon and Rainbow Trout (steelhead) are being sustained by natural reproduction, and abundance has remained stable or increased from previous reporting periods to the current reporting period. Levels of natural reproduction by these species have allowed management agencies to reduce stocking of non-native salmonines while simultaneously meeting the rehabilitation goals for Lake Trout. The only stocking that remains caters to small-scale fisheries in isolated areas of Lake Superior.

STATUS OF WALLEYE IN LAKE SUPERIOR IN 2017[24]

Eric Bergland[25]

The fish community objective (FCO) for Walleye (Horns et al. 2003) in Lake Superior is to

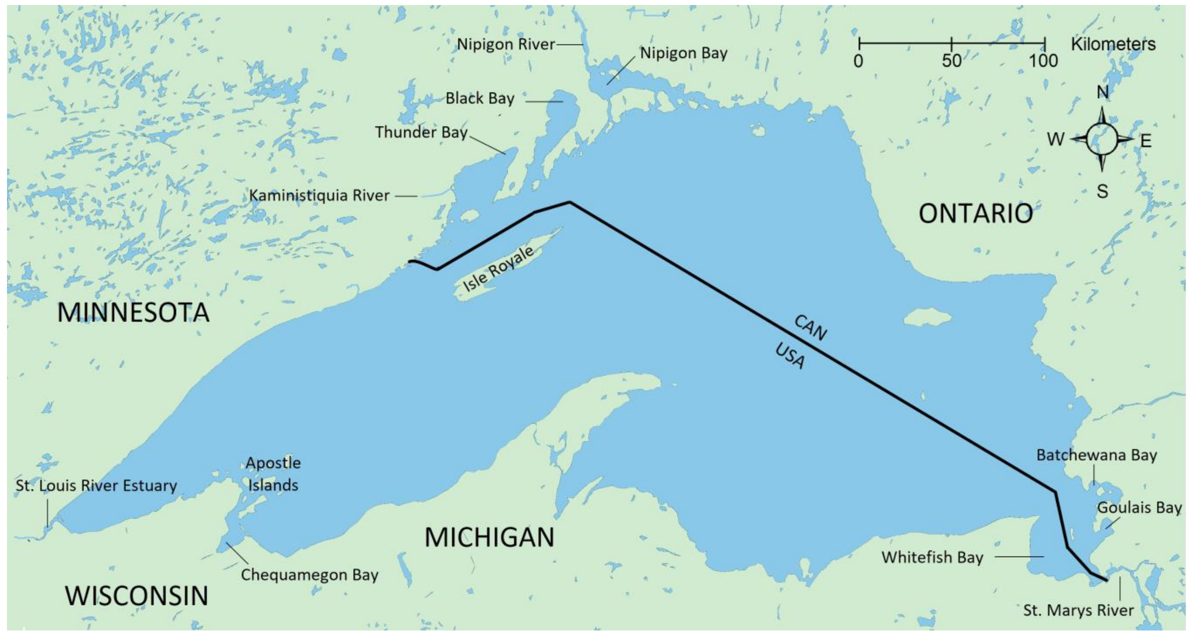
> *Maintain enhance, and rehabilitate self-sustaining populations of walleye and their habitat over their historical range.*

Progress towards achieving the FCO is largely guided by the walleye rehabilitation plan for Lake Superior (Hoff 2002), and, as such, reporting on population status and management approaches has been specific to individual populations and habitats or political jurisdictions. Walleye is not typically ubiquitous in Lake Superior but rather is typically associated with shallow embayments, such as Nipigon, Black, Whitefish, and Chequamegon Bays and the St. Louis River Estuary (Fig. 35).

[24]Complete publication including maps of place names, abstract, other chapters, scientific fish names, and references is available at http://www.glfc.org/pubs/SpecialPubs/Sp21_02.pdf.

[25]**E. Bergland**. Ontario Ministry of Natural Resources and Forestry, Upper Great Lakes Management Unit Lake Superior, 435 James Street South, Suite 221e, Thunder Bay, ON P7E 6S7, Canada (e-mail: eric.bergland@ontario.ca).

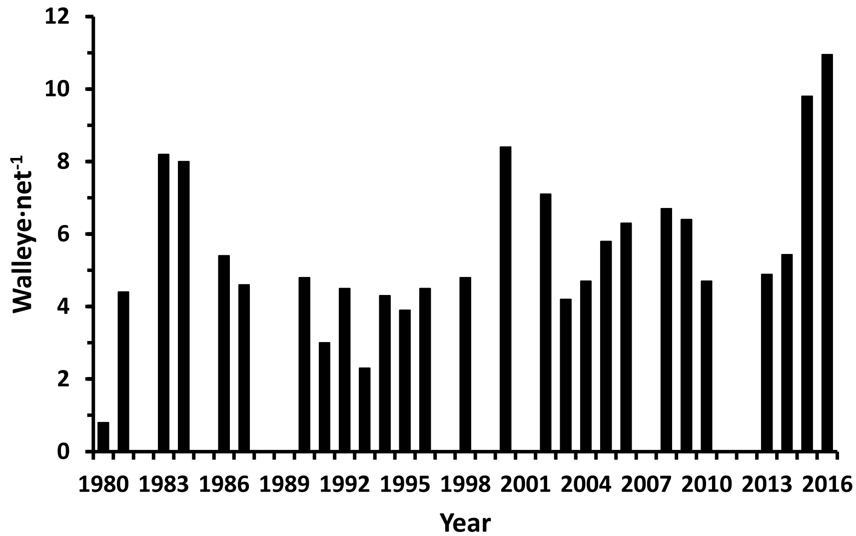
Fig. 35. Lake Superior showing locations of sites mentioned in the text.



Population Status

The St. Louis River Estuary in western Lake Superior remains the only area with a Walleye population known to be near historical levels of abundance, and the estuary supports one of the largest self-sustaining recreational Walleye fisheries on the lake. The adult Walleye population was 50,000 fish in 2015 based on a mark-recapture study jointly conducted by the states of Wisconsin and Minnesota that released 6,300 marked fish, some of which were subsequently recovered during an open-water recreational creel survey (Varian 2017; Olson et al. 2018). During the 2015 creel survey, it was estimated that recreational anglers removed nearly 21% of the Walleye population (9,321 fish; 8,510 kg) whereas the commercial fishery harvested <1%. The spawning population in the estuary is known to inhabit both the river and Lake Superior, as inferred through carbon and nitrogen stable-isotope ratios, angler tag returns, and the size structure of angler-harvested fish (Olson et al. 2018). Relative abundance of Walleye in the estuary has remained stable, although it appears that a large 2012 year-class has increased gillnet catch rate in 2015-2016 to the highest level seen since 1980 (Fig. 36). Interestingly, the 2012 year-class was produced the year following a significant June flood event in western Lake Superior.

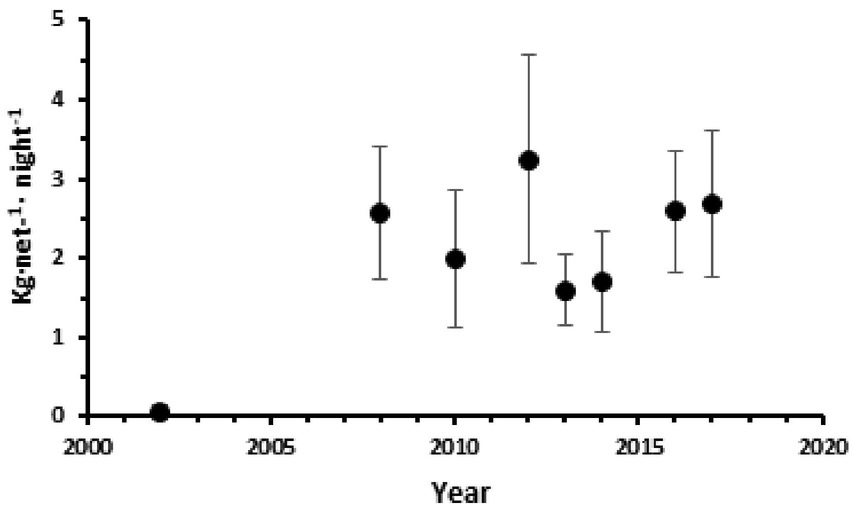
Fig. 36. The annual catch-per-unit effort of Walleye captured during graded-mesh gillnet surveys conducted by the Minnesota DNR in the St. Louis River Estuary, 1980-2016. No surveys were conducted in years without bars.



Walleye rehabilitation efforts in Canadian waters shifted towards increased assessment to understand what progress is being made toward rehabilitation goals. Thunder Bay and the Kaministiquia River, Ontario, both have small but healthy self-sustaining Walleye populations, and both locations show evidence of consistent recruitment. Progress at achieving rehabilitation of Walleye in Black Bay, Ontario, is being evaluated through semi-annual assessment surveys, which show abundance has remained stable during the current reporting period (2012-2016). The Ontario Ministry of Natural Resources and Forestry (OMNRF) conducted fall Walleye index netting (FWIN) surveys in Black Bay during the current reporting period and captured an average of 2.3 kg•net^{-1}•night^{-1} compared to only 0.1 kg•net^{-1}•night^{-1} in 2002 (Fig. 37). Prior to 2012, less than 10 age-classes were found in FWIN catches; in subsequent years, upwards of 20 age-classes (mean age 4 yr) have been captured, which shows consistent recruitment. Preliminary results from an OMNRF acoustic telemetry project in Black Bay suggest Walleye exhibit a wide range of movement patterns, including extended forays outside of Black Bay into Lake Superior.

Walleye populations in other parts of Lake Superior are much less abundant than in the St. Louis River Estuary and Black Bay. In Nipigon Bay and the Nipigon River, Ontario, Walleye abundance is low but increasing, growth rate is high, and mortality is low (Marshall 2013). Limited assessment information on Walleye populations in Batchewana Bay and Goulais Bay, Ontario, show that abundance is low in both areas.

Fig. 37. Kilograms of Walleye caught per net night (black dot) and 95% confidence interval about the mean (vertical bars) during fall Walleye index netting in Black Bay, Lake Superior, 2002 and 2008-2016.



Stocking continues to play a role in maintaining and enhancing Walleye populations in both Wisconsin and Michigan waters of Lake Superior. During the current reporting period, approximately 22 million Walleye larvae and fingerlings have been stocked by either state agencies or by the Bad River Band of Lake Superior Chippewa and the Chippewa Ottawa Resource Authority. The number of Walleye stocked during the current reporting period was about 28 million fish—less than were stocked during the previous reporting period (2006-2011) when ~50 million Walleyes were stocked. The annual lakewide commercial harvest of Walleye averaged only 4,500 kg during the current reporting period because there were only relatively small license quotas or incidental catch.

As of 2016, the FCO for Walleye in Lake Superior is not being met. Although certain populations are showing signs of improvement since the last reporting period, many populations remain below historical levels while others remain relatively unchanged. Fishery-management agencies have addressed their concerns for Walleye populations throughout Lake Superior during the reporting period by limiting commercial and recreational harvests and promoting nearshore habitat-rehabilitation efforts and the improvement and protection of spawning habitat.

STATUS OF BROOK TROUT REHABILITATION IN LAKE SUPERIOR IN 2017[26]

Henry R. Quinlan[27]

The fish community objective (FCO) for Brook Trout (Horns et al. 2003) in Lake Superior is to

> *Maintain widely distributed, self-sustaining populations in as many of the historical habitats as is practical.*

Brook Trout populations in Lake Superior remain stable or have increased in remote regions or in areas where protective regulations exist for lake and tributary environments across large expanses of habitat (Bobrowski et al. 2011; Blankenheim 2013; Miller et al. 2016). These areas include Nipigon Bay and Lake Nipigon, Ontario; Isle Royale, Michigan; and the northern portion of the Minnesota shoreline (Fig. 38). Relative abundance of Brook Trout caught during electrofishing surveys along the Nipigon Bay shoreline during the current reporting period (2012-2016) was 0.4 fish•km^{-1} of shoreline in 2015 and 1.3 fish•km^{-1} in 2016 while, at Isle Royale, mean relative abundance was 3.0 fish•km^{-1} of shoreline in 2015-2016, similar to 3.2 fish•km^{-1} during the previous reporting period (2006-2011) (Ontario Ministry of Natural Resources and Forestry and U.S. Fish and Wildlife Service, unpublished data). In Minnesota, stream surveys conducted every five years show more large Brook Trout ($\geq$300 mm total length (TL)) were present in the 2007-2008 and 2013 surveys than in similar surveys in 1997 and 2002 (Blankenheim 2013), and several legal-sized fish (>508 mm TL)

---

[26]Complete publication including maps of place names, abstract, other chapters, scientific fish names, and references is available at http://www.glfc.org/pubs/SpecialPubs/Sp21_02.pdf.

[27]H.R. Quinlan. U.S. Fish and Wildlife Service, Ashland Fish and Wildlife Conservation Office, 2800 Lakeshore Drive East, Ashland, WI 54806, USA (e-mail: henry_quinlan@fws.gov).

were captured for the first time in the 2013 survey (Blankenheim 2013). Brook Trout is present in other areas but is infrequently encountered, and data are not available to evaluate its abundance or population demographics. These areas include most of the shoreline in Ontario and central portion of Michigan and in areas that were stocked.

Tagging and stable-isotope studies indicate that Lake Superior Brook Trout diversity includes numerous life histories that exhibit a range of migration patterns, likely due to density dependence, environmental stochasticity, or proximity to the lake (Stimmel 2006; Huckins et al. 2008; Coppaway 2011; Robillard et al. 2011a, b; Velez-Espino et al. 2013; Kusnierz et al. 2014). The coaster form of Brook Trout hatches in tributaries, but sometime thereafter it migrates into Lake Superior, grows to large size (>500 mm TL), and lives very near shore (<10 m) before migrating back into tributaries to spawn (Newman et al. 2003). Many Brook Trout living in tributaries do not migrate into Lake Superior, and these "stream-resident" forms seldom grow to be as large as the coaster. In the Salmon Trout River, Michigan, Brook Trout sampled above and below the first barrier upstream from Lake Superior were composed of two genetically differentiated populations, and researchers surmised that a stream-resident life-history strategy may be exceedingly rare or non-existent in the lower river (Scribner et al**.** 2012**).**

A total of 586,000 Brook Trout were stocked in U.S. waters or in tributaries that could be accessed by migratory fish during the current reporting period (http://www.glfc.org/fishstocking/). The Tobin Harbor, Siskiwit Bay, and Lake Nipigon strains of Lake Superior Brook Trout were stocked during the reporting period, although only the Tobin Harbor strain remains available for stocking as of 2017. Nearly half of the stocked fish (278,000) were not marked because they were stocked as fry and were too small to mark externally.

Fig. 38. Lake Superior showing locations of sites mentioned in the text.

Fishery agencies developed a standardized shoreline sampling protocol to facilitate evaluation of progress toward the FCO and rehabilitation goals (Newman et al. 2003; H. Quinlan, USFWS, personal communication, 2020). The protocol is designed to provide measures of distribution and relative abundance within and among locations where rehabilitation projects are taking place. In 2015 and 2016, standardized shoreline electrofishing surveys were conducted in six Lake Superior locations (Table 2).

Table 2. Locations surveyed and findings from implementation of a standardized shoreline electrofishing protocol for wild-origin Brook Trout in Lake Superior during 2015 and 2016.

Location	**Years**	**Kms Surveyed**	**Catch-Per-Unit Effort (fish•km^{-1})**	**Shoreline with Brook Trout (%)**
Nipigon Bay (Ontario)	2015	28	0.4	50
	2016	38	1.3	60
Grand Portage (Minnesota)	2015	52	0.5	30
	2016	44	1.2	40
Red Cliff (Wisconsin)	2015	9	0.1	10
	2016	12	0.1	10
Chequamegon Bay (Wisconsin)	2015	9	0.0	0
	2016	7	0.0	0
Tobin Harbor (Michigan)	2015	16	2.4	70
	2016	16	3.6	90
Huron Bay (Michigan)	2015	8	0.1	10

Critical Brook Trout habitat in tributaries is protected in many areas of the basin through governmental regulations, natural-resource-agency ownership and conservation easement agreements; designation as exceptional or outstanding water resources or wild and scenic rivers; and Land Conservation Trusts. In Wisconsin and Minnesota, more than 50% of the total tributary habitat that supports self-sustaining cold-water migratory fish is protected (Goldsworthy et al. 2016). Habitat-restoration projects in support of cold-water fish occur periodically in each jurisdiction around Lake Superior, but, despite these tributary and watershed protection and restoration efforts, habitat degradation remains an impediment to achievement of the Brook Trout FCO. Tributaries and watersheds received the lowest rating of seven habitat-conservation targets in the Lake Superior Biodiversity Conservation Assessment (Superior Work Group of the Lake Superior Lakewide Action and Management Plan 2015).

Conclusions and Recommendations

The Brook Trout FCO was not met during the current reporting period. Brook Trout populations are stable or increasing in regions where highly protective and/or conservative fishery regulations exist in both lake and tributary habitats. Erosion, sedimentation, loss of channel complexity, warming water temperatures, and high flood-flow rates continue to impede Brook Trout rehabilitation in tributaries (Fitzpatrick et al. 2015; Superior Work Group of the Lake Superior Lakewide Action and Management Plan 2015) despite tributary and watershed protection and restoration efforts. There is evidence that non-indigenous salmonines negatively impact Brook Trout in some Lake Superior tributaries (Huckins et al. 2008; Ferringa et al. 2016); thus additional research on interactions among native and non-native salmonines is warranted. Stocked fish should be externally marked when possible and internally marked (i.e., otolith branding) when not externally marked. A recently established standardized assessment protocol will help assess future progress toward achievement of the FCO.

STATUS OF LAKE STURGEON IN LAKE SUPERIOR IN 2017[28]

Thomas Pratt[29], Henry R. Quinlan, Joshua T. Schloesser, Bradley A. Ray, and S. Ben Michaels

The fish community objective (FCO) for Lake Sturgeon (Horns et al. 2003) in Lake Superior is to

> *Rehabilitate and maintain spawning populations of lake sturgeon that are self-sustaining throughout their native range.*

The Lake Sturgeon FCO was further refined to include a self-sustaining population having a minimum of 1,500 mature adults using a common tributary for spawning, an equal sex ratio, the presence of 20 or more year-classes, and annual recruitment (Auer 2003). It is likely that 4 of the 21 historical Lake Sturgeon populations meet these criteria: the Bad and White Rivers (Wisconsin) and Sturgeon River (Michigan) based on mark-recapture estimates from the spawning run (Schloesser and Quinlan 2010; Hayes and Caroffino 2012), the Goulais River (Ontario) based on mark-recapture estimates in Goulais Bay (Pratt et al. 2014), and the Pic River (Ontario)

---

[28]Complete publication including maps of place names, abstract, other chapters, scientific fish names, and references is available at http://www.glfc.org/pubs/SpecialPubs/Sp21_02.pdf.

T.C. Pratt. Fisheries and Oceans Canada, Great Lakes Laboratory for Fisheries and Aquatic Sciences, 1219 Queen Street East, Sault Ste Marie, ON P6A 2E5, Canada.

H.R. Quinlan and J.T. Schloesser. U.S. Fish and Wildlife Service, Ashland Fish and Wildlife Conservation Office, 2800 Lakeshore Drive East, Ashland, WI 54806, USA.

B.A. Ray. Wisconsin Department of Natural Resources, P.O. Box 589, 141 South Third Street, Bayfield, WI 54814, USA.

S.B. Michaels. Great Lakes Indian Fish and Wildlife Commission, P.O. Box 9, 72682 Maple Street, Odanah, WI 54861, USA

[29]Corresponding author (e-mail: thomas.pratt@dfo-mpo.gc.ca).

based on catches from the juvenile lakewide assessment (Figs. 39, 40). The Pic River needs further assessment to confirm the number of mature adults. Other populations show signs of progression towards recovery based on the number of fish captured during the lakewide juvenile assessment in the St. Louis, Black Sturgeon, and Batchawana Rivers (Fig. 40) or based on spawning surveys in the Kaministiquia (Welsh et al. 2015) and White Rivers (Anishinabek Ontario Fisheries Resource Center, unpublished data).

The status of Lake Sturgeon in other tributaries is not as robust. Lake Sturgeon is believed to be extirpated in 6 tributaries (Fig. 39). Low numbers captured during lakewide juvenile assessments (Fig. 40), during spawning, or during other adult assessments indicate that populations in the Michipicoten, Prairie, and Nipigon Rivers remain low and vulnerable to extirpation (Fig. 40). Spawning was confirmed in the Michipicoten River for the first time in 2016. There are few long-term time series of Lake Sturgeon in Lake Superior, and, perhaps not surprising for a long-lived, late-maturing species, there is no change in population trajectory during the current reporting period (2012-2016) from the previous (2006-2011) reporting period (Fig. 41).

Fig. 39. Location of historically known Lake Sturgeon populations in Lake Superior along with their status.

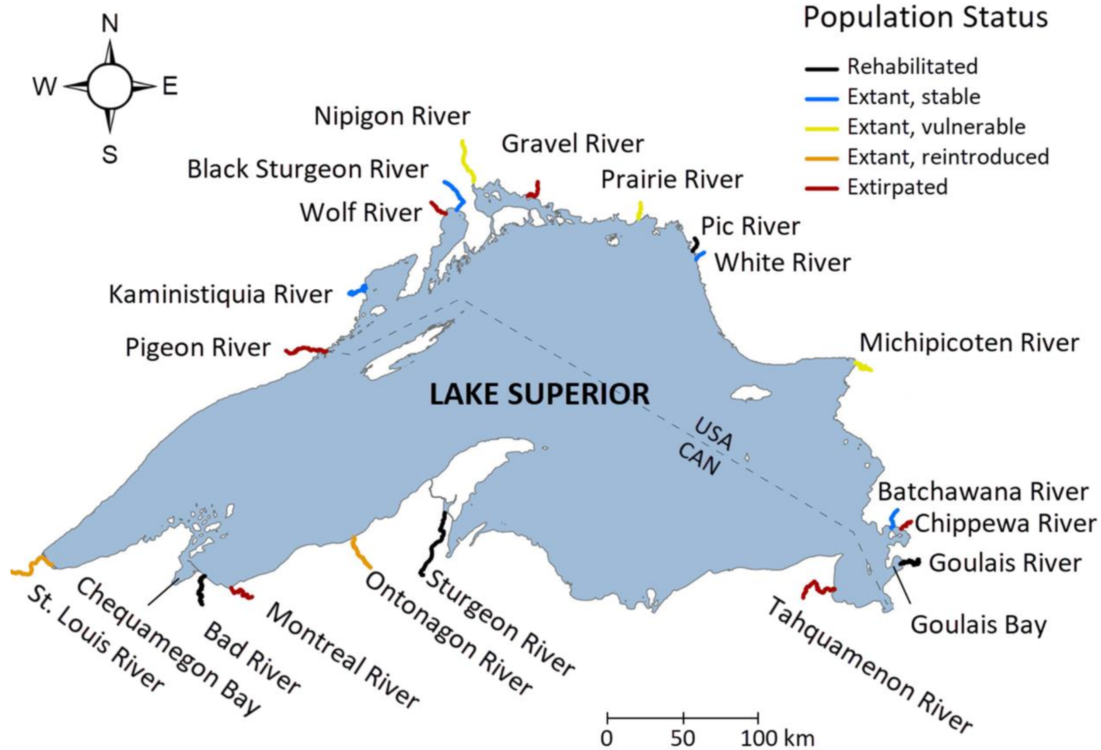


Fig. 40. Geometric mean catch rate (fish•km^{-1}) of Lake Sturgeon during lakewide juvenile assessments in 2011 and 2016. The surveys were conducted off the mouth of all historical spawning tributaries using standardized nets and locations (Schloesser et al. 2014).

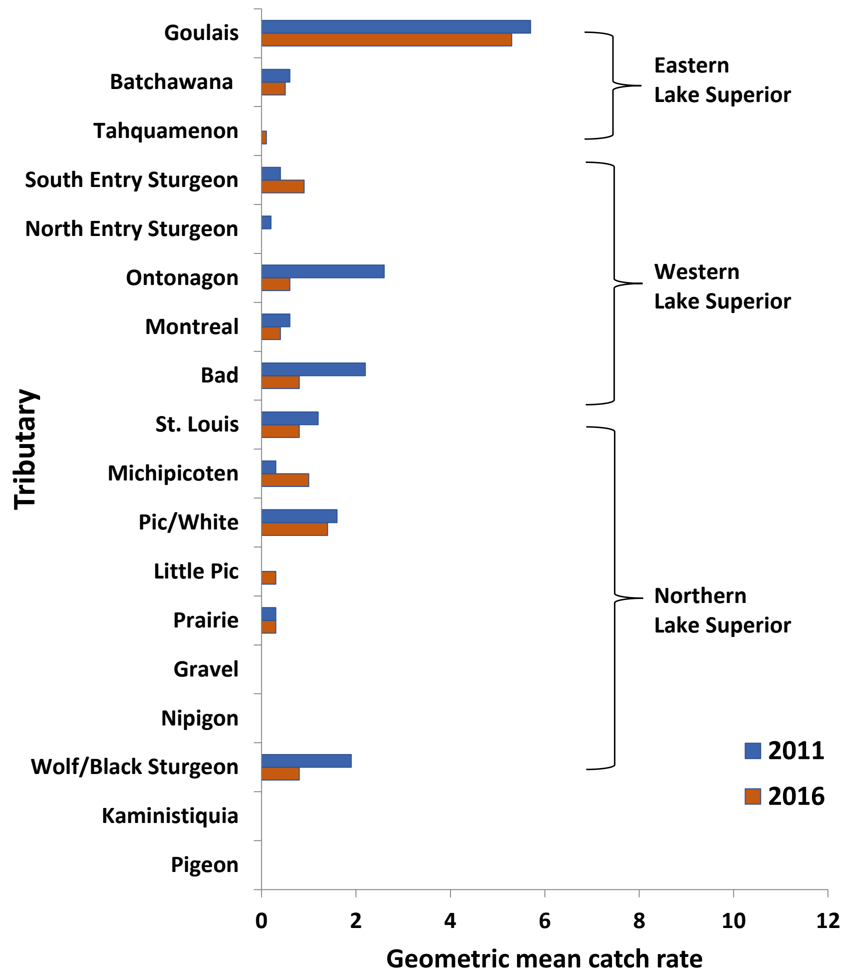
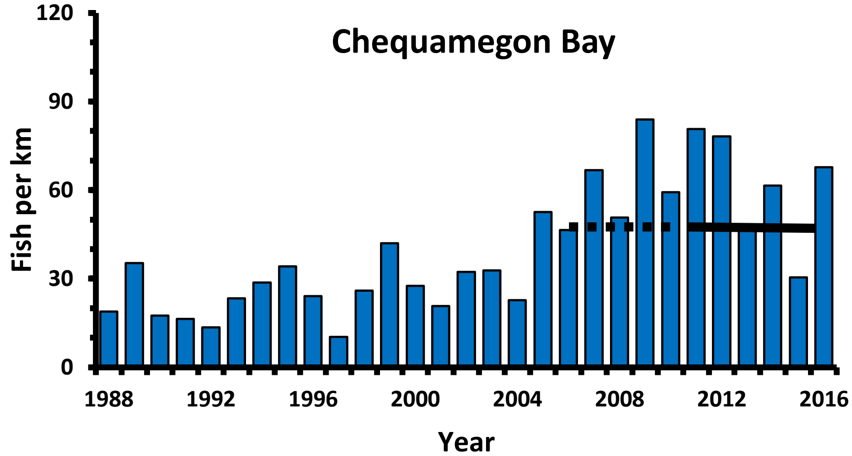
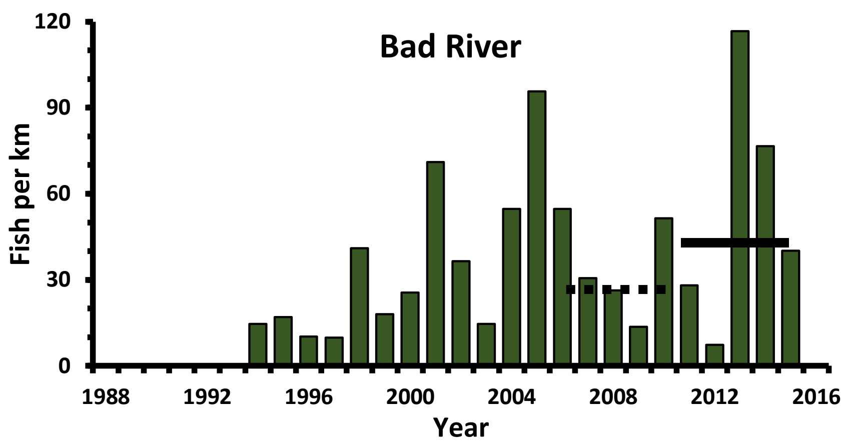
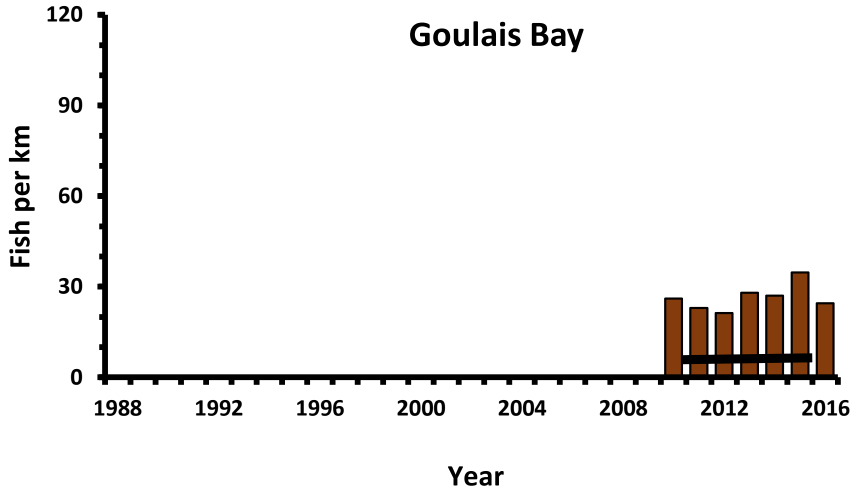


Fig. 41. Mean number of Lake Sturgeon caught per kilometer of gillnet in Chequamegon Bay, off the mouth of the Bad River, and in Goulais Bay, 1998-2016. Horizontal lines represent the mean catch rate during the previous (2006-2011) and present (2012-2016) reporting periods (years without bars were not sampled).







In summary, the FCO for Lake Sturgeon is not being met. Few Lake Superior Lake Sturgeon populations are considered fully rehabilitated, and more than half the historical populations are extirpated or persist at small population sizes. Protective regulations should be maintained to keep mortality as low as possible while rehabilitation progresses. Impediments to successful Lake Sturgeon rehabilitation continue to be habitat loss or degradation due to hydropower operations and barriers. Low levels of abundance in some small remnant populations also limit range expansion into unoccupied, historically used habitat. Agencies should continue to support the 5-year Cooperative Science and Monitoring Initiative to assess progress towards Lake Sturgeon rehabilitation.

STATE OF LAKE SUPERIOR IN 2017: NATIVE-SPECIES DIVERSITY[30]

Jared T. Myers[31], Michael J. Seider, and Thomas C. Pratt

The fish community objective (FCO) for species diversity (Horns et al. 2003) in Lake Superior is to

> *Protect and sustain the diverse community of indigenous fish species not specifically mentioned earlier (burbot, minnows, yellow perch, northern pike, and suckers). These species add to the richness of the fish community and should be recognized for their ecological importance and cultural, social, and economic value.*

The fish communities that inhabit Lake Superior's inshore embayments and tributaries contrast starkly with those of the open lake. While the FCO recognizes the value of protecting indigenous warm- and cool-water species that are not actively managed, there has not been a dedicated, lakewide survey for evaluating their status and relative abundance. Fortunately, a multi-gear survey to monitor the abundance of embayment and tributary fish communities was implemented during the current reporting period (2012-2016) in the St. Louis River, the upper St. Marys River, and Thunder Bay. The objective of this sampling effort was to establish an early detection program of non-native species, but the use of paired fyke nets, bottom

---

[30]Complete publication including maps of place names, abstract, other chapters, scientific fish names, and references is available at http://www.glfc.org/pubs/SpecialPubs/Sp21_02.pdf.

J.T. Myers and M.J. Seider. U.S. Fish and Wildlife Service, Ashland Fish and Wildlife Conservation Office, 2800 Lakeshore Drive East, Ashland, WI 54806, USA.

T.C. Pratt. Fisheries and Oceans Canada, Great Lakes Laboratory for Fisheries and Aquatic Sciences, 1219 Queen Street East, Sault Ste Marie, ON P6A 2E5, Canada.

[31]Corresponding author (e-mail: jared_myers@fws.gov).

trawls, and boat electrofishing ensured a comprehensive view of the fish communities at each location (Table 3).

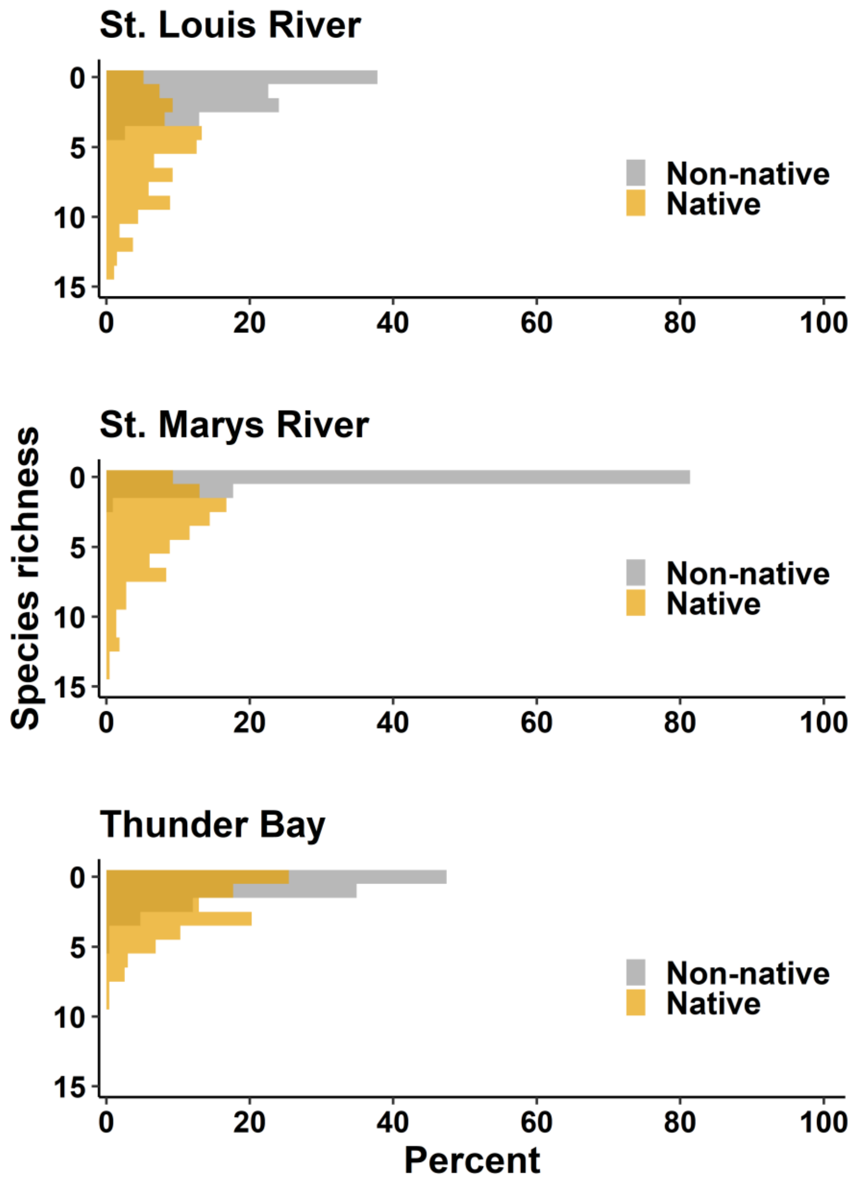
Table 3. Number of sites sampled with different survey gear and the number of fish species encountered during annual non-native-species surveillance surveys conducted at three locations in Lake Superior, 2012-2016.

		Sampling Gear/Number of Sites				**Species Encountered***	
Location	**Year**	**Electrofish**	**Fyke**	**Trawl**	**Total**	**Non-native**	**Total**
Thunder Bay	2012	15	15	15	45	7	29
	2013	20	20	10	50	7	25
	2014	20	20	10	50	5	20
	2015	20	19	10	49	3	19
	2016	15	13	10	38	5	20
St. Marys River	2012	15	14	16	45	5	25
	2013	19	20	10	49	3	25
	2014	12	20	10	42	2	31
	2015	17	20	10	47	3	32
	2016	7	15	10	32	2	27
St. Louis River	2012	20	20	10	50	8	30
	2013	20	20	10	50	6	29
	2014	40	20	10	70	7	33
	2015	20	20	10	50	8	32
	2016	20	20	10	50	9	35

*Due to the difficulty associated with taxonomic identification of young *Lepomis* spp. and *Ameiurus* spp., all were combined by genus and analyzed as single groups.

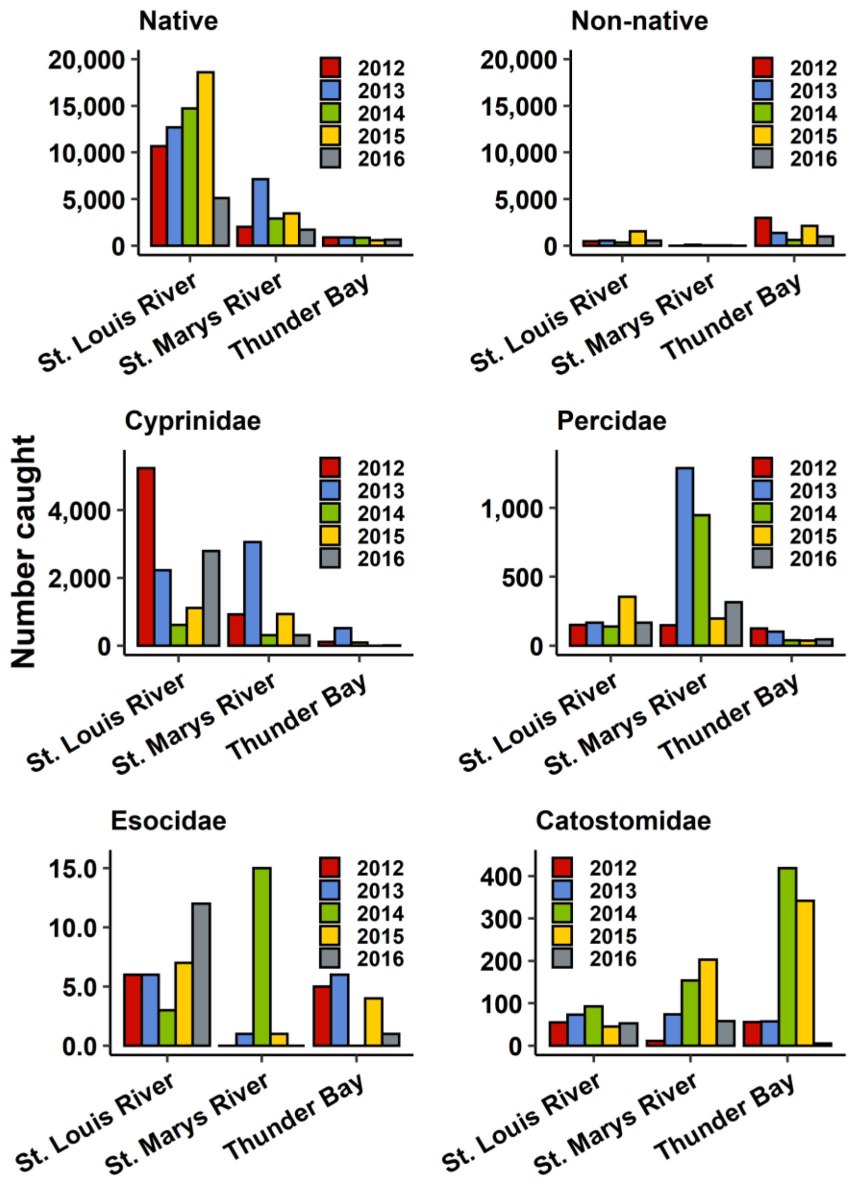
The incidence of native species within individual samples was greater than that of non-native species for each of the locations surveyed during the reporting period (Fig. 42). While the St. Louis River is recognized for its vulnerability to new invasive species (see Peterson et al. 2011), catches during the reporting period were still dominated by native fish. Of the 270 samples collected in the St. Louis River, 70% contained more than four native species, and 97% had less than three non-native species represented within individual samples (Fig. 42). Surveys conducted in the upper St. Marys River were consistent with previous assessments (Pratt and O'Connor 2011) in that invasive fish were not common. More than 81% of the 215 samples from the upper St. Marys River had no non-native species present while 78% of the samples had greater than two native species present within individual samples (Fig. 42). Thunder Bay is similar to the St. Louis River in that it is vulnerable to factors that could reduce native-species diversity (Hoffman et al. 2016); however, 57% of the 232 samples had more than two native species, and 47% of the samples had no non-native species (Fig. 42).

Fig. 42. Incidence of native and non-native fish species (as a percentage of total sampling effort) captured during non-native-species surveys at three locations in Lake Superior, 2012-2016.


St. Louis River
St. Marys River
Thunder Bay
Species richness
Percent
Non-native
Native
0
5
10
15
0
20
40
60
80
100

While there does not appear to have been a dramatic shift in the status of native fish species during the current reporting period (Fig. 43) or from previous state of the lake reports (Pratt et al. 2010, 2016), we acknowledge that the data available to adequately address the FCO for species diversity are currently limited. We are encouraged by the potential for non-native-species surveillance surveys to be used not only for early detection and monitoring but also for other questions related to nearshore fish communities. Hoyle et al. (2017) used indices of biotic integrity to evaluate the status and trends of native-species richness, abundance, and biomass at 11 nearshore areas in Lake Ontario. Given that similar multi-gear sampling efforts are implemented at many nearshore areas across the Great Lakes, we believe a valuable perspective could be gained by using a structured process to compare fish communities both within and across each of the Great Lakes. Coordination between lake technical committees to evaluate similar fish community objectives could provide fishery managers with valuable information and unique perspectives moving forward.

Fig. 43. Number of fish caught according to origin (native vs. non-native) and family during non-native-species surveillance surveys conducted at three locations in Lake Superior, 2012-2016.



Native
Non-native
Cyprinidae
Percidae
Esocidae
Catostomidae
Number caught
2012
2013
2014
2015
2016
St. Louis River
St. Marys River
Thunder Bay

STATUS OF SEA LAMPREY IN LAKE SUPERIOR IN 2017[32]

Todd B. Steeves[33] and Jessica M. Barber

The fish community objective (FCO) for Sea Lamprey (Horns et al. 2003) in Lake Superior is to

> *Suppress sea lampreys to population levels that cause only insignificant mortality on adult lake trout.*

The management objective in the FCO is to suppress populations until the annual Sea Lamprey-induced mortality rate on adult Lake Trout is insignificant, i.e., <5%. Sea Lamprey control began in Lake Superior in 1958 in response to increased mortality on Lake Trout that occurred after the invasion of Sea Lamprey in the late 1930s (Hansen et al. 1995). Since then, control efforts have been refocused from eradication to optimal suppression (Heinrich et al. 2003), as stated in the FCO (Horns et al. 2003; Pratt et al. 2016). To achieve the FCO, the target maximum for adult Sea Lamprey abundance is 9,600 (±2,500; 95% confidence interval) in a group of 7 index tributaries, and this level of abundance should help achieve a target marking rate of no more than 5 marks per 100 Lake Trout. This target level of abundance was modified in 2015 from the previous target maximum of 36,000 adult Sea Lampreys (Pratt et al. 2016), which reflected a modeled lakewide estimate of abundance (Mullett et al. 2003). The new index was

---

[32]Complete publication including maps of place names, abstract, other chapters, scientific fish names, and references is available at http://www.glfc.org/pubs/SpecialPubs/Sp21_02.pdf.

T.B. Steeves. Fisheries and Oceans Canada, Sea Lamprey Control Centre, 1219 Queen Street East, Sault Ste Marie, ON P6A 2E5, Canada.

J.M. Barber. U.S. Fish and Wildlife Service, Sea Lamprey Control, 3090 Wright Street, Marquette, MI 49855, USA.

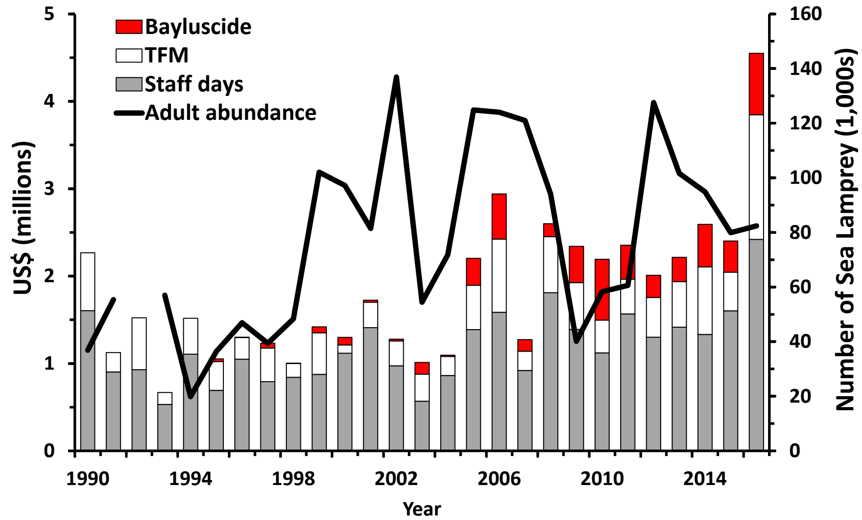
[33]Corresponding author (e-mail: mike.steeves@dfo-mpo.gc.ca**).**

thought to be a more reliable estimate of Sea Lamprey abundance because it did not depend on extrapolating abundance from sampled to non-sampled tributaries. Both the previous lakewide and the current index targets for Sea Lamprey abundance represent the estimated mean for a 5-year period (1994-1998) when marking rates were closest to 5 marks per 100 fish. The annual index of adult Sea Lamprey abundance during the current state of the lake reporting period (2012-2016) was 24,600, and the index has remained very near the levels observed during the 2 previous reporting periods: 23,800 Sea Lampreys during 2001-2005, and 21,000 Sea Lampreys during 2006-2011(Fig. 44).

Control Measures

Sea Lamprey has been collected from 165 of the 1,566 tributaries to Lake Superior. Of the 165 tributaries, 119 have been treated at least once during 2007-2016, and 53 tributaries have consistent recruitment of Sea Lamprey and receive regular lampricide treatments on a 4- to 6-year cycle (Mullett and Sullivan 2017). Lampricide usage has increased since 2005 (Fig. 44). The average amount of 3-trifluoromethyl-4-nitrophenol (TFM) used to treat tributaries during the reporting period increased to 16,000 $kg \bullet y^{-1}$ from 7,120 $kg \bullet y^{-1}$ (US$320,000) during 2001-2005, and 11,100 $kg \bullet y^{-1}$ (US$502,000) during 2006-2011. The average TFM usage during the reporting period includes 32,500 kg (US$1,400,000) during 2016 as part of an effort to further reduce Sea Lamprey abundance. This increased effort will be repeated every 3 years as part of an adaptive management approach to suppression in Lakes Superior, Michigan, and Huron.

Fig. 44. Annual expenditure (US$) on granular Bayluscide, 3-trifluoromethyl-4-nitrophenol (TFM), and staff days used to control Sea Lamprey in Lake Superior and indices of spawning Sea Lamprey abundance (black line) from 1990 through 2016. The effects of control efforts do not affect the index of adult Sea Lamprey abundance for at least two years.



Lentic Areas

Assessment of larval populations in embayments and lentic areas that are closely associated with Sea Lamprey-producing tributaries has increased since 2004, resulting in increased application of granular Bayluscide to control these populations (Fig. 44). Use of RoxAnn™ technology has resulted in sonar-based quantification of substrates and subsequent evaluation of abundance and distribution of larvae within these substrates. Assessments have resulted in the treatment of 56 lentic areas (544 ha) with granular Bayluscide during the reporting period. Larval abundance in these areas will be monitored, and Bayluscide application will be scheduled as part of the annual control program.

Barriers

The Strategic Vision of the Great Lakes Fishery Commission for the First Decade of the New Millennium (GLFC 2008, 2011) has a milestone that designates alternative control technologies to

> *Accomplish at least 50% of sea lamprey suppression...while reducing TFM use by 20%...*

As of 2016, there were 18 barriers on Lake Superior tributaries that blocked or reduced access to spawning habitats by migrating adult Sea Lamprey (Mullett and Sullivan 2017), which eliminated the need for lampricide application in those areas. There are 11 low-head barriers constructed expressly to stop Sea Lamprey migration. Barriers constructed since 1990 have either been of variable-crest design (Big Carp River, Ontario), where the barrier crest can be lowered to the stream bed to enable fish passage when Sea Lamprey is not migrating, or the barriers have incorporated trap-and-sort fishways to allow passage of desired fish species (Brule River, Minnesota, and Big Carp River, Ontario). There are also 7 structures constructed for other purposes that have been modified to block migrating Sea Lamprey.

Conclusions and Recommendations

The FCO for Sea Lamprey is not being met. Adult index targets were not met in any year during the reporting period. Marking rates on Lake Trout were above the target maximum of 5 marks per 100 fish in 7 of 11 management units in 2016 (Fig. 18), and statistical catch-at-age models (Modeling Subcommittee, Technical Fisheries Committee 2018) indicate that Sea Lamprey remains a significant source of mortality on lean Lake Trout. Ironically, the Lake Trout FCO for Lake Superior is being met (see Status of Lake Trout in Lake Superior in 2017 chapter) even though the Sea Lamprey FCO is not. However, the Lake Trout FCO uses information exclusively from lean Lake Trout, and we know little about the extent and effects of Sea Lamprey attacks on alternative host species (e.g., siscowet Lake Trout, Lake Whitefish, and Cisco) and the role Sea Lamprey plays in abundance and mortality of these species. Abundant alternative hosts likely account for the disparity in FCO outcomes; nevertheless, re-evaluation of the Sea Lamprey FCO may be warranted if this inconsistency continues. Additionally, control agents should continue to monitor tributaries post-treatment to detect new recruitment, monitor tributaries with large numbers of treatment survivors, and monitor lentic areas to identify larval populations that require control.

STATE OF LAKE SUPERIOR IN 2017: AQUATIC NUISANCE SPECIES[34]

Jared T. Myers[35], Michael J. Seider, Mark J. Brouder, Anett S. Trebitz, and Joel C. Hoffman

The fish community objective (FCO) for aquatic nuisance species (Horns et al. 2003) in Lake Superior is to

> *Prevent the introduction of any non-indigenous aquatic species that is not currently established in Lake Superior; prevent or delay the spread of non-indigenous aquatic species, where feasible; and eliminate or reduce populations of non-indigenous nuisance species, where feasible.*

Complete prevention of new species introductions, along with containment and reduction of non-native nuisance species that are already present, is a challenging but appropriate goal for Lake Superior. To evaluate the effectiveness of the current regulatory framework for aquatic nuisance species, federal, state, provincial, and tribal natural-resource agencies worked together to implement non-native-species surveillance programs at eight locations. These assessment programs were modeled after the approach developed by Trebitz et al. (2009) and Hoffman et al. (2011, 2016) and

---

[34]Complete publication including maps of place names, abstract, other chapters, scientific fish names, and references is available at http://www.glfc.org/pubs/SpecialPubs/Sp21_02.pdf.

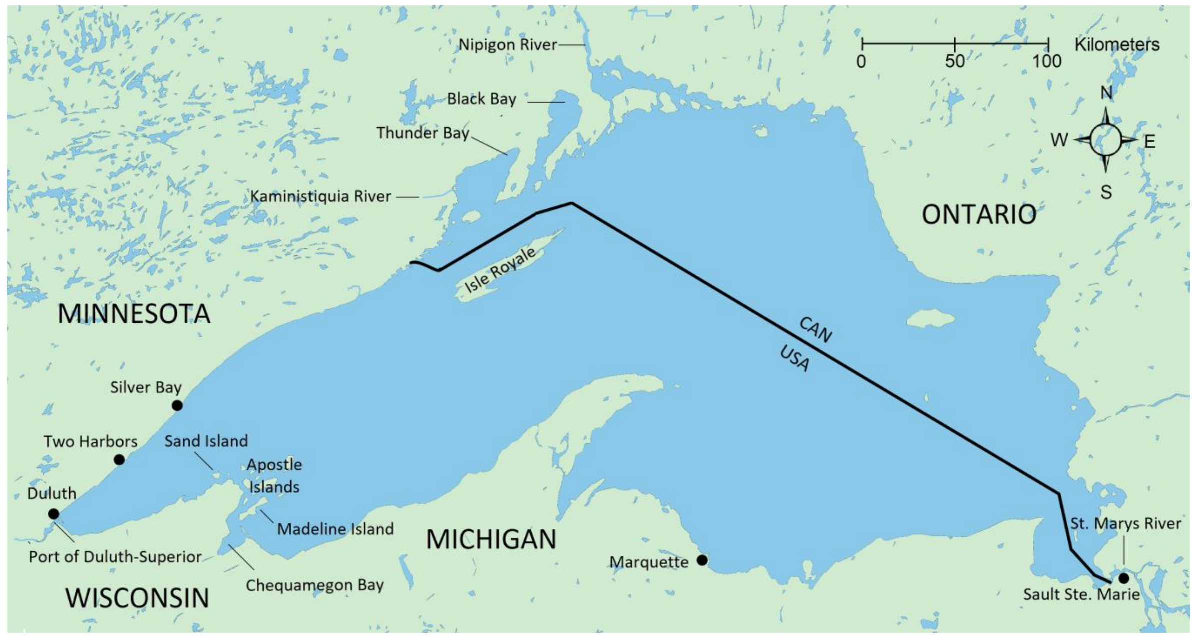
J.T. Myers, M.J. Seider, and M.J. Brouder. U.S. Fish and Wildlife Service, Ashland Fish and Wildlife Conservation Office, 2800 Lakeshore Drive East, Ashland, WI 54806, USA.

A.S. Trebitz and J.C. Hoffman. U.S. Environmental Protection Agency, Center for Computational Toxicology and Ecology, Great Lakes Toxicology and Ecology Division, 6201 Congdon Boulevard, Duluth, MN 55804, USA.

[35]Corresponding author (e-mail: jared_myers@fws.gov).

involve an adaptive cycle of assessment, refinement, and implementation that uses performance measures to improve detection probability. Taxa accumulation curves and randomization analyses have been the primary tools for evaluating if gear allocation, sample distribution, and overall sampling effort are appropriate for the location of interest. Non-native-species surveillance surveys have typically relied on the deployment of traditional sampling gears and taxonomic identification using physical characteristics. The new approach, however, uses DNA-based identification approaches, such as metabarcoding of ichthyoplankton and zooplankton samples and eDNA metabarcoding for fish detection to improve survey accuracy in the future. These techniques have been the subject of experimentation in the Port of Duluth-Superior (metabarcoding for ichthyoplankton samples and fish detection) and Apostle Islands (metabarcoding of zooplankton samples) (Fig. 45). Continuing to adhere to an adaptive approach for early detection will ensure the delivery of a surveillance program that is responsive, transparent, efficient, and effective.

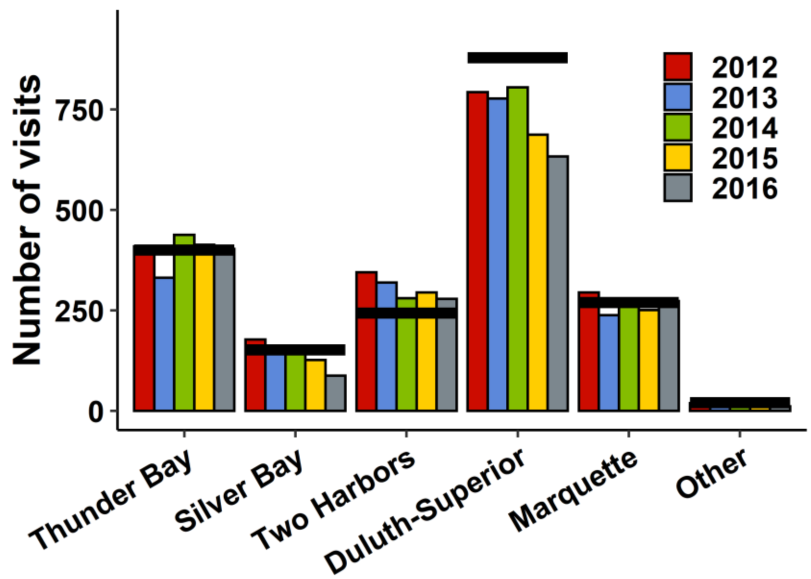
Fig. 45. Lake Superior showing locations of sites mentioned in the text.



Each of the 18 non-native fish species known to exist in Lake Superior was observed at least once during the current 5-year reporting period (2012-2016), but no new non-native fish species were found. One particularly noteworthy observation was the reappearance of White Bass in the Port of Duluth-Superior. This species had not been documented since the 1980s, yet both adult and juvenile specimens of 96-362 mm total length from the 2010, 2011, and 2014 year-classes were collected in 2015 and 2016. The invertebrate banded mystery snail (*Viviparus georgianus*) was collected in 2014 while bottom trawling in the upper St. Marys River. The banded mystery snail is native to the southeastern part of the U.S. and the Mississippi River system but is considered invasive in the Great Lakes. The non-native faucet snail (*Bithynia tentaculata*), first detected in the Chequamegon Bay area in 2010, was found to be established and abundant in the Port of Duluth-Superior in 2012 and 2013 (Trebitz et al. 2015). Lastly, zebra mussels (*Dreissena polymorpha*) and quagga mussels (*D. bugensis*) were first detected in the Port of Duluth-Superior in 1989 and 2005, respectively (Griffiths et al. 1991; Grigorovich et al. 2008). These mussels have likely expanded their range to the Apostle Islands, as zebra mussels were found on a shipwreck near Sand Island in 2015 and 2016, and quagga mussels were found attached to commercial fishing gear near Madeline Island in 2011 and throughout the reporting period. Given the evidence for a new introduction (i.e., banded mystery snail), the spread of faucet snails and zebra and quagga mussels, and the reemergence of White Bass, we argue the FCO for aquatic nuisance species has not been met.

While there are a host of pathways by which new invaders could reach Lake Superior, ballast water still poses the highest risk (O'Malia et al. 2018). Progress has been made in the management of ballast from ocean-going vessels, but domestic vessels operating within the Great Lakes still have a high potential for spreading species within the region (Briski et al. 2012). The principal cargos handled at Lake Superior ports are outbound iron ore, coal, and grain; a scenario that leads to many of the inbound vessels arriving with ballast water from the four lower Great Lakes. Lake Superior ports had an average of 1,864 vessel visits per year and 40% of those were to the Port of Duluth-Superior (Fig. 46), making it the largest bulk cargo port in the Great Lakes. An average of 15 million metric tons of ballast water was discharged annually at the Port of Duluth-Superior during the reporting period (Fig. 46), and 99.7% of the balance was from domestic vessels. During the reporting period, there was a total of 143 million metric tons of ballast water discharged into U.S. waters of Lake Superior, and 99.8% of the ballast water was from domestic vessels (Fig. 47). Given the risk of secondary infestations from domestic vessels, fishery managers should be mindful of the species that are most likely to be introduced by monitoring the status and distribution of non-native species in the lower Great Lakes. Policy makers should seek to reduce the risk of new invasions by continuing to implement the actions described within the Lake Superior Aquatic Invasive Species Complete Prevention Plan (Lake Superior Binational Program 2014).

Fig. 46. Number of visits and volume of ballast water discharged by commercial shipping vessels at Lake Superior ports, 2012-2016. Horizontal black bars represent the averages for the previous reporting period (2006-2011) (NBIC 2016; TBPA 2018).


Number of visits
750
500
250
0
2012
2013
2014
2015
2016
Thunder Bay
Silver Bay
Two Harbors
Duluth-Superior
Marquette
Other

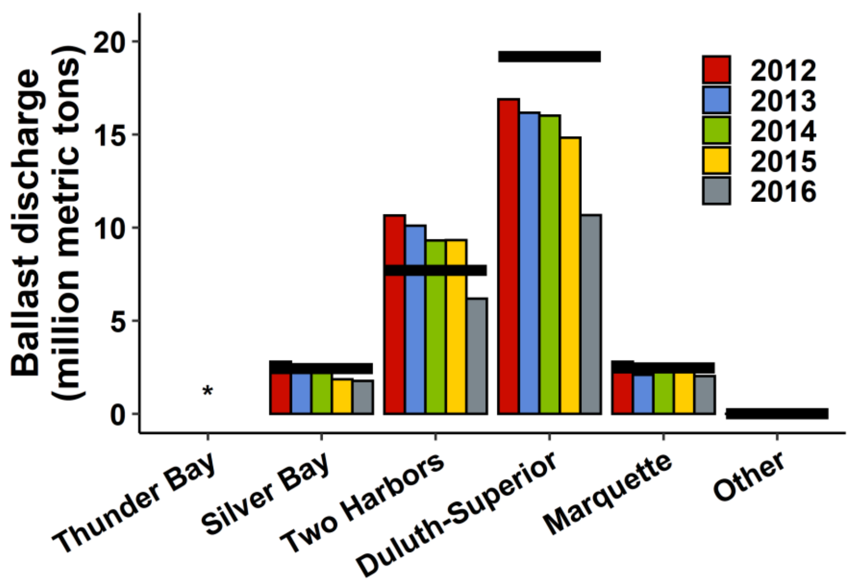
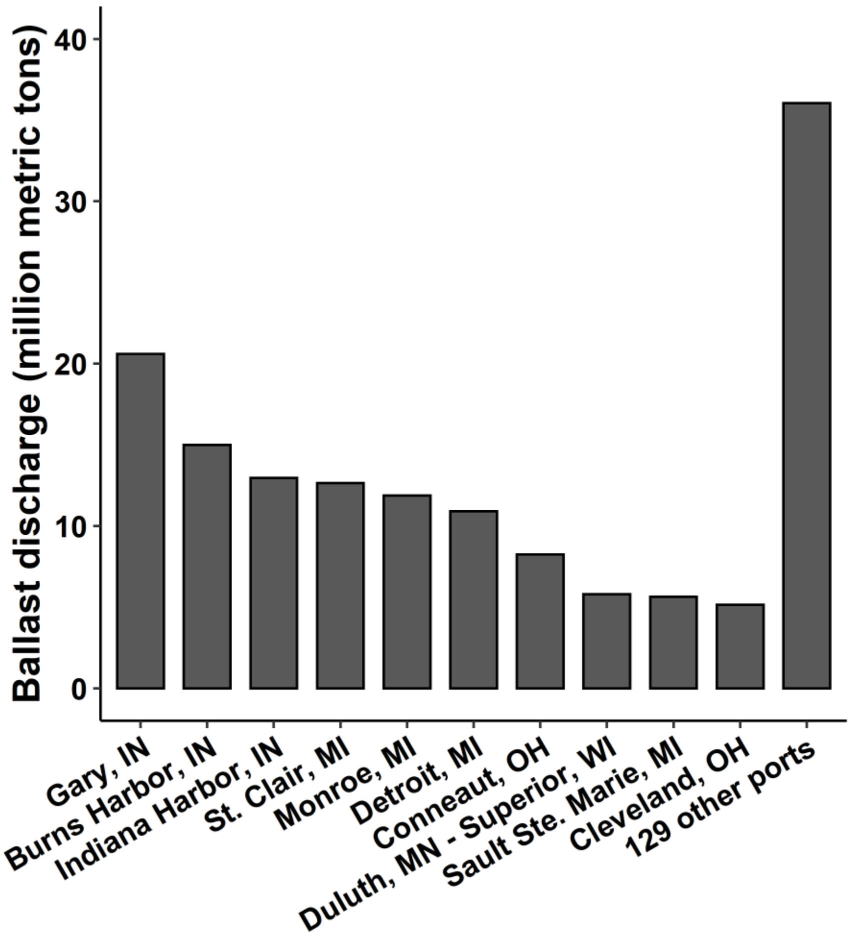

Ballast discharge
(million metric tons)
20
15
10
5
0
*
2012
2013
2014
2015
2016
Thunder Bay
Silver Bay
Two Harbors
Duluth-Superior
Marquette
Other

Fig. 47. Top 10 ranking of Lake Superior ballast water sources, as measured by the last port visited by vessels discharging into U.S. waters of Lake Superior. Cumulative discharge is the total volume for the current reporting period of 2012-2016 (NBIC 2016).



OVERVIEW OF PROGRESS IN FISHERY MANAGEMENT ON LAKE SUPERIOR AS OF 2017[36]

Mark P. Ebener[37]

Since fish community objectives (FCOs) were first developed (Busiahn 1990; Horns et al. 2003), considerable progress has been made at achieving them, and this trend continued during the current reporting period (2012-2016) (Table 4). At least three of the four components of the overall objective (Horns et al. 2003) were met because the fish community is diverse, self-regulating, dominated by indigenous species, and supports sustainable fisheries. Primary production and zooplankton abundance were stable during the reporting period and unchanged from the two previous reporting periods, indicating the lower food web is healthy. Abundance of the invertebrates *Mysis diluviana* and *Diporeia* spp. were stable during the reporting period, and *Diporeia* density exceeded target levels defined in the Great Lakes Water Quality Agreement (UN 1978). A healthy lower food web supports a diverse assemblage of prey fish that appears to match primary production. Lake Whitefish abundance was lower than during the previous reporting period, but it was within the FCO target range and at the same level as during the 2001-2005 reporting period. Lake Trout of the lean, siscowet, and humper forms continued to be the dominant predators in nearshore and offshore waters, and their abundance was stable at the same level observed during the two previous reporting periods. Lastly, the fish community of littoral areas and embayments continues to be diverse and composed mostly of indigenous species.

---

[36]Complete publication including maps of place names, abstract, other chapters, scientific fish names, and references is available at http://www.glfc.org/pubs/SpecialPubs/Sp21_02.pdf.

[37]**M.P. Ebener**. Fresh Lake Whitefish Company, 4234 I75 Business Spur, #250, Sault Ste. Marie, MI 49783, USA (e-mail: tflwc@yahoo.com).

Table 4. Status of each fish community objective (FCO) for Lake Superior during the current reporting period, management issues related to achieving or maintaining the FCO, and recommendations for research or management that may help maintain or achieve each FCO.

FCO	FCO Status	Management Issues	Recommendations
Overall	Mostly met	Degraded tributary habitat; continued avenues for non-indigenous species invasions	Provide fish passage around first downstream barriers; expand non-indigenous species prevention programs
Brook Trout	Unmet	Habitat degradation in tributaries; inter-specific competition in tributaries	Stabilize flows and prevent erosion; reduce interactions with other salmonines; mark all stocked fish; eexpand standardized assessment protocol
Lake Trout	Met	Reduced genetic fitness; Sea Lamprey impact on siscowets	Determine survival of siscowets from Sea Lamprey attack
Lake Sturgeon	Unmet	Low population sizes; habitat loss or degradation from hydroelectric development and barriers	Maintain protective regulations to keep mortality low; increase passage around barriers, maintain run-of-the-river flows, and remove unused barriers; support the 5-year Cooperative Science and Monitoring Initiative Lake Sturgeon survey
Walleye	Unmet	Low population sizes; habitat degradation	Rehabilitate tributary habitat; improve and protect spawning habitat; keep harvests low

FCO	FCO Status	Management Issues	Recommendations
Prey fish	Met	Continued decline in recruitment of Cisco; declining biomass of most nearshore and offshore prey fish	Investigate recruitment dynamics of Cisco; create a separate FCO for Cisco; continue to monitor commercial yields of Cisco and develop harvest-control rules for managing the fishery
Habitat	Unmet	Habitat degradation in tributaries	Continue protection and rehabilitation
Siscowet	Met	Unknown spawning habitat; effects of Sea Lamprey predation	Identify spawning habitat and protect it; estimate probability of surviving Sea Lamprey attack to understand role of siscowets in buffering other species from attack
Non-native salmonines	Met	None	No action
Lake Whitefish	Met	Slow lakewide decline in abundance	Continue to conduct and expand fishery-independent surveys; continue to reduce levels of exploitation if there are declines
Species diversity	Mostly met	Inadequate knowledge	Expand sampling and coordinate with other Great Lakes regarding detection of invasive species
Nuisance species	Unmet	High potential for spreading nuisance species by domestic shipping vessels	Implement actions within the Lake Superior Aquatic Invasive Species Complete Prevention Plan (Lake Superior Binational Program 2014) to reduce the risk of new invasions

FCO	FCO Status	Management Issues	Recommendations
Sea Lamprey	Unmet	Abundance greater than target; Sea Lamprey mortality on Lake Trout greater than target; effects of Sea Lamprey on other species; effects of attacks on species other than Lake Trout	Monitor tributaries post-treatment; detect new recruitment, identify tributaries with large numbers of treatment survivors; sample lentic areas to identify larval populations that require control

While physical habitat in the nearshore and offshore waters remained good during the reporting period, degraded embayment and tributary habitats continued to prevent achievement of the FCOs for Brook Trout, Lake Sturgeon, and Walleye. The original FCOs identified populations of Brook Trout, Lake Sturgeon, and Walleye as being severely depleted from historical levels due to over-exploitation and degradation of tributary habitat (Busiahn 1990). Subsequently, the technical and lake committees approved rehabilitation plans for all three species (Hoff 2002; Auer 2003; Newman et al. 2003). Since then, fishery agencies have (1) created brood stocks and planted all life stages in historically important habitat; (2) established restrictive harvest regulations to protect adults and expand age structure; (3) implemented standardized sampling protocols; and (4) stabilized stream flows on several large tributaries, such as the Nipigon and Kaminsitiquia Rivers in Ontario. These actions have helped stabilize some Brook Trout, Lake Sturgeon, and Walleye populations, but they are rather small-scale efforts and have not been coordinated at a lakewide level. Physical habitat continues to be degraded in many tributaries that historically contained Brook Trout and, for the most part, Brook Trout populations are restricted to the very upper reaches. Barriers created for hydroelectric generation either block Lake Sturgeon and Walleye from historically important spawning grounds or reduce stream flows necessary for reproduction. In tributaries without man-made barriers, Lake Sturgeon is relatively abundant and appears healthy, further illustrating the negative effect barriers have on Lake Sturgeon.

Attainment of the FCOs for Brook Trout and Lake Sturgeon will be difficult and can be attained only through development of large-scale management actions like those implemented for Lake Trout rehabilitation and Sea Lamprey control. Brook Trout rehabilitation depends on implementing proper land-use practices within hundreds of drainages throughout the Lake Superior basin (particularly in the U.S.) and coordinating management among fishery agencies and hundreds of small municipalities and township governments. Attainment of the Lake Sturgeon FCO will be just as difficult because hydroelectric generation remains a necessity for many municipalities, particularly in Canada, and removal of these barriers will be difficult if not impossible. Given these obstinate realities, the Lake Superior Committee should either consider modifying the FCOs for Brook Trout and Lake Sturgeon or consider lakewide actions that focus management on achievement of the FCOs. Large-scale management actions to foster achievement of the Brook Trout and Lake Sturgeon FCOs will also benefit the habitat FCO and insure stability of the entire fish community.

Attainment of the Sea Lamprey FCO continues to be difficult. Expenditures on control measures during the current reporting period were, on average, identical to the previous reporting period and unfortunately did not reduce Sea Lamprey abundance or lamprey-induced mortality of Lake Trout. A nearly doubling of control expenditures from 2015 to 2016 was very encouraging and should reduce Sea Lamprey abundance after 2016, but that level of control may be necessary in perpetuity. Lake Trout populations have been rehabilitated in Lake Superior despite the fact that the Sea Lamprey FCO has not been met. Given the high levels of siscowet and lean Lake Trout abundance in the lake and the diverse structure of the fish community, Sea Lamprey populations may be satiated and incapable of inflicting the levels of damage observed in the 1940s and 1950s. If true, the FCO for Sea Lamprey should be considered for revision.

While the prey-fish FCO appears to have been met, biomass of nearly all prey-fish species declined from the previous reporting period to the current reporting period, continuing declines that began prior to 2000. Large and continual declines in the biomass of prey fish have also been occurring in Lakes Huron and Michigan due to predator consumption and reduced productivity in the lower food web caused by dreissenid mussels (Bunnell et al. 2018). There is no evidence that productivity of the lower food web has declined in Lake Superior (see Status of the Lower Food Web in Lake Superior in 2017 chapter), indicating that predation, primarily by Lake Trout forms, is probably to blame for the declining biomass of prey fish.

Poor recruitment by Cisco during the last 15 years is exacerbating the declines in prey-fish biomass because Lake Trout must compensate for the loss of small Cisco by consuming the other less-abundant prey fish. Abundance of Cisco declined by 65% from 2011 (the end of the last reporting period) to 2016 (the end of the current reporting period) while biomass declined 69% during the same time. The last abundant year-class of Cisco was produced in 2003. The declines in biomass of prey fish began during 1997-1999 for Bloater, Slimy and Spoonhead Sculpins, and Ninespine Stickleback while Rainbow Smelt biomass was 50% lower during the current (2012-2016) and previous (2006-2011) reporting periods than prior to 2006. Ray et al. (2007) found Rainbow Smelt was the most-common prey of lean and siscowet Lake Trout, and both forms showed a positive selection for Rainbow Smelt in Lake Superior during the spring of 1986-2001. Siscowet showed a positive selection for Rainbow Smelt after 1998 while leans reduced their reliance on Rainbow Smelt at the same time. Siscowets also selected sculpins while leans showed a positive selection for coregonines after 1991 and an increase in selection of Ninespine Stickleback from 1986 to 2001. Based on the trends in biomass and Lake Trout consumption, we believe that predation by Lake Trout in combination with other predators is reducing the biomass of most prey fish in Lake Superior. Consequently, the prey-fish FCO is certainly in danger of not being met by the next reporting period.

Productivity of the food web and the biomass of each trophic level of Lake Superior show the fish community to be relatively healthy, stable, and dominated by self-sustaining indigenous species during the current state of the lake reporting period. The fish community continues to be in a state of flux but generally for the positive. Lake Trout populations have matured to the point where they are exhibiting density-dependent reproduction (Corradin et al. 2008) and depensatory predation on the biomass of prey fish. Consumption of prey by other predators is secondary to consumption by Lake Trout. Cisco is still abundant, but it is also still producing only occasional strong year-classes; this lack of recruitment is being felt across the prey-fish community through consumption by Lake Trout. Lake Whitefish populations are at levels of abundance and supporting large-scale sustainable fisheries, as envisioned in the FCOs. Indigenous Brook Trout, Lake Sturgeon, and Walleye are reproducing but not in all the historically important spawning areas. It is safe to say that neither Brook Trout nor Lake Sturgeon have fared as well as Lake Trout during the current reporting period or the previous two decades when their rehabilitation strategies were first developed. The Sea Lamprey objective was not met during the reporting period, but more control effort was put forth and should result in benefits during future state of the lake reports.

LITERATURE CITED

Auer, N.A. [ED.]. 2003. A lake sturgeon rehabilitation plan for Lake Superior [online]. Available from http://glfc.org/pubs/misc/2003_02.pdf [accessed 16 February 2021].

Austin, J.A., and Colman, S.M. 2007. Lake Superior summer water temperatures are increasing more rapidly than regional air temperatures: a positive ice albedo feedback. Geophys. Res. Lett. **34**: 1-5.

Austin, J.A., and Colman, S.M. 2008. A century of temperature variability in Lake Superior [online]. Available from https://aslopubs.onlinelibrary.wiley.com/doi/pdf/10.4319/lo.2008.53.6.2724 [accessed 16 February 2021].

Bailie, S.M., Muir, A.M., Scribner, K., Bentzen, P., and Krueger, C.C. 2016. Loss of genetic diversity and reduction of genetic distance among lake trout *Salvelinus namaycush* ecomorphs, Lake Superior 1959 to 2013. J. Great Lakes Res. **42**: 204-216.

Baldwin, A.K., Corsi, S.R., and Mason, S.A. 2016. Plastic debris in 29 Great Lakes tributaries: relation to watershed attributes and hydrology. Environ. Sci. Technol. **50**(19): 10377-10385.

Barbiero, R.P., Rudstam, L.G., Watkins, J.M., and Lesht, B.M. 2019. A cross-lake comparison of crustacean zooplankton communities in the Laurentian Great Lakes, 1997-2016. J. Great Lakes Res. **45**: 672-690.

Blankenheim, J. 2013. Status of coaster brook trout in the Minnesota Lake Superior tributaries. Minn. Dept. Nat. Res., Div. Fish Wildl., Sect. Fish. Study 3, Job 3.

Bobrowski, R.J., Chase, M., Swainson, R., van Ogtrop, A., Bobrowicz, S., Cullis, K., and Sobchuk, M. 2011. Update on brook trout rehabilitation in the Ontario waters of Lake Superior, Lake Nipigon, and the Nipigon River, Public Workshop Proceedings [online]. Available from http://thegreaterlakesuperiorfoundation.org/pdf/2011CoasterWorkshopProceedingsFINAL.pdf [accessed 16 February 2021].

Briski, E., Wiley, C.J., and Bailey, S.A. 2012. Role of domestic shipping in the introduction or secondary spread of nonindigenous species: biological invasions within the Laurentian Great Lakes. J. Appl. Ecol. **49**: 1124-1130.

Bronte, C.R. 1993. Evidence of spring spawning lake trout in Lake Superior. J. Great Lakes Res. **19**: 625-629.

Bronte, C.R., and Moore, S.A. 2007. Morphological variation of siscowet lake trout in Lake Superior. Trans. Am. Fish. Soc. **136**: 509-517.

Bronte, C.R., and Sitar, S.P. 2008. Harvest and relative abundance of siscowet lake trout in Michigan waters of Lake Superior, 1929-61. Trans. Am. Fish. Soc. **137**: 916-926.

Bronte, C.R., Ebener, M.P., Schreiner, D.R., DeVault, D.S., Petzold, M.M., Jensen, D.A., Richards, C., and Lozano, S.J. 2003. Fish community change in Lake Superior, 1970-2000. Can. J. Fish. Aquat. Sci. **60**: 1552-1574.

Bunnell, D.B., Carrick, H.J., Madenjian, C.P., Rutherford, E.S., Vanderploeg, H.A., Barbiero, R.P., Hinchey-Malloy, E., Pothoven, S.A., Riseng, C.M., and nine others. 2018. Are changes in lower trophic levels limiting prey-fish biomass and production in Lake Michigan? [online]. Available from www.glfc.org/pubs/misc/2018-01.pdf [accessed 16 February 2021].

Busiahn, T.R. [ED.] 1990. Fish community objectives for Lake Superior [online]. Available from www.glfc.org/pubs/SpecialPubs/Sp90_1.pdf [accessed 16 February 2021].

Conner, D.J., Bronte, C.R., Selgeby, J.H., and Collins, H.L. 1993. Food of salmonine predators in Lake Superior, 1981-1987 [online]. Available from www.glfc.org/pubs/TechReports/Tr59.pdf [accessed 16 February 2021].

Cook, D.G. 1975. A preliminary report on the benthic macroinvertebrates of Lake Superior. Environ. Can., Fish. Marine Serv., Burlington, ON. Tech. Rep. No. 572.

Coppaway, C.W. 2011. Dynamics of residency for brook charr (*Salvelinus fontinalis*) in Lake Superior tributaries. M.Sc. thesis, Univ. of Guelph, Guelph, ON.

Corradin, L.M., Hansen, M.J., Schreiner, D.R., and Seider, M.J. 2008. Recruitment dynamics of lake trout in western Lake Superior during 1988-1995. N. Am. J. Fish. Manage. **28**: 663-677.

Cox, S.P., and Kitchell, J.F. 2004. Lake Superior ecosystem, 1929-1998: simulating alternative hypotheses for recruitment failure of lake herring (*Coregonus artedi*). Bull. Marine Sci. **74**: 671-683.

Dobiesz, N.E., and Lester, N.P. 2009. Changes in mid-summer water temperature and clarity across the Great Lakes between 1968 and 2002. J. Great Lakes Res. **35**: 371-384.

Ebener, M.P. [ED.]. 2007. The state of Lake Superior in 2000 [online]. Available from www.glfc.org/pubs/SpecialPubs/Sp07_2.pdf [accessed 16 February 2021].

Ebener, M.P., Bence, J.R., Newman, K.R., and Schneeberger, P.J. 2005. Application of statistical catch-at-age models to assess lake whitefish stocks in the 1836 treaty-ceded waters of the upper Great Lakes, pp. 271-309. *In* Proceedings of a workshop on the dynamics of lake whitefish (*Coregonus clupeaformis*) and the amphipod *Diporeia* spp. in the Great Lakes. *Edited by* L.C. Mohr and T.F. Nalepa [online]. Available from www.glfc.org/pubs/TechReports/Tr66.pdf [accessed 16 February 2021].

Ebener, M.P., Kinnunen, R.E., Schneeberger, P.J., Mohr, L.C., Hoyle, J.A., and Peeters, P. 2008. Management of commercial fisheries for lake whitefish in the Laurentian Great Lakes of North America. *In* International governance of fisheries ecosystem: learning from the past, finding solutions for the future. *Edited by* M.G. Schechter, W.W. Taylor, and N.J. Leonard. Am. Fish. Soc. Symp. 62, Bethesda, MD. pp. 99-143.

EC and USEPA (Environment Canada and the U.S. Environmental Protection Agency). 2014. State of the Great Lakes 2011. Cat No. En161-3/1-2011E-PDF. EPA 950-R-13-002 [online]. Available from http://binational.net/wp-content/uploads/2014/11/sogl-2011-technical-report-en.pdf [accessed 16 February 2021].

Eschmeyer, P.H. 1955. The reproduction of lake trout in southern Lake Superior. Trans. Am. Fish. Soc. **84**: 47-74.

Ferringa, M., Huckins, C., Mattes, W., Baker, E., Zorn, T., Littlefield, J., and Scribner, K. 2016. Genetic and phenotypic evidence of splake presence in brook trout and lake trout spawning habitats. J. Great Lakes Res. **42**: 738-742.

Fetterolf, Jr., C.M. 1980. Why a Great Lakes Fishery Commission and why a sea lamprey international symposium? Can. J. Fish. Aquat. Sci. **27**: 1588-1593.

Fisch, N.C., Bence, J.R., Myers, J.T., Berglund, E.K., and Yule, D.L. 2019a. Evaluating the sustainability of a cisco fishery in Thunder Bay, Ontario, under alternative harvest policies [online]. Available from https://afspubs.onlinelibrary.wiley.com/doi/full/10.1002/nafm.10290 [accessed 16 February 2021].

Fisch, N.C., Bence, J.R., Myers, J.T., Berglund, E.K., and Yule, D.L. 2019b. A comparison of age-and size-structured assessment models applied to a stock of cisco in Thunder Bay, Ontario [online]. Available from https://www.sciencedirect.com/science/article/pii/S0165783618302492 [accessed 16 February 2021].

Fitzpatrick, F.A., Peppler, M.C., Saad, D.A., Pratt, D.M., and Lenz, B.N. 2015. Geomorphic, flood, and groundwater-flow characteristics of Bayfield Peninsula streams, Wisconsin, and implications for brook-trout habitat [online]. Available from https://pubs.usgs.gov/sir/2014/5007/pdf/sir2014-5007.pdf [accessed 16 February 2021].

Gamble, A.E., Hrabik, T.R., Stockwell, J.D., and Yule, D.L. 2011a. Trophic connections in Lake Superior part I: the offshore fish community [online]. Available from https://www.sciencedirect.com/science/article/pii/S0380133011001560 [accessed 16 February 2021].

Gamble, A.E., Hrabik, T.R., Yule, D.L., and Stockwell, J.D., 2011b. Trophic connections in Lake Superior part II: the nearshore fish community [online]. Available from https://www.sciencedirect.com/science/article/pii/S0380133011001614 [accessed 16 February 2021].

GLFC (Great Lakes Fishery Commission). 2007. A joint strategic plan for management of Great Lakes fisheries (as revised, 10 June 1997) [online]. Available from www.glfc.org/pubs/misc/jsp97.pdf [accessed 16 February 2021].

GLFC (Great Lakes Fishery Commission). 2008. Strategic vision of the Great Lakes Fishery Commission for the first decade of the new millennium [online]. Available from http://www.glfc.org/pubs/misc/StrategicVision2008.pdf [accessed 03 April 2021].

GLFC (Great Lakes Fishery Commission). 2011. Strategic vision of the Great Lakes Fishery Commission 2011-2020 [online]. Available from www.glfc.org/pubs/misc/StrategicVision2011.pdf [accessed 16 February 2021].

Goetz, F., Sitar, S., Rosauer, D., Swanson, P., Bronte, C.R., Dickey, J., and Simchick, C. 2011. The reproductive biology of siscowet and lean lake trout in southern Lake Superior. Trans. Am. Fish. Soc. **140**: 1472-1491.

Goetz, F., Sitar, S., Jasonowicz, A., and Seider, M.J. 2017. Reproduction of lake trout morphotypes at Isle Royale in northern Lake Superior. Trans. Am. Fish. Soc. **146**: 268-282.

Goldsworthy, C., Reeves, K., Blankenheim, J., and Peterson, N. 2016. Fisheries management plan for the Minnesota waters of Lake Superior. Minn. Dept. Nat. Res., Div. Fish Wildl. Sec. Fish. Spec. Pub. 163.

Gorman, O.T. 2007. Changes in a population of exotic rainbow smelt in Lake Superior: boom to bust, 1974-2005. J. Great Lakes Res. **33**(Suppl. 1): 75-90.

Gorman, O.T. 2012. Successional change in the Lake Superior fish community: population trends in ciscoes, rainbow smelt, and lake trout, 1958-2008. Adv. Limn. **63**: 337-362.

Gorman, O.T., and Hoff, M.H. 2009. Changes in the Lake Superior fish community during 1978-2003: chronicling the recovery of a native fauna. *In* The state of Lake Superior. *Edited by* M. Munawar and I.F. Munawar. Aquat. Ecosyst. Health Manage. Soc. pp. 493-532.

Gorman, O.T., and Selgeby, J.H. 2020. The Lake Superior nearshore fish community, 1953-2019: reflecting a history of change and facing an uncertain future in the 21st century. Aquat. Ecosyst. Health Manage. Soc., accepted for publication.

Gorman, O.T., Ebener, M.P., and Vinson, M.R. [EDS.]. 2010. The state of Lake Superior in 2005 [online]. Available from www.glfc.org/pubs/SpecialPubs/Sp10_1.pdf [accessed 16 February 2021].

Griffiths, R.W., Schloesser, D.W., Leach, J.H., and Kovalak, W.P. 1991. Distribution and dispersal of the zebra mussel (*Dreissena polymorpha*) in the Great Lakes region. Can. J. Fish. Aquat. Sci. **48**: 1381-1388.

Grigorovich, I.A., Kelly, J.R., Darling, J.A., and West, C.W. 2008. The quagga mussel invades the Lake Superior basin. J. Great Lakes Res. **34**: 342-350.

Guinand, B., Page, K., Burnham-Curtis, M., and Scribner, K. 2012. Genetic signatures of historical bottlenecks in sympatric lake trout (*Salvelinus namaycush*) morphotypes in Lake Superior. Environ. Biol. Fish. **95**: 323-334.

Hansen, M.J. [ED.]. 1990. Lake Superior: the state of the Lake in 1989 [online]. Available from www.glfc.org/pubs/SpecialPubs/Sp90_3.pdf [accessed 25 February 2021].

Hansen, M.J. [ED.]. 1994. The state of Lake Superior in 1992 [online]. Available from www.glfc.org/pubs/SpecialPubs/Sp94_1.pdf [accessed 25 February 2021].

Hansen, M.J. 1996. A lake trout restoration plan for Lake Superior [online]. Available from www.glfc.org/pubs/misc/LakeTroutRepSup.pdf [accessed 25 February 2021].

Hansen, M.J., Peck, J.W., Schorfhaar, R.G., Selgeby, J.H., Schreiner, D.R., Schram, S.T., Swanson, B.L., MacCallum, W.R., Burnham-Curtis, M.K., and three others. 1995. Lake trout (*Salvelinus namaycush*) populations in Lake Superior and their restoration in 1959-1993. J. Great. Lakes Res. **21**(Suppl. 1): 152-175.

Hansen, M.J., Nate, N.A., Muir, A.M., Bronte, C.R., Zimmerman, M.S., and Krueger, C.C. 2016. Life history variation among four lake trout morphs at Isle Royale, Lake Superior. J. Great Lakes Res. **42**: 421-432.

Hartig, J.H., Krantzberg, G., Munawar, M., Doss, M., Child, M., Kalinauskas, R., Richman, L., and Blair, C. 2018. Achievements and lessons learned from the 32-year old Canada-U.S. effort to restore impaired beneficial uses in Great Lakes areas of concern. Aquat. Ecosyst. Health Manage. **21**(4): 506-520.

Hayes, D.B., and Caroffino, D.C. [EDS.]. 2012. Michigan's lake sturgeon rehabilitation strategy [online]. Available from http://www.michigandnr.com/PUBLICATIONS/PDFS/ifr/ifrlibra/Special/Reports/sr62/SR62.pdf [accessed 25 February 2021].

Heinrich, J.W., Mullett, K.M, Hansen, M.J., Adams, J.V., Klar, G.T., Johnson, D.A., Christe, G.C., and Young, R.J. 2003. Sea lamprey abundance and management in Lake Superior, 1957-1999. J. Great Lakes Res. **29**(Suppl. 1): 566-583.

Hoffman, M.J., and Hittinger, E. 2017. Inventory and transport of plastic debris in the Laurentian Great Lakes. Mar. Pollut. Bull. **115**: 273-281.

Hoffman, J.C., Kelly, J.R., Trebitz, A.S., Peterson, G.S., and West, C.W. 2011. Effort and potential efficiencies for aquatic non-native species early detection. Can. J. Fish. Aquat. Sci. **68**: 2064-2079.

Hoffman, J.C., Schloesser, J., Trebitz, A.S., Peterson, G.S., Gutsch, M., Quinlan, H., and Kelly, J.R. 2016. Sampling design for early detection of aquatic invasive species in Great Lakes ports. Fisheries **41**(1): 26-37.

Horns, W.H., Bronte, C.R., Busiahn, T.R., Ebener, M.P., Eshenroder, R.L., Gorenflo, T., Kmiecik, N., Mattes, W., Peck, J.W., and two others. 2003. Fish-community objectives for Lake Superior [online]. Available from www.glfc.org/pubs/SpecialPubs/Sp03_1.pdf [accessed 05 October 2020].

Hoyle, J.A., Connerton, M.J., Dittman, D.E, Gorsky, D., Lantry, J.R., Mathers, A., Schlueter, S.L., Walsh, M.G., Weidel, B.C., and one other. 2017. Nearshore fish community. *In* The state of Lake Ontario in 2014. *Edited by* R. O'Gorman [online]. http://www.glfc.org/pubs/SpecialPubs/Sp17_02.pdf [accessed 25 February 2021].

Huckins, C., Baker, E., Fausch, K., and Leonard, J. 2008. Ecology and life history of coaster brook trout and potential bottlenecks in their rehabilitation. N. Am. J. Fish. Manage. **28**: 1321-1342.

Huff, A., and Thomas, A. 2014. Lake Superior climate change impacts and adaptation [online]. Available from https://www.epa.gov/sites/production/files/2015-11/documents/lake-superior-climate-change-impacts-report-201401-139pp.pdf .

IJC (International Joint Commission). 2012. Great Lakes water quality agreement [online]. Available from https://www.ijc.org/sites/default/files/2018-07/GLWQA_2012.pdf [accessed 25 February 2021].

Isaac, E.J., 2010. An evaluation of the importance of *Mysis relicta* to the Lake Superior fish community. M.Sc. thesis. Univ. Minn. Duluth, Duluth, MN.

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.

Jude, D.J., Rudstam, L.G., Holda, T.J., Watkins, J.M., Euclide, P.E., and Balcer, M.D. 2018. Trends in *Mysis diluviana* abundance in the Great Lakes, 2006-2016. J. Great Lakes Res. **44**: 590-599.

Kao, Y., Adlerstein, S.A., and Rutherford, E.S. 2016. Assessment of top-down and bottom-up controls on the collapse of Alewives (*Alosa pseudoharengus*) in Lake Huron. Ecosystems **19**: 803-831.

Kerfoot, W.C., Green, S.A., Brooks, C., Sayers, M., Feen, M., Sawtell, R., Shuchman, R., and Reif, M. 2017. Stamp sand threat to Buffalo Reef and Grand Traverse Bay: LiDAR/MSS assessments prior to “trough” dredging. GLNPO/USACE Report. 87 pp.

Kitchell, J.F., Cox, S.P., Harvey, C.J., Johnson, T.B., Mason, D.M., Schoen, K.K., Aydin, K., Bronte, C., Ebener, M., and six others. 2000. Sustainability of the Lake Superior fish community: interactions in a food web context. Ecosystems **3**: 545-560.

Kusnierz, P.C., Stimmell, S.P., and Leonard, J.B.K. 2014. Migration, size, and age structure of brook trout (*Salvelinus fontinalis*) from two Lake Superior tributaries. Am. Midl. Nat. **172**: 119-130.

Lake Superior Binational Program. 2014. Lake Superior aquatic invasive species complete prevention plan [online]. Available from https://www.epa.gov/sites/production/files/2015-11/documents/lake-superior-aquatic-invasive-species-complete-prevention-plan-201401-92pp.pdf [accessed 25 February 2021].

LAMP (Lake Superior Lakewide Action and Management Plan). 2016. Lake Superior lakewide action and management plan 2015-2019 [online]. Available from https://www.epa.gov/sites/production/files/2016-10/documents/lake_superior_lamp_2015-2019.pdf [accessed 30 March 2021].

LAMP (Lake Superior Lakewide Action and Management Plan). 2017. Lake Superior lakewide action and management plan 2017 annual report [online]. Available from https://binational.net/wp-content/uploads/2017/10/LS_LAMP_AR_2017_FINAL_English.pdf [accessed 30 March 2021].

Langseth, B.J., Rogers, M., and Zhang, H. 2012. Modeling species invasions in Ecopath with Ecosim: an evaluation using Laurentian Great Lakes models. Ecol. Model. **247**: 251-261.

Lawrie, A.H., and Rahrer, J.F. 1972. Lake Superior: effects of exploitation and introductions on the salmonid community. J. Fish. Res. Board Can. **29**: 765-776.

Lepak, T.A, Ogle, D.H., and Vinson, M.R. 2017. Age, year-class strength variability, and partial age validation of kiyis from Lake Superior. N. Am. J. Fish. Manage. **37**: 1151-1160.

Marshall, T. 2013. The status of walleye in Nipigon Bay area of concern: 2012 [online]. Available from https://www.documentcloud.org/documents/3705332-The-Status-of-Walleye-in-Nipigon-Bay-Area-of.html [accessed 30 March 2021].

Matthias, B.G., and Yule, D.L. 2020. Compilation of data for parameterization of an EcoPath model of Lake Superior at the beginning of the 21st century (2001-2016) [online]. Available from https://www.sciencebase.gov/catalog/item/5f43d7c682ce4c3d1222d328 https://doi.org/10.5066/P9W93YXH [accessed 25 February 2021].

McGoldrick, D.J., and Murphy, E.W. 2016. Concentration and distribution of contaminants in lake trout and walleye from the Laurentian Great Lakes (2008-2012). Environ. Pollut. **217**: 85-96.

Miller, L., Schreiner, D., Blankenheim, J., Ward, M., Quinlan, H., and Moore, S. 2016. Effects of restrictive harvest regulations on rehabilitation of coaster brook trout in Minnesota's portion of Lake Superior. J. Great Lakes Res. **42**: 883-892.

Modeling Subcommittee, Technical Fisheries Committee. 2018. Technical fisheries committee administrative report 2018: status of lake trout and lake whitefish populations in the 1836 treaty-ceded waters of Lakes Superior, Huron, and Michigan, with recommended yield and effort levels for 2018 [online]. Available from https://www.michigan.gov/documents/dnr/2018StatusStocksReport_631815_7.pdf [accessed 25 February 2021].

Moody, E.K., Weidel, B.C., Ahrenstorff, T.D., Mattes, W.P., and Kitchell, J.F. 2011. Evaluating the growth potential of sea lampreys (*Petromyzon marinus*) feeding on siscowet lake trout (*Salvelinus namaycush*) in Lake Superior. J. Great Lakes Res. **37**: 343-348.

Muir, A.M., Bronte, C.R., Zimmerman, M.S., Quinlan, H.R., Glase, J.D., and Krueger, C.C. 2014. Ecomorphological diversity of lake trout at Isle Royale, Lake Superior. Trans. Am. Fish. Soc. **143**: 972-987.

Mullet, K.A., Heinrich, J.W., Adams, J.V., Young, R.J., Henson, M.P., McDonald, R.B., and Fodale, 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.

NBIC (National Ballast Information Clearinghouse). 2016. NBIC database [online]. Available from https://nbic.si.edu/database/ [accessed 25 February 2021].

Negus, M.T., Schreiner, D.R., Halpern, T.N., Schram, S.T., Seider, M.J., and Pratt, D.M. 2007. Bioenergetics evaluation of the fish community in the western arm of Lake Superior in 2000 and 2004 [online]. Available from https://files.dnr.state.mn.us/publications/fisheries/investigational_reports/542.pdf [accessed 25 February 2021].

Newman, L., DuBois, R. and Halpern, T. 2003. A brook trout rehabilitation plan for Lake Superior [online]. Available from www.glfc.org/pubs/misc/2003_03.pdf [accessed 05 October 2020].

Olson, K., Piszczek, P., Hoffman, J., and Margenau, T. 2018. Population dynamics, sport and commercial harvest and management of St. Louis River walleye (1981-2015) [online]. Available from https://dnr.wi.gov/files/PDF/pubs/fh/ManageReports/FH156.pdf [accessed 25 February 2021].

O'Malia, E., Johnson, L., and Hoffman, J.C. 2018. Pathways and places associated with nonindigenous aquatic species introductions in the Laurentian Great Lakes. Hydrobiologia **817**(1): 23-40.

O'Reilly, C.M., Sharma, S., Gray, D.K., Hampton, S.E., Read, J.S., Rowley, R.J., Schneider, P., Lenters, J.D., McIntyre, P.B., and 55 others. 2015. Rapid and highly variable warming of lake surface waters around the globe [online]. Available from https://agupubs.onlinelibrary.wiley.com/doi/10.1002/2015GL066235 [accessed 25 February 2021].

Peterson, G.S., Hoffman, J.C., Trebitz, A.S., West, C.W., and Kelly, J.R. 2011. Establishment patterns of non-native fishes: lessons from the Duluth-Superior harbor and lower St. Louis River, an invasion-prone Great Lakes coastal ecosystem. J. Great Lakes Res. **37**: 349-358.

Pratt, T.C. 2007. Physical habitat. *In* The state of Lake Superior in 2000. *Edited by* M.P. Ebener [online]. Available from http://glfc.org/pubs/SpecialPubs/Sp07_2.pdf [accessed 25 February 2021].

Pratt, T.C., and O'Connor, L.M. 2011. An assessment of the health and historical changes of the nearshore fish community of the St. Marys River. J. Great Lakes Res. **37**: 61-69.

Pratt, T.C., Quinlan H.R., Czypinski, G.D., Schram, S.T., and Gorman, O.T. 2010. Inshore fish community: ecological interactions. *In* The state of Lake Superior in 2005. *Edited by* O.T. Gorman, M.P. Ebener, and M.R. Vinson [online]. Available from www.glfc.org/pubs/SpecialPubs/Sp10_1.pdf [accessed 25 February 2021].

Pratt, T.C., Gardner, W.M., Pearce, J., Greenwood, S., and Chong, S.C. 2014. Identification of a robust Lake Sturgeon (*Acipenser fulvescens* Rafinesque, 1917) population in Goulais Bay, Lake Superior. J. Appl. Ichthyol. **30**: 328-1334. doi.org/ 10.1111/jai.12566.

Pratt, T.C., Gorman, O.T., Mattes, W.P., Myers, J.T., Quinlan, H.R., Schreiner, D.R., Seider, M.J., Sitar, S.P., Yule, D.L., and one other. 2016. The state of Lake Superior in 2011 [online]. Available from www.glfc.org/pubs/SpecialPubs/Sp16_01.pdf [accessed 25 February 2021].

Ray, B.A., Hrabik, T.R., Ebener, M.P., Gorman, O.T., Schreiner, D.R., Schram, S.T., Sitar, S.P., Mattes, W.P., and Bronte, C.R. 2007. Diet and prey selection by Lake Superior lake trout during spring, 1986-2001. J. Great Lakes Res. **33**: 104-113.

Robillard, M., Casselman, J., McLaughlin, R., and Mackereth, R. 2011a. Alternative growth histories in populations of Lake Superior brook trout: critical support for partial migration. Biol. Conserv. **144**: 1931-1939.

Robillard, M.M., McLaughlin, R.L., and Mackereth, R.W. 2011b. Diversity in habitat use and trophic ecology of brook trout in Lake Superior and tributary streams revealed through stable isotopes. Trans. Am. Fish. Soc. **140:** 943-953.

Rogers, M.W., Bunnell, D.B., Madenjian, C.P., and Warner, D.M. 2014. Lake Michigan offshore ecosystem structure and food web changes from 1987 to 2008. Can. J. Fish.Aquat. Sci. **71**: 1072-1086.

Schloesser, J., and Quinlan, H. 2010. Status of the 2010 lake sturgeon spawning population in the Bad and White Rivers, Wisconsin [online]. Available from https://www.fws.gov/midwest/sturgeon/documents/bad-white-rivers-2010-spawn-assmt.pdf [accessed 25 February 2021].

Schloesser, J.T., Quinlan, H.R., Pratt, T.C., Baker, E.A., Adams, J.V., Mattes, W.P., Greenwood, S., Chong, S., Bergland, E., and 13 others. 2014. Lake Superior lake sturgeon index survey: 2011 status report [online]. Available from https://www.researchgate.net/publication/322861487_Lake_Superior_Lake_Sturgeon_Index_Survey_2011_Status_Report [accessed 25 February 2021].

Schreiner, D.R. 1994. Habitat. *In* the state of Lake Superior in 1992. Edited by M.J. Hansen [online]. Available from http://glfc.org/pubs/SpecialPubs/Sp94_1.pdf [accessed 25 February 2021].

Scribner, K., Huckins, C., Baker, E., and Kanefsky, J. 2012. Genetic relationships and gene flow among resident and migratory brook trout in the Salmon Trout River. J. Great Lakes Res. **38**: 152-158. doi:10.1016/j.jglr.2011.11.009.

Selgeby, J.H. 1982. Decline of lake herring (*Coregonus artedii*) in Lake Superior: an analysis of the Wisconsin herring fishery 1936-78. Can. J. Fish. Aquat. Sci. **39**: 554-563.

Sitar, S.P., Morales, H.M., Mata, M.T., Bastar, B.B., Dupras, D.M., Kleaver, G.D., and Rathbun, K.D. 2008. Survey of siscowet lake trout at their maximum depth in Lake Superior. J. Great Lakes Res. **34**: 276-286.

Sitar, S.P., Chong, S.C., Ebener, M.P., Halpern, T.N., Mattes, W.P., Seider, M.J., and Symbal, M.J. 2010. Nearshore fish community: lake trout. *In* The state of Lake Superior in 2005. *Edited by* O.T. Gorman, M.P. Ebener, and M.R. Vinson [online]. Available from www.glfc.org/pubs/SpecialPubs/Sp10_1.pdf [accessed 25 February 2021].

Sitar, S.P., Jasonowicz, A.J., Murphy, C.A., and Goetz, F.W. 2014. Estimates of skipped spawning in lean and siscowet lake trout in southern Lake Superior: implications for stock assessment. Trans. Am. Fish. Soc. **143**: 660-672.

Smith, S.E., Sitar, S.P., Goetz, F.W., Huertas, M., Armstrong, B.M., and Murphy, C.A. 2016. Differential physiological response to sea lamprey parasitism between lake trout (*Salvelinus namaycush*) morphotypes from Lake Superior. Can. J. Fish. Aquat. Sci.**73**: 1815-1829.

Stimmel, S.P. 2006. Migratory activity of two strains of brook trout (*Salvelinus fontinalis*) in Pictured Rocks National Lakeshore characterized using stationary RFID systems. M.Sc. thesis, North. Mich. Univ., Marquette, MI.

Stockwell, J.D., Ebener, M.P., Black, J.A., Gorman, O.T., Hrabik, T.R., Kinnunen, R.E., Mattes, W.P., Oyadomari, J.K., Schram, S.T., and four others. 2009. A synthesis of cisco recovery in Lake Superior: implications for native fish rehabilitation in the Laurentian Great Lakes. North Am. J. Fish. Manage. **29**: 626-652. doi:10.1577/M08-002.1.

Sullivan, P., and Mullett, K. 2017. Sea lamprey control in the Great Lakes 2017 [online]. Available from www.glfc.org/pubs/slcp/annual_reports/ANNUAL_REPORT_2017.pdf [accessed 25 February 2021].

Superior Work Group of the Lake Superior Lakewide Action and Management Plan. 2015. A biodiversity conservation assessment for Lake Superior [online]. Available from http://www.natureconservancy.ca/assets/documents/on/lake-superior/A-Biodiversity-Conservation-Assessment-for-Lake-Superior-Vol-1-Final-Draft-Updated-March2015.pdf [accessed 25 February 2021].

TBPA (Thunder Bay Port Authority). 2018. Thunder Bay Port Authority 2018 annual report [online]. Available from https://www.portofthunderbay.ca/wp-content/uploads/2019/07/3659_PATB_AnnualReport2018_9x9_12pages_v6.pdf [accessed 25 February 2021].

Trebitz, A.S., Kelly, J.R., Hoffman, J.C., Peterson, G.S., and West, C.W. 2009. Exploiting habitat and gear patterns for efficient detection of rare and non-native benthos and fish in Great Lakes coastal ecosystems. Aquat. Invasions **4**: 651-667.

Trebitz, A.S., Shepard, G., Brady, V., Schmude, K. 2015. The non-native faucet snail (*Bithynia tentaculata*) makes the leap to Lake Superior. J. Great Lakes Res. **41**(4): 1197-1200.

UN (United Nations). 1978. Great Lakes Water Quality Agreement of 1978 [online]. Available from https://treaties.un.org/doc/publication/unts/volume%201153/volume-1153-i-18177-english.pdf [accessed 28 March 2021].

USGS (U.S. Geological Survey). 2017. Compiled reports to the Great Lakes Fishery Commission of the annual bottom trawl and acoustics surveys for 2016 [online]. Available from http://www.glfc.org/pubs/lake_committees/common_docs/CompiledReportsfromUSGS2017.pdf [accessed 25 February 2021].

USGS (U.S. Geological Survey). 2019. Great Lakes research vessel operations 1958-2018. (ver. 3.0, April 2019): U.S. Geological Survey data release [online]. Available from https://doi.org/10.5066/F75M63X0 [accessed 25 February 2021].

Varian, A. 2017. A stratified random access based creel survey of the open water and winter fishery on the St. Louis River Estuary, St. Louis County, Minnesota (May 9th, 2015 through March 1st, 2016). Minn. Dept. Nat. Res. Completion Rep.

Velez-Espino, L.A., McLaughlin, R.L., and Robillard, M. 2013. Ecological advantages of partial migration as a conditional strategy. Theor. Popul. Biol. **85**: 1-11.

Vinson, M.R., Evrard, L.M., Gorman, O.T., and Yule, D.L. 2016. Status and trends in the Lake Superior fish community, 2015. *In* Compiled reports to the Great Lakes Fishery Commission of the annual bottom trawl and acoustics surveys, 2015 [online]. Available from http://www.glfc.org/pubs/lake_committees/common_docs/CompiledReportsfromUSGS2016.pdf [accessed 25 February 2021].

Welsh, A.B., Baerwald, M.R., Friday, M., and May, B. 2015. The effect of multiple spawning events on cohort genetic diversity of lake sturgeon (*Acipenser fulvescens*) in the Kaministiquia River. Environ. Biol. Fish. **98**: 755-762.

Yousef, F., Shuchman, R., Sayers, M., Fahnenstiel, G., and Henareh, A. 2017. Water clarity of the Upper Great Lakes: tracking changes between 1998-2012. J. Great Lakes Res. **43**: 239-247.

Yule, D.L., Stockwell, J.D., Cholwek, G.A., Evrard, L.M., Schram, S., Seider, M.J., and Symbal, M. 2006. Evaluation of methods to estimate lake herring spawner abundance in Lake Superior. Trans. Am. Fish. Soc. **135**: 680- 694. doi:10.1577/T05-203.1.

Yule, D.L., Stockwell, J.D., Schreiner, D.R., Evrard, L.M., Balge, M., and Hrabik, T.R. 2009. Can pelagic forage fish and spawning cisco (*Coregonus artedi*) biomass in the western arm of Lake Superior be assessed with a single summer survey? Fish. Res. **96**: 39-50. doi.10.1016/j.fishres.2008.09.012.

Yule, D.L., Schreiner, D.R., Addison, P.A., Seider, M.J., Evrard, L.M., Geving, S.A., and Quinlan, H.R. 2012. Repeat surveys of spawning cisco (*Coregonus artedi*) in western Lake Superior: timing, distribution and composition of spawning stocks. Adv. Limnol. **63**: 65-87. doi:10.1127/advlim/63/2012/65.

Yule, D.L., Adams, J.V., Hrabik, T.R., Vinson, M.R., Woiak, Z., and Ahrenstorff, T.D. 2013. Use of classification trees to apportion single echo detections to species: application to the fish community of Lake Superior. Fish. Res. **140**: 123-132. doi:10.1016/j.fishres.2012.12.012.

Yurista, P.M., Kelly, J.R., and Miller, S.E. 2009. Lake Superior zooplankton biomass: alternate estimates from a probability-based net survey and spatially extensive LOPC surveys. J. Great Lakes Res. **35**: 337-346.

Special Publications

79-1 Illustrated Field Guide for the Classification of Sea Lamprey Attack Marks on Great Lakes Lake Trout. Everett Louis King, Jr., and Thomas A. Edsall.
82-1 Recommendations for Freshwater Fisheries Research and Management from the Stock Concept Symposium (STOCS). Alfred H. Berst and George R. Spangler.
82-2 A Review of the Adaptive Management Workshop Addressing Salmonid/Lamprey Management in the Great Lakes. Joseph F. Koonce (Editor), Lorne A. Greig, Bryan A. Henderson, Douglas B. Jester, C. Kenneth Minns, and George R. Spangler.
82-3 Identification of Larval Fishes of the Great Lakes Basin with Emphasis on the Lake Michigan Drainage. Edited by Nancy A. Auer. (Cost: $10.50 U.S., $12.50 CAN)
83-1 Quota Management of Lake Erie Fisheries. Joseph F. Koonce (Editor), Douglas B. Jester, Bryan A. Henderson, Richard W. Hatch, and Michael L. Jones.
83-2 A Guide to Integrated Fish Health Management in the Great Lakes Basin. Edited by Fred P. Meyer, James W. Warren, and Timothy G. Carey.
84-1 Recommendations for Standardizing the Reporting of Sea Lamprey Marking Data. Randy L. Eshenroder and Joseph F. Koonce.
84-2 Working Papers Developed at the August 1983 Conference on Lake Trout Research. Edited by Randy L. Eshenroder, Thomas P. Poe, and Charles H. Olver.
84-3 Analysis of the Response to the Use of "Adaptive Environmental Assessment Methodology" by the Great Lakes Fishery Commission. C. Kenneth Minns, John M. Cooley, and John Forney.
85-1 Lake Erie Fish Community Workshop. Edited by Jerry R. Paine and Roger B. Kenyon.
85-2 A Workshop Concerning the Application of Integrated Pest Management (IPM) to Sea Lamprey Control in the Great Lakes. Edited by George R. Spangler and Lawrence D. Jacobson.
85-3 Presented Papers from the Council of Lake Committees Plenary Session on Great Lakes Predator-Prey Issues, March 20, 1985. Edited by Randy L. Eshenroder.
85-4 Great Lakes Fish Disease Control Policy and Model Program. Edited by John G. Hnath.
85-5 Great Lakes Law Enforcement/Fisheries Management Workshop. Edited by Wilbur L. Hartman and Margaret A. Ross.
85-6 TFM (3-trifluoromethyl-4-nitrophenol) vs. the Sea Lamprey: A Generation Later. Great Lakes Fishery Commission.
86-1 The Lake Trout Rehabilitation Model: Program Documentation. Carl J. Walters, Lawrence D. Jacobson, and George R. Spangler.
87-1 Guidelines for Fish Habitat Management and Planning in the Great Lakes. Great Lakes Fishery Commission.
87-2 Workshop to Evaluate Sea Lamprey Populations "WESLP". Edited by B.G. Herbert Johnson.
87-3 Temperature Relationships of Great Lakes Fishes: A Data Compilation. Donald A. Wismer and Alan E. Christie.
88-1 Committee of the Whole Workshop on Implementation of the Joint Strategic Plan for Management of Great Lakes Fisheries. Edited by Margaret Ross Dochoda.
88-2 A Proposal for a Bioassay Procedure to Assess Impact of Habitat Conditions on Lake Trout Reproduction in the Great Lakes. Edited by Randy L. Eshenroder.
88-3 Age Structured Stock Assessment of Lake Erie Walleye. Richard B. Deriso, Stephen J. Nepszy, and Michael R. Rawson.
88-4 The International Great Lakes Sport Fishery of 1980. Daniel R. Talhelm.
89-1 A Decision Support System for the Integrated Management of Sea Lamprey. Joseph F. Koonce and Ana B. Locci-Hernandez.
90-1 Fish Community Objectives for Lake Superior. Edited by Thomas R. Busiahn.
90-2 International Position Statement and Evaluation Guidelines for Artificial Reefs in the Great Lakes. Edited by John E. Gannon.
90-3 Lake Superior: The State of the Lake in 1989. Edited by Michael J. Hansen.
90-4 An Ecosystem Approach to the Integrity of the Great Lakes in Turbulent Times. Edited by Clayton J. Edwards and Henry A. Regier.
91-1 Status of Walleye in the Great Lakes. Edited by Peter J. Colby, Cheryl A. Lewis, and Randy L. Eshenroder.

91-2 Lake Michigan: An Ecosystem Approach for Remediation of Critical Pollutants and Management of Fish Communities. Randy L. Eshenroder, John H. Hartig, and John E. Gannon.
91-3 The State of the Lake Ontario Fish Community in 1989. Steven J. Kerr and Gerry C. LeTendre.
93-1 Great Lakes Fish Disease Control Policy and Model Program (Edited by John G. Hnath); Protocol to Minimize the Risk of Introducing Emergency Disease Agents with Importation of Salmonid Fishes from Enzootic Areas (Edited by Rodney W. Horner and Randy L. Eshenroder).
94-1 The State of Lake Superior in 1992. Edited by Michael J. Hansen.
94-2 An Introduction to Economic Valuation Principles for Fisheries Management. Lee G. Anderson.
95-1 Fish-Community Objectives for Lake Huron. Ron L. DesJardine, Thomas K. Gorenflo, Robert N. Payne, and John D. Schrouder.
95-2 The State of Lake Huron in 1992. Edited by Mark P. Ebener.
95-3 Fish-Community Objectives for Lake Michigan. Randy L. Eshenroder, Mark E. Holey, Thomas K. Gorenflo, and Richard D. Clark, Jr.
99-1 Fish-Community Objectives for Lake Ontario. Thomas J. Stewart, Robert E. Lange, Sandra D. Orsatti, Clifford P. Schneider, Alastair Mathers, and Marion E. Daniels.
03-01 Fish-Community Objectives for Lake Superior. William H. Horns, Charles R. Bronte, Thomas R. Busiahn, Mark P. Ebener, Randy L. Eshenroder, Thomas Gorenflo, Neil Kmiecik, William Mattes, James W. Peck, Michael Petzold, and Donald R. Schreiner.
S Fish-Community Goals and Objectives for Lake Erie. Philip A. Ryan, Roger Knight, Robert MacGregor, Gary Towns, Rick Hoopes, William Culligan.
05-01 The State of Lake Michigan in 2000. Edited by Mark E. Holey and Thomas N. Trudeau.
05-02 The State of Lake Huron in 1999. Edited by Mark P. Ebener.
07-01 The State of Lake Ontario in 2003. Edited by Bruce J. Morrison and Steven R. LaPan.
07-02 The State of Lake Superior in 2000. Edited by Mark P. Ebener.
08-01 The State of Lake Huron in 2004. Edited by James R. Bence and Lloyd C. Mohr.
08-02 The State of Lake Michigan in 2005. Edited by David F. Clapp and William Horns.
09-01 Standard Operating Procedures for Fisheries Acoustic Surveys in the Great Lakes. Sandra L Parker-Stetter, Lars G. Rudstam, Patrick J. Sullivan, and David M. Warner.
09-02 The State of Lake Erie in 2004. Edited by Jeffrey T. Tyson, Roy A. Stein, and John M. Dettmers.
10-01 The State of Lake Superior in 2005. Edited by Owen T. Gorman, Mark P. Ebener, and Mark R. Vinson.
12-01 The State of Lake Michigan in 2011. Edited by David B. Bunnell.
13-01 The State of Lake Huron in 2010. Edited by Stephen C. Riley.
14-01 The State of Lake Ontario in 2008. Edited by Angela C. Adkinson and Bruce J. Morrison.
14-02 Model Program for Fish Health Management in the Great Lakes. Kenneth A. Phillips, Andrew Noyes, Ling Shen, and Gary Whelan.
16-01 The State of Lake Superior in 2011. Thomas C. Pratt, Owen T. Gorman, William P. Mattes, Jared T. Myers, Henry R. Quinlan, Donald R. Schreiner, Michael J. Seider, Shawn P. Sitar, Daniel L. Yule, and Peder M. Yurista.
17-01 The State of Lake Erie in 2009. Edited by James L. Markham and Roger Knight.
17-02 The State of Lake Ontario in 2014. Edited by Robert O'Gorman.
19-01 The State of Lake Michigan in 2016. Edited by Charles P. Madenjian.
20-01 The State of Lake Huron in 2018. Edited by Stephen C. Riley and Mark P. Ebener.
21-01 The State of Lake Erie in 2015. Edited by Todd C. Wills and Janice Kerns.