COMPILED REPORTS TO THE GREAT LAKES FISHERY COMMISSION OF THE ANNUAL BOTTOM TRAWL AND ACOUSTICS SURVEYS, 2017

Great Lakes Fishery Commission

2018

PREPARED BY
THE U.S. GEOLOGICAL SURVEY, GREAT LAKE SCIENCE CENTER

USGS
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Suggested Citation

USGS (U.S. Geological Survey). 2018. Compiled reports to the Great Lakes Fishery Commission of the annual bottom trawl and acoustics surveys for 2017 [online]. Available from http://www.glfc.org/pubs/lake_committees/common_docs/CompiledReportsfromUSGS2017.pdf [accessed day-month-year].

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Status and Trends in the Lake Superior Fish Community, 2017[1,2]

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Abstract
In 2017, the Lake Superior fish community was sampled with daytime bottom trawls at 76 nearshore and 36 offshore stations. Spring nearshore and summer offshore water temperatures in 2017 were similar to slightly cooler than the 1991-2017 average. In the nearshore zone, a total of 28,902 individual fish from 27 species or morphotypes were collected. The number of species collected at each station ranged from 0 to 13, with a mean of 5.5 and median of 5. Lakewide nearshore mean biomass was 3.8 kg/ha which was below the long-term average of 8.7 kg/ha and the median lakewide biomass was 1.8 kg/ha. which was similar to the long-term average median value of 1.9 kg/ha. Lake Whitefish, Rainbow Smelt, Bloater, Longnose Sucker, and lean Lake Trout were the species with the highest lakewide average biomass. In the offshore zone, a total of 16,674 individuals from 13 species were collected lakewide. The average and median observed species richness at each station was 3.8 and 4 species, respectively, and ranged from 2 to 6 species. Deepwater Sculpin, Kiyi, and siscowet Lake Trout made up 99% of the total number of individuals and biomass collected in offshore waters. Mean and median lakewide biomass for all species in 2017 was 6.8 kg/ha and 6.6 kg/ha, respectively. This was similar to the long-term mean of 6.9 kg/ha and greater than that observed in 2014-2016. Nearshore average larval *Coregonus* densities in 2017 were greater than observed in any previous year; whereas offshore larval *Coregonus* densities were much less than observed in previous years.

Introduction
The U.S. Geological Survey Lake Superior Biological Station conducts annual daytime bottom trawl surveys in nearshore (~15-80 m) and offshore (100-300 m) waters of Lake Superior. These surveys provide data for assessment of long-term trends in lakewide fish species occurrences, relative abundance, and biomass. Rather than absolute abundance and biomass estimates, these data have historically been considered population indices. Age and diet analyses are conducted for selected species. The nearshore survey has been conducted in spring since 1978 in U.S. waters, and since 1989 in Canadian waters. The offshore survey has been conducted in summer since 2011. We report population biomass estimates for a number of common species and recruitment indices of the density of age-1 fish for selected commercial and recreational species (Rainbow Smelt, Cisco, Bloater, Lake Whitefish, and Lake Trout, scientific names are provided in Table 1) from nearshore surveys, and population biomass estimates from offshore surveys. Results presented for age-1 and older fish are based solely on bottom trawl sampling. Larval fish are collected using surface trawls. Fishing gear bias should be considered when interpreting the results of this survey, particularly for species with lower vulnerability to daytime bottom trawls, such as adult Cisco, and adult Lake Trout. In addition to fish sampling at each station, we collect epilimnetic (30 m) and whole water column (100 m) zooplankton collections, and an electronic water profile that collects data on depth, water temperature, specific conductance, pH, dissolved oxygen, chlorophyll a, photosynthetic active radiation (PAR), and beam transmission. Herein we report on bottom and surface trawl collections and water temperatures.

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[1]Presented at Great Lakes Fishery Commission, Lake Michigan Committee Meeting, Sault Ste. Marie, ON on March 22, 2018

[2]The data associated with this report are available at: U.S. Geological Survey, Great Lakes Science Center, 2018, Great Lakes Research Vessel Operations 1958-2017 (ver. 2.0, March 2018): U.S. Geological Survey Data Release, https://doi.org/10.5066/F75M63X0.

Methods

Nearshore survey bottom trawling

Nearshore sites are located around the perimeter of the lake (Figure 1). In 2017, 76 of 79 long-term sites were sampled between 15 May and 15 June (Figure 1). Three locations were not sampled due to commercial fishing operations, weather, or mechanical problems. At each location, a single bottom trawl tow was conducted with a 12-m Yankee bottom trawl with either a chain or 6-inch rubber roller foot rope. The roller foot rope was used at sites with steeper rockier bottoms to reduce snagging. The median start and end depths for bottom trawl tows were 18 m (range 11-38 m) and 54 m (range 12-143 m), respectively. The median distance trawled was 2.0 km (range 0.5-5.0 km). The median trawl wingspread was 9.1 m (range 7.5-10.6 m). Fish collections were sorted by species, counted, and weighed in aggregate to the nearest gram. Total length was measured on a maximum of 50 individuals per species per trawl. Length data for these individuals were then extrapolated to the entire catch, if necessary. Relative density (fish/ha) and biomass (kg/ha) were estimated by dividing sample counts and aggregate weights by the area of the bottom swept by each trawl tow (ha). Biomass estimates are reported for all species combined and individually for Burbot, Cisco, Bloater, Rainbow Smelt, Lake Whitefish, Sculpin species (Slimy Sculpin, Spoonhead Sculpin, and Deepwater Sculpin), and hatchery-, lean-, and siscowet Lake Trout. For Cisco, Bloater, Lake Whitefish, and Rainbow Smelt, age-1 year-class strength was estimated as the mean lakewide relative density of age-1 fish. Age-1 fish designations were based on total length; Cisco <140 mm, Bloater <130 mm, Lake Whitefish <160 mm, and Rainbow Smelt <100 mm. Young Lake Trout densities are presented for small, < 226 mm (ca. ≤ age-3) fish. These age-1 size cutoffs were based on past unpublished aging analyses and are approximate and are known to vary among years.

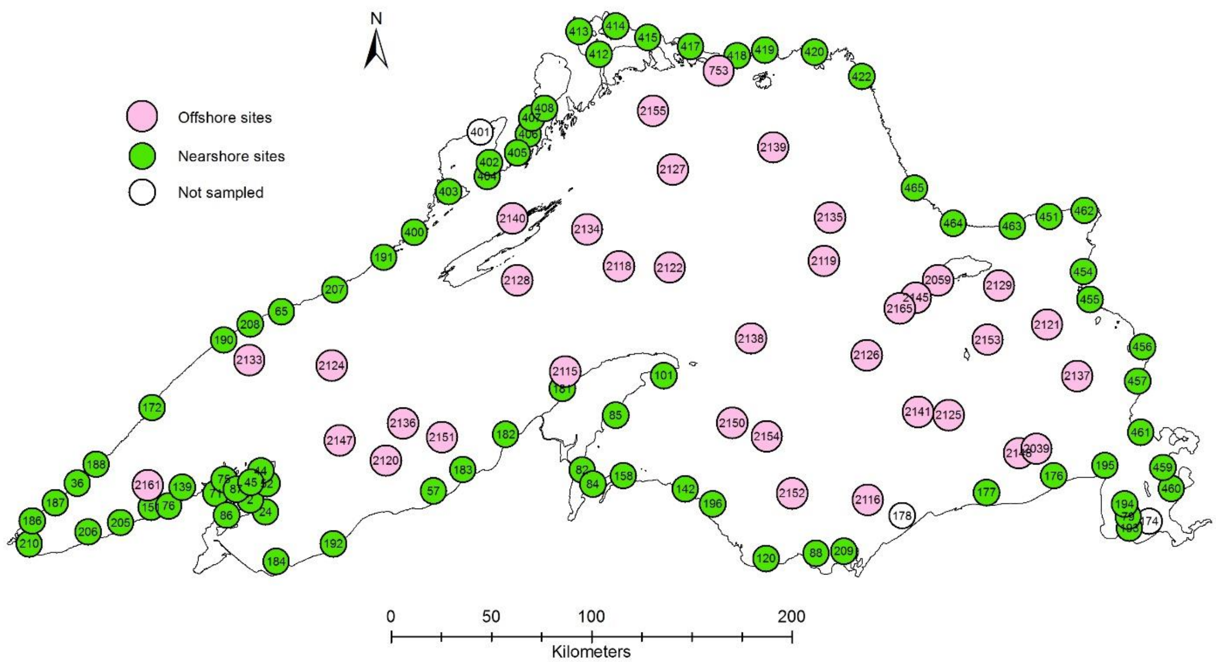

Figure 1. Location of 76 nearshore (green circles) and 36 offshore (pink circles) stations sampled May-July 2017. Samples collected at each location included bottom trawls for demersal fish, surface trawls for larval fish, epilimnetic (30 m) and whole water column (100 m) zooplankton collections, and an water profile that electronically collected data on depth, temperature, specific conductance, pH, dissolved oxygen, Chlorophyll a, photosynthetic active radiation, and beam transmission.

Offshore survey bottom trawling

Offshore sites are located around the lake and were selected using a spatially-balanced, depth-weighted probabilistic sampling design that targets depths >85 m (Figure 1). Sample sites were selected in 2011 and thesame sites have been sampled annually thereafter. In 2017, 36 locations were sampled during daylight hours from 5-20 July 2017. A single bottom trawl tow was conducted at each site using a 12-m Yankee bottom trawl with a 6-inch rubber roller foot rope. All tows were made on-contour. Station depths ranged from 85 to 308 m. The median trawl distance was 1.7 km (range 1.6-2.0 km). The median trawl wing spread was 10.2 m (range 9.2-11.2 m). Catches were processed similarly to that described for nearshore trawls. Biomass estimates are presented for all species and individually for Kiyi, Deepwater Sculpin, and siscowet Lake Trout. These three species made up > 99% of the total fish number (Table 1) and total biomass of fish collected in offshore waters.

Surface water trawling

To describe the abundance and spatial distribution of larval *Coregonus* a paired 1 m^2 500 micron mesh neuston net was fished 0.5 m below the lake surface. All trawls were diurnal and were made for 10 minutes. The median trawl distance was 0.7 km (range 0.6-0.8 km). A total of 115 trawls were made at 112 locations from 15 May to 20 July 2017. A site near Grand Marais, Minnesota was sampled on four dates. We are not able to identify larval *Coregonus* to species, so it is assumed these fish are a mix of Cisco, Bloater, and Kiyi. In addition to *Coregonus* species, a few larval Sculpin and Pacific Salmon are collected, but are not reported on.

Results

Nearshore survey

Nearshore water temperatures in 2017 were near the long-term average (Figure 2a). Nearshore temperatures in June averaged 5.7 °C (range = 3.8-15.2 °C) at the surface and 4.0 °C (range = 3.3-3.9 °C) at 100 m. The long-term average (1991-2017) water temperatures for these same locations and dates is 6.3 °C at the surface and 3.5 °C at 100 m.

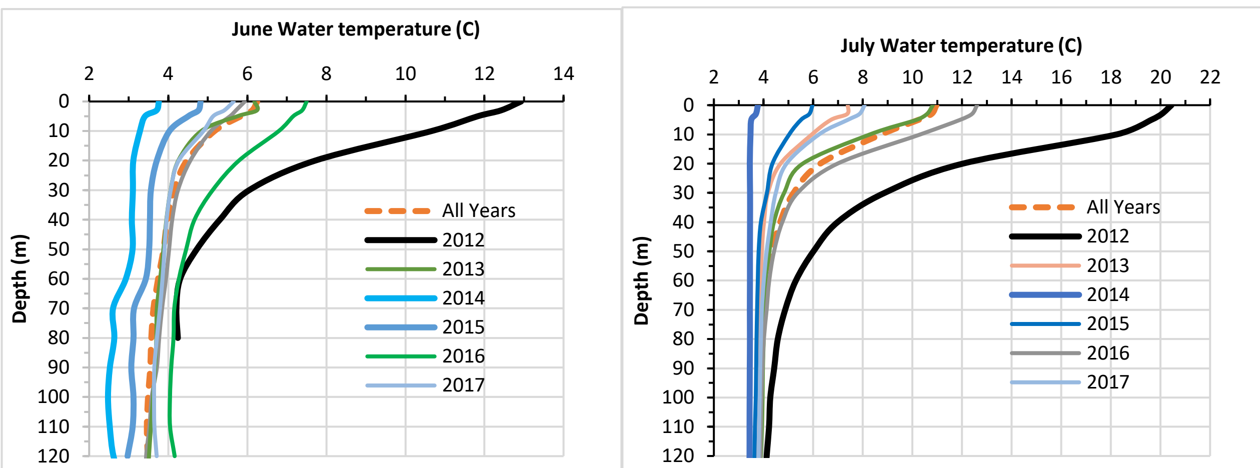

Figure 2. a) Average nearshore water temperature profiles collected in June. B) Average offshore water temperatures collected in July. All years is the average of temperatures collected from 1991-2017.

A total of 28,902 individual fish from 27 species or morphotypes were collected (Table 1). The number of species collected at each station ranged from 0 to 13, with a mean of 5.5 and median of 5. Lakewide mean biomass was 3.8 kg/ha, which was below the long-term average of 8.7 kg/ha (Table 2, Figure 3). Lakewide median biomass was 1.8 kg/ha, which was similar to the long-term average median value of 1.9 kg/ha (Figure 3).

Individual station biomass was non-normally distributed and left-skewed (Figure 4). The skewness of the distribution of individual station biomass estimates in 2017 was 2.0, which was one of the lower values in the time series (Figure 4). Individual stations with the highest biomass were site 183-14 Mile Point north of Ontonagon, Michigan, and sites 2-Stockton Island, 205-Port Wing, and 86-Basswood Island which are in or near the Apostle Islands, Wisconsin.

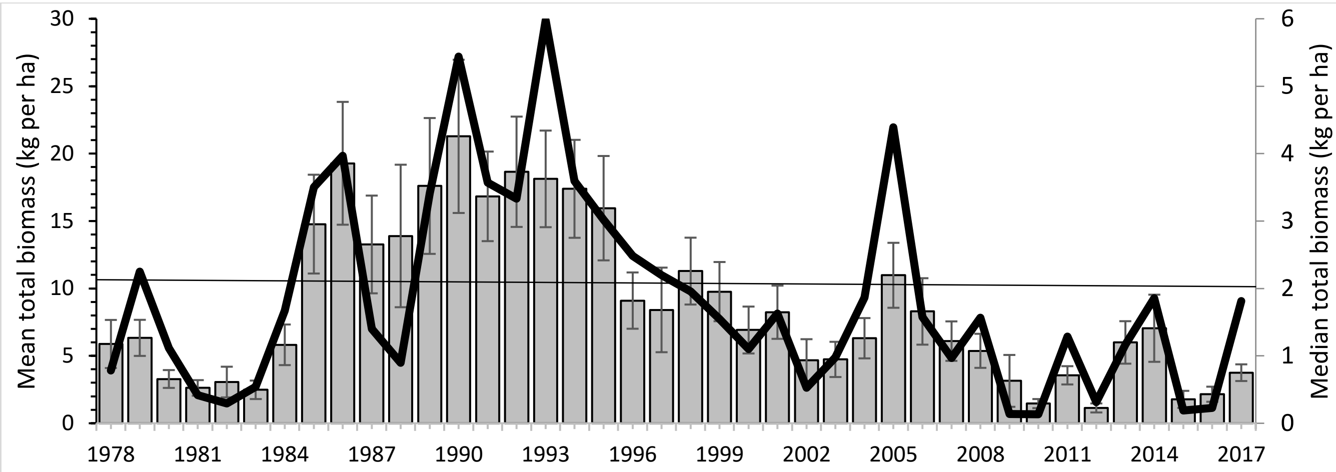

Figure 3. Annual mean + SE (bars, left y-axis) and median (line, right y-axis) lakewide nearshore biomass estimates for all fish species collected in bottom trawls from 1978-2017. The horizontal line is the long-term average mean and median values.

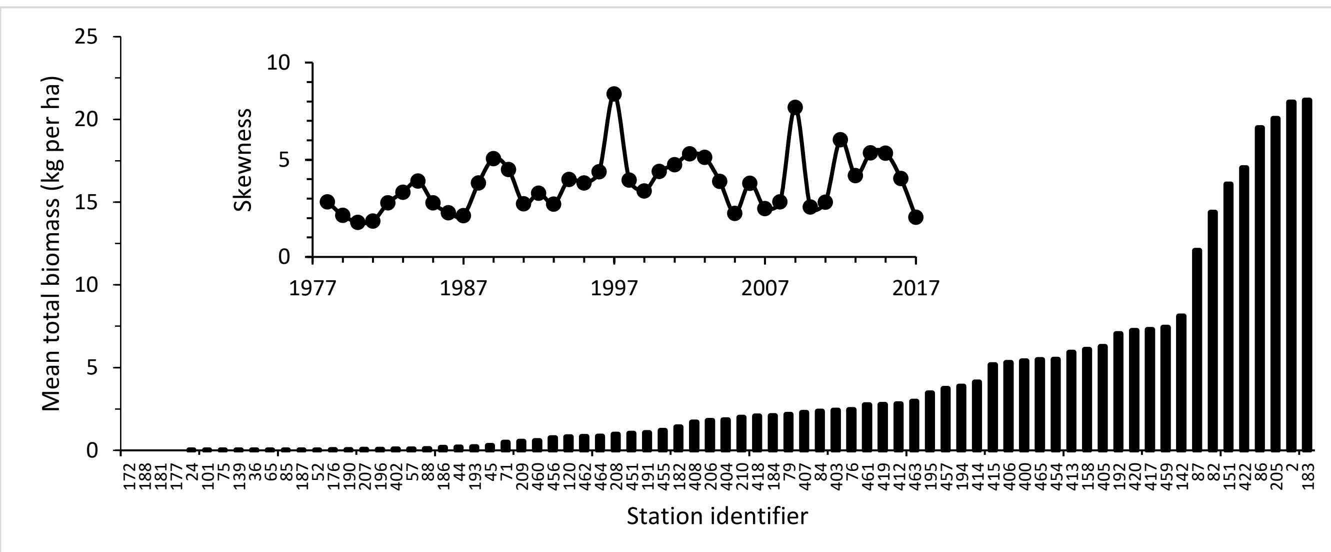

Figure 4. Estimated biomass at individual nearshore sampling stations in 2017. Station locations are shown in Figure 1. The in set plot shows the annual skewness in the distribution of individual station biomass estimates. Higher skewness values indicate greater differences in fish biomass among sampling locations.

Cisco – Lakewide mean nearshore biomass of Cisco was 0.2 kg/ha in 2017. This was similar to that observed the past two years and below the long-term average of 2.3 kg/ha and median annual average of 1.1 kg/ha (Table 2). Density of age-1 Cisco was 1.4 fish/ha in 2017, which indicated a small, but measureable recruitment year. The long-term median annual average density of age-1 Cisco is 3.3 fish/ha. Over the 40-year history of the nearshore survey, densities of age-1 Cisco <1.4 fish/ha have been observed in 17 of the 40 years. The age-1 cisco density was 14.3 and 5.0 fish/ha in 2014 and 2015.

Bloater – Lakewide mean nearshore biomass for Bloater was 0.5 kg/ha in 2017. This was below the long-term average of 1.6 kg/ha and median annual average of 0.9 kg/ha (Table 2). Age-1 Bloater density was 5.8 fish/ha in

2017. This was below the long-term average of 9.3 fish/ha and greater than the median annual average of 0.8 fish/ha (Table 3).

Lake Whitefish – Lakewide mean nearshore biomass for Lake Whitefish was 1.1 kg/ha in 2017. This was less than the long-term average of 2.1 kg/ha and median annual average of 1.9 kg/ha (Table 2). Age-1 Lake Whitefish density was 1.4 fish/ha in 2017, which was below the long-term average of 7.0 fish/ha and less than the long-term median annual average of 5.5 fish/ha (Table 3).

Rainbow Smelt – Lakewide mean nearshore biomass for Rainbow Smelt was 0.9 kg/ha in 2017. This was similar to the long-term average of 1.2 kg/ha and median of 1.0 kg/ha. This year was the first year since 2008 that Rainbow Smelt biomass was near 1 kg/ha (Table 2). Age-1 Rainbow Smelt density was 147 fish/ha in 2017, which was a bit less than the long long-term average of 159 fish/ ha and similar to the long-term median annual average of 150 fish/ha (Table 3).

Sculpin – Lakewide mean nearshore biomass for Sculpin was 0.01 kg/ha in 2017. This was below the long-term average of 0.06 kg/ha and median of 0.05 kg/ha. Sculpin biomass has not exceeded 0.06 kg/ha since 1998 (Table 2).

Other forage fish species – The combined mean nearshore lakewide biomass for all other forage fish species was 0.7 kg/ha in 2017. This was similar to the long-term mean and median of 0.7 kg/ha (Table 2). Miscellaneous species included Ninespine Stickleback, Trout-perch, Kiyi, Shortjaw Cisco, Pygmy Whitefish, Round Whitefish, and Longnose Sucker. The highest biomass of these fishes were Long-nose Sucker (0.5 kg/ha), followed by Trout-Perch (0.1 kg/ha), and Pygmy Whitefish (0.04 kg/ha).

Burbot – Lakewide mean nearshore biomass for Burbot was 0.03 kg/ha. Burbot biomass has not exceeded the long-term average of 0.12 kg/ha or the long-term median of 0.1 since 2008 (Table 2).

Lake Trout – Eleven hatchery Lake Trout were collected during the 2017 nearshore survey. Hatchery Lake Trout biomass has been near zero since 2002, with the exception of 2005 (Figure 5). Lean Lake Trout biomass was 0.2 kg/ha. This was less than the long-term average and median of 0.3 kg/ha (Table 2). Siscowet Lake Trout nearshore biomass was 0.1 kg/ha, which was similar to the long-term average and median of 0.1 kg/ha (Table 2). Densities of age-3 and younger lean and siscowet Lake Trout were 0.4 and 0.01 fish/ha in 2017, respectively. Young lean Lake Trout densities were greater than the long-term average of 0.3 fish/ha, while young siscowet Lake Trout densities were less than the long-term average of 0.03 fish/ha (Table 3).

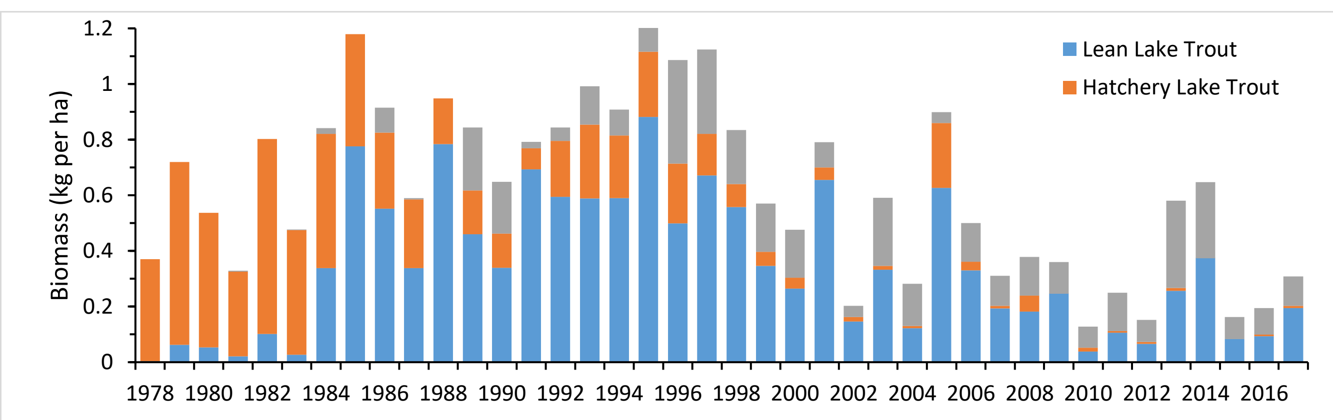

Figure 5. Mean annual lakewide biomass estimates for hatchery, lean, and siscowet Lake Trout estimated from bottom trawls in nearshore locations from 1978-2017.

Offshore survey

Offshore water temperatures were cooler than average (2011-2017) and warmer than observed in 2014 and 2015. Offshore water temperatures in July averaged 8.1 °C (range = 3.9-15.7 °C) at the surface and 3.8 °C (range = 3.6-3.9 °C) at 100 m (Figure 2).

A total of 16,674 individuals from 13 species were collected lakewide at 36 offshore sites (Table 1). The average and median observed species richness at each station was 3.8 and 4 species, respectively, and ranged from 2 to 6 species. Deepwater Sculpin, Kiyi, and siscowet Lake Trout made up 99% of the total number of individuals and biomass collected in offshore waters (Table 1, Figure 6). Ninespine Stickleback, Pygmy Whitefish, Spoonhead Sculpin, and Slimy Sculpin were the most common other species collected (Table 1), but these species were generally limited to depths <100 m. Variation in biomass estimates across offshore sites was low. The standard error in biomass estimates across sites was 0.5 kg/ha for total biomass, 0.4 kg/ha for siscowet Lake Trout, 0.2 kg/ha for Kiyi, and 0.3 kg/ha for Deepwater Sculpin.

Mean and median lakewide biomass for all species in 2017 was 6.8 kg/ha and 6.6 kg/ha, respectively. This was similar to the long-term mean of 6.9 kg/ha and greater than that observed in 2014-2016 (Figure 7).

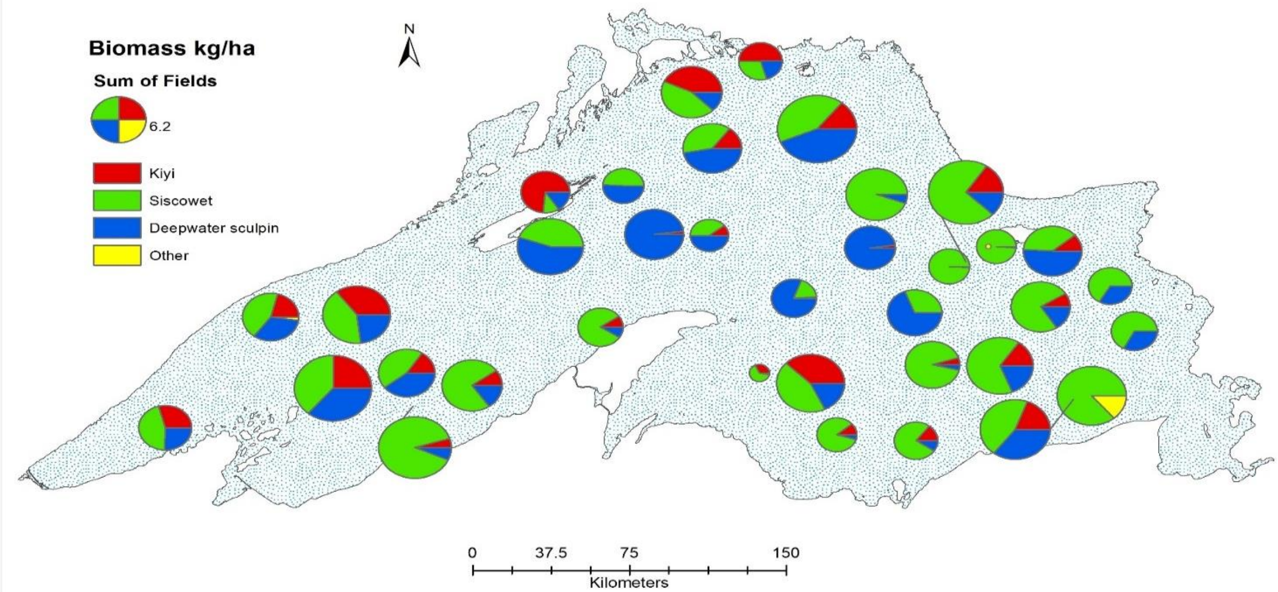

Figure 6. Mean lakewide biomass estimates for Kiyi, siscowet Lake Trout, Deepwater Sculpin, and other species estimated from offshore bottom trawls in 2017. Pie diameter is proportional to the biomass collected at that site, which ranged from 0.9-13 kg/ha. The pie in the legend is scaled to 6.2 kg/ha with the size of the pies on the map scaled accordingly to that reference.

Siscowet Lake Trout – Lakewide average biomass in 2017 (3.7 kg/ha) for siscowet Lake Trout was greater than the long-term mean (3.0 kg/ha) and higher than any previous year other than 2011 (3.7 kg/ha, Figure 7).

Kiyi – Lakewide average biomass of Kiyi in 2017 (1.0 kg/ha) was less than the long-term (1.6 kg/ha) average, but slightly greater than that observed in 2016 (0.7 kg/ha, Figure 7).

Deepwater Sculpin – Lakewide average biomass of Deepwater Sculpin in 2017 (2.0 kg/ha) was similar to the long-term average (2.0 kg/ha) and greater than that observed in 2016 (0.9 kg/ha, Figure 7).

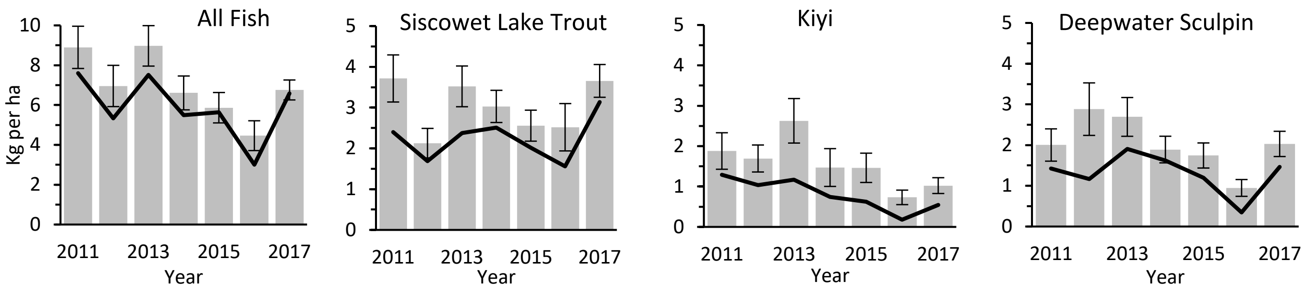

Figure 7. Annual mean ± SE (bars) and median (line) lakewide offshore biomass estimates for all species, siscowet Lake Trout, Kiyi and Deepwater Sculpin collected in bottom trawls from 2011-2017.

Larval Coregonus collections

A total of 21,019 larval *Coregonus* individuals were collected from May-July 2017. The lakewide nearshore mean larval *Coregonus* density was 1,934 fish/ha (range 0-73,130 fish/ha) and the median density was 88 fish/ha. Average densities in 2017 were greater than observed in any previous year; whereas the median value was less than observed in 2015 and 2016 (Figure 8). Offshore larval *Coregonus* densities were much less than observed in previous years. Average densities in 2017 were 46 fish/ha (range 0-473 fish/ha) as compared to >200 fish/ha in previous years (Figure 8). Larval *Coregonus* were first collected the week of 15 May 2017 and averaged >11 mm in length. This suggests a hatch date around mid-April based on previous year's collections and the length at hatch observed for Cisco raised in the laboratory (~9 mm, Oyadomari and Auer 2008, CJFAS 65:1447-1358). Estimated hatch dates were early-May in 2016, mid-May in 2015 and the end of May in 2014. Growth of nearshore larval fish in 2017, as determined by the change in total length over time, was less than that observed in previous years (Figure 9).

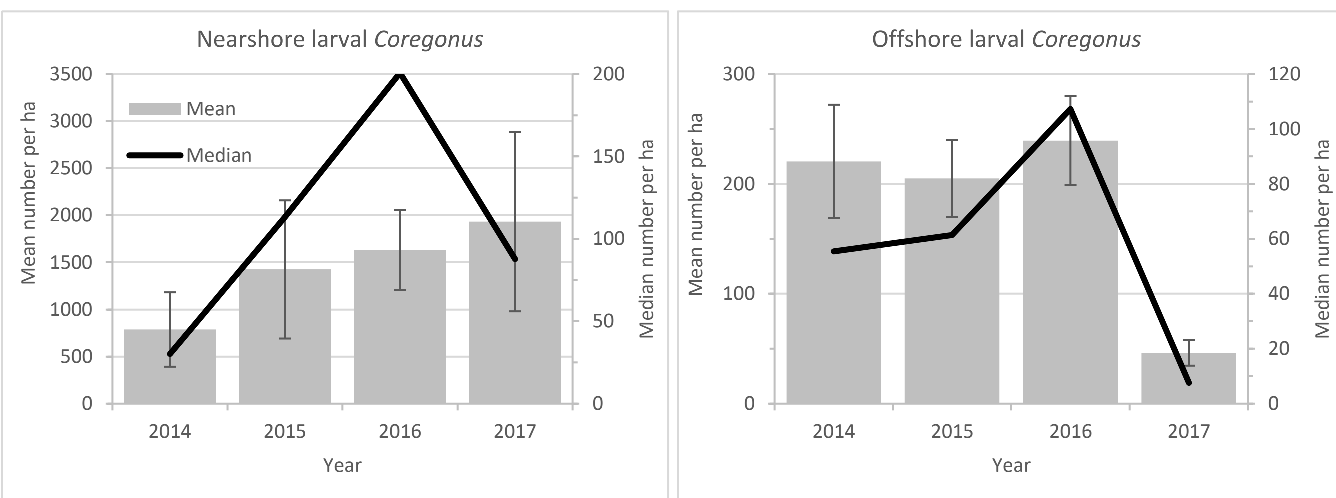

Figure 8. Annual mean ± SE (bars) and median (line) lakewide nearshore and offshore larval Coregonus abundance from 2014-2017.

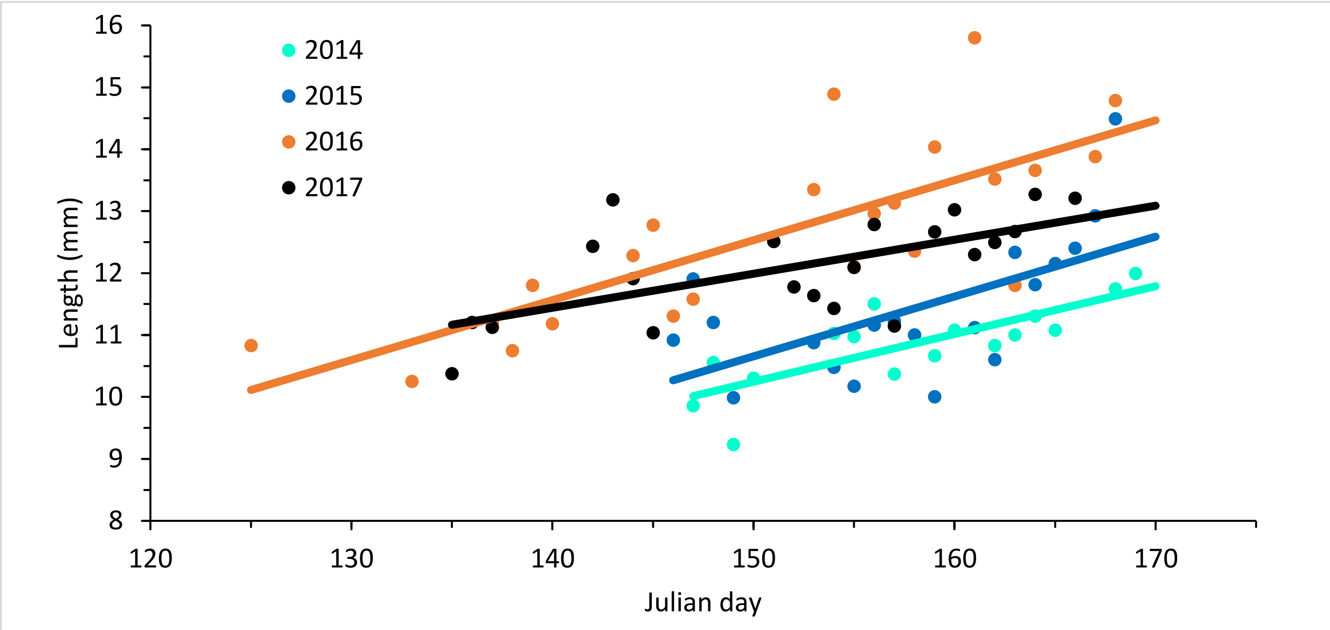

Figure 9. Average nearshore larval Coregonus *total length over time for the years 2014-2017. Annual growth rates are described by the slope of the regression line in mm per day. Growth was 0.08 mm per day in 2014, 0.1 mm per day in 2015, 0.1 mm per day in 2016, 0.05 mm per day in 2017,*

Summary

Over the 40-year history of the Lake Superior nearshore survey, estimated total biomass of demersal fish species has been dependent on recruitment and survival of age-1+ Bloater, Cisco, and Lake Whitefish populations as well as survival of Rainbow Smelt to age-3 or older. The lack of significant recruitment (survival to age-1) in *Coregonus* species in recent years, particularly of Cisco, has caused low prey fish biomass. This is of concern to fishery managers. Factors underlying low recruitment are not known, but are being actively studied. Offshore demersal fish biomass estimates have exceeded nearshore demersal fish biomass estimates over the years (2011-2017) this survey has been conducted. Offshore demersal fish biomass was higher in 2017 than observed in 2016; which reversed a 4-5 year decline in Deepwater Sculpin, Kiyi, and siscowet Lake Trout biomass. It will be interesting to see what the estimated offshore biomass levels will be in 2018.

After four years of collection, larval *Coregonus* population dynamics remain a mystery with respect to their ability to forecast *Coregonus* survival to age-1. Larval *Coregonus* abundance estimates and growth rates were lower in 2014 than estimated in 2015 and 2016, yet survival of age-1 *Coregonus* was higher for the 2014 year class than the 2015 and 2016 year classes. In 2017, lakewide nearshore mean larval *Coregonus* densities were higher and growth rates were lower than the previous 3 years; how this will translate to age-1 survival will be a key finding of our sampling in 2018.

The combination of our near- and offshore bottom and surface trawl surveys provide a lakewide picture of the status and trends of the Lake Superior fish community susceptible to bottom trawls particularly with respect to describing recruitment dynamics for *Coregonus* species and lake trout morphotypes. Our plan is to continue these surveys into the future and adapt them as needed to address emerging issues.

Note: All GLSC sampling and handling of fish during research are carried out in accordance with guidelines for the care and use of fishes by the American Fisheries Society (http://fisheries.org/docs/wp/Guidelines-for-Use-of-Fishes.pdf).

Table 1. *Fish species and the number of individuals collected in nearshore and offshore bottom trawl surveys in Lake Superior in 2017. Sampling locations shown in Figure 1.*

Common name	Scientific *name*	Nearshore	Offshore
Rainbow Smelt	*Osmerus mordax*	19236	8
Trout-Perch	*Percopsis omiscomaycus*	2836	0
Bloater	*Coregonus hoyi*	1837	2
Ninespine Stickleback	*Pungitius pungitius*	1521	59
Pygmy Whitefish	*Prosopium coulteri*	804	21
Lake Whitefish	*Coregonus clupeaformis*	573	0
Cisco	*Coregonus artedii*	444	0
Slimy Sculpin	*Cottus cognatus*	333	16
Lean Lake Trout	*Salvelinus namaycush*	123	3
Longnose Sucker	*Catostomus catostomus*	75	0
Deepwater Sculpin	*Myoxocephalus thompsoni*	74	14995
Spoonhead Sculpin	*Cottus ricei*	60	17
Kiyi	*Coregonus kiyi*	59	1250
Shortjaw Cisco	*Coregonus zenithicus*	49	1
Siscowet Lake Trout	*Salvelinus namaycush siscowet*	19	298
Eurasian Ruffe	*Gymnocephalus cernuus*	13	0
Hatchery Lake Trout	*Salvelinus namaycush*	11	0
Burbot	*Lota lota*	8	2
Alewife	*Alosa pseudoharengus*	3	1
Threespine Stickleback	*Gasterosteus aculeatus*	3	0
Lake Chub	*Hybopsis plumbea*	3	0
Blackfin Cisco	*Coregonus nigripinnis*	2	0
Spottail Shiner	*Notropis hudsonius*	2	0
Sea Lamprey	*Petromyzon marinus*	1	0
Round Whitefish	*Prosopium cylindraceum*	1	0
Pink Salmon	*Oncorhynchus gorbuscha*	1	0
White sucker	*Catostomus commersoni*	1	0
Total		28902	16674

Table 2. *Mean annual Lake Superior nearshore bottom trawl lakewide biomass (kg/ha) estimates for common fishes. Sculpin includes Slimy, Spoonhead, and Deepwater sculpin. Mean and median total biomass includes all species. Other species includes Ninespine Stickleback, Trout-Perch, Kiyi, Shortjaw Cisco, Pygmy Whitefish, Round Whitefish, and Longnose Sucker.*

Year	Sites	Total species	Total mean biomass	Total median biomass	Rainbow Smelt	Cisco	Lake Whitefish	Bloater	Hatchery lake trout	Lean lake trout	Siscowet lake trout	Burbot	Sculpin	Other species
1978	43	17	5.88	0.78	4.07	0.01	0.70	0.13	0.37	0.00	0.00	0.17	0.14	0.29
1979	49	17	6.33	2.25	2.17	0.06	1.27	0.45	0.66	0.06	0.00	0.30	0.20	1.15
1980	48	16	3.28	1.11	0.87	0.28	0.58	0.28	0.48	0.05	0.00	0.19	0.19	0.35
1981	48	19	2.62	0.42	0.21	0.36	0.67	0.41	0.30	0.02	0.00	0.24	0.18	0.22
1982	32	18	3.06	0.29	0.25	0.35	0.85	0.43	0.70	0.10	0.00	0.06	0.03	0.29
1983	50	19	2.48	0.54	0.92	0.17	0.20	0.43	0.45	0.03	0.00	0.07	0.06	0.15
1984	53	21	5.82	1.67	0.80	0.65	1.27	1.75	0.48	0.34	0.02	0.20	0.06	0.25
1985	53	19	14.77	3.50	1.33	6.53	2.14	2.69	0.40	0.78	0.00	0.05	0.08	0.77
1986	53	19	19.28	3.97	2.84	8.65	2.65	3.79	0.27	0.55	0.09	0.18	0.07	0.19
1987	53	16	13.26	1.40	1.78	5.69	2.00	2.57	0.25	0.34	0.00	0.14	0.07	0.44
1988	53	19	13.89	0.90	1.18	3.10	2.40	5.97	0.16	0.78	0.00	0.08	0.04	0.17
1989	76	21	17.60	3.41	2.08	6.21	5.54	1.71	0.16	0.46	0.23	0.21	0.08	0.93
1990	81	22	21.28	5.44	1.95	10.12	2.36	4.85	0.12	0.34	0.19	0.11	0.08	1.17
1991	84	22	16.83	3.57	1.17	10.23	2.74	0.81	0.08	0.69	0.02	0.21	0.10	0.78
1992	85	24	18.65	3.33	1.02	3.40	3.70	8.39	0.20	0.59	0.05	0.17	0.07	1.06
1993	87	23	18.12	5.98	2.12	4.99	3.67	4.28	0.27	0.59	0.14	0.27	0.09	1.71
1994	87	23	17.39	3.59	1.89	7.24	5.42	0.42	0.23	0.59	0.09	0.11	0.08	1.32
1995	87	27	15.95	3.02	2.21	3.96	5.84	0.57	0.23	0.88	0.10	0.14	0.09	1.92
1996	87	26	9.10	2.48	1.28	1.04	1.63	3.09	0.22	0.50	0.37	0.19	0.11	0.66
1997	85	30	8.41	2.20	1.35	1.35	2.77	0.86	0.15	0.67	0.30	0.10	0.06	0.80
1998	87	22	11.29	1.95	1.47	1.09	2.26	4.37	0.08	0.56	0.19	0.07	0.07	1.12
1999	83	23	9.76	1.54	1.11	2.73	1.28	3.13	0.05	0.35	0.17	0.07	0.04	0.83
2000	85	25	6.92	1.10	0.83	2.42	1.60	0.94	0.04	0.27	0.17	0.02	0.04	0.59
2001	83	32	8.24	1.63	1.52	1.15	2.78	1.19	0.05	0.65	0.09	0.13	0.04	0.63
2002	84	26	4.68	0.53	0.18	1.48	1.69	0.57	0.02	0.15	0.04	0.10	0.02	0.44
2003	86	26	4.74	0.98	0.31	0.64	1.84	0.88	0.01	0.33	0.24	0.01	0.02	0.45
2004	75	25	6.31	1.87	0.32	1.80	1.88	1.15	0.01	0.12	0.15	0.20	0.03	0.65
2005	52	27	10.97	4.39	1.00	2.23	4.37	1.65	0.23	0.63	0.04	0.31	0.01	0.51
2006	55	24	8.29	1.57	0.95	2.25	1.70	1.79	0.03	0.33	0.14	0.08	0.02	1.00
2007	56	31	6.09	0.97	1.77	0.27	1.86	0.90	0.01	0.19	0.11	0.12	0.02	0.84
2008	59	23	5.37	1.57	0.94	0.38	2.37	0.17	0.06	0.18	0.14	0.29	0.02	0.83
2009	64	20	3.14	0.14	0.38	0.30	0.15	1.18	0.00	0.25	0.11	0.04	0.02	0.72
2010	76	24	1.46	0.13	0.22	0.31	0.27	0.23	0.01	0.04	0.08	0.03	0.05	0.23
2011	82	21	3.56	1.28	0.62	0.41	0.94	0.56	0.01	0.11	0.14	0.02	0.05	0.70
2012	72	25	1.14	0.31	0.16	0.02	0.15	0.35	0.01	0.07	0.08	0.02	0.03	0.26
2013	79	27	5.99	1.17	0.53	0.52	2.98	0.49	0.01	0.26	0.31	0.10	0.02	0.77
2014	73	27	7.05	1.86	0.43	0.35	4.31	0.50	0.00	0.37	0.27	0.08	0.02	0.72
2015	76	21	1.77	0.19	0.22	0.23	0.54	0.40	0.00	0.08	0.08	0.00	0.02	0.19
2016	76	20	2.15	0.23	0.44	0.22	0.53	0.38	0.01	0.09	0.10	0.05	0.02	0.33
2017	76	27	3.75	1.81	0.94	0.16	1.11	0.49	0.01	0.19	0.11	0.03	0.01	0.70
Mean	69	23	8.67	1.88	1.15	2.33	2.08	1.63	0.17	0.34	0.11	0.12	0.06	0.68
Median	76	23	6.63	1.57	0.97	1.07	1.85	0.87	0.10	0.33	0.09	0.10	0.05	0.68

Table 3. *Annual Lake Superior nearshore bottom trawl lakewide mean age-1 density (number/ha) estimates for Cisco, Bloater, Lake Whitefish, and Rainbow Smelt and for small lean and siscowet Lake Trout. Age-1 fish were defined by species-specific lengths: Cisco <140 mm, Bloater <130 mm, Lake Whitefish <160 mm, and Rainbow Smelt <100 mm. Lean and siscowet Lake Trout data are for fish <226 mm, ca. < age 3.*

Year	Year Class	Sampling sites	Rainbow Smelt	Cisco	Bloater	Lake Whitefish	Kiyi	Lean lake trout	Siscowet lake trout
1978	1977	43	95.76	0.03	0.82	2.62	0.00	0.11	0.00
1979	1978	49	234.14	6.30	30.08	3.90	0.00	0.17	0.00
1980	1979	48	96.79	0.11	1.57	1.97	0.00	0.12	0.00
1981	1980	48	106.26	13.48	6.85	16.43	0.00	0.28	0.03
1982	1981	32	63.81	0.16	0.75	4.16	0.00	0.22	0.00
1983	1982	50	103.58	0.05	0.82	0.45	0.00	0.20	0.00
1984	1983	53	224.39	21.76	4.74	8.04	0.00	0.59	0.00
1985	1984	53	149.51	748.02	44.00	2.47	0.00	0.65	0.00
1986	1985	53	150.41	68.92	30.55	3.45	0.00	0.43	0.06
1987	1986	53	275.59	5.44	4.23	11.91	0.00	0.36	0.02
1988	1987	53	155.27	0.52	6.86	6.11	0.01	0.26	0.00
1989	1988	76	274.78	226.80	37.69	36.08	0.00	0.13	0.07
1990	1989	81	272.04	425.64	57.26	8.78	0.01	0.22	0.02
1991	1990	84	162.03	236.87	11.38	17.54	0.00	0.33	0.01
1992	1991	85	176.94	9.08	10.71	11.84	0.06	0.40	0.02
1993	1992	87	155.24	3.34	0.22	7.68	0.02	0.42	0.10
1994	1993	87	198.62	0.76	0.06	4.95	0.02	0.57	0.01
1995	1994	87	401.83	1.47	0.00	13.52	0.02	0.86	0.02
1996	1995	87	168.25	0.96	0.05	6.33	0.01	1.13	0.10
1997	1996	85	253.04	11.09	0.18	8.80	0.00	0.39	0.04
1998	1997	87	145.01	1.18	0.12	7.74	0.02	0.60	0.02
1999	1998	83	216.18	90.76	0.40	9.17	0.05	0.16	0.05
2000	1999	85	58.40	3.85	0.48	0.77	0.26	0.18	0.01
2001	2000	83	256.32	0.83	0.12	2.37	0.00	0.26	0.02
2002	2001	84	56.79	0.53	0.12	13.68	0.00	0.12	0.03
2003	2002	86	77.83	33.20	0.58	7.74	0.01	0.09	0.01
2004	2003	75	70.28	175.34	27.22	6.36	0.11	0.12	0.01
2005	2004	52	110.39	8.19	12.07	2.97	0.12	0.30	0.03
2006	2005	55	249.56	18.58	13.61	5.51	0.13	0.24	0.10
2007	2006	56	360.93	0.41	0.32	19.74	0.01	0.05	0.03
2008	2007	59	280.69	0.20	0.28	0.63	0.00	0.10	0.04
2009	2008	64	71.64	0.27	0.59	3.00	0.00	0.04	0.03
2010	2009	76	45.37	14.03	2.46	6.64	0.01	0.02	0.02
2011	2010	82	73.98	0.30	0.76	3.98	0.01	0.22	0.01
2012	2011	72	11.05	0.03	0.06	1.90	0.00	0.20	0.03
2013	2012	79	142.90	0.17	0.22	5.46	0.00	0.18	0.03
2014	2013	73	68.46	0.01	0.06	2.27	0.00	0.00	0.03
2015	2014	76	30.66	14.31	8.57	1.00	0.09	0.07	0.03
2016	2015	76	83.04	4.99	9.76	1.62	0.12	0.19	0.04
2017	2016	76	146.95	1.37	5.81	1.39	0.17	0.42	0.01
Mean		69	156.87	53.73	8.31	7.02	0.03	0.29	0.03
Median		76	148.23	3.59	0.82	5.49	0.01	0.22	0.02

Status and Trends of Prey Fish Populations in Lake Michigan, 2017[1,2,3]

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Abstract

The U.S. Geological Survey Great Lakes Science Center has conducted lake-wide surveys of the fish community in Lake Michigan each fall since 1973 using standard 12-m bottom trawls towed along contour at depths of 9 to 110 m at each of seven index transects. The resulting data on relative abundance, size and age structure, and condition of individual fishes are used to estimate various population parameters that are in turn used by state and tribal agencies in managing Lake Michigan fish stocks. All seven established index transects of the survey were completed in 2017. The survey provides relative abundance and biomass estimates between the 5-m and 114-m depth contours of the lake (herein, lake-wide) for prey fish populations, as well as for burbot and yellow perch. Lake-wide biomass of alewives in 2017 was estimated at 0.09 kilotonnes (kt, 1 kt = 1000 metric tonnes), which was a record low, and 75% lower than in 2016. Age distribution of alewives remained truncated with no alewife age exceeding 5 years. Bloater biomass increased by more than 50% from 5.9 kt in 2016 to 9.1 kt in 2017. Round goby biomass declined by more than half from 1.1 kt in 2016 to 0.5 kt in 2017. Rainbow smelt biomass increased twofold up to 0.6 kt in 2017, but was still under 1 kt for the eighth straight year. Slimy sculpin biomass decreased from 0.8 kt in 2016 to 0.2 kt in 2017, whereas deepwater sculpin biomass in 2017 was 2.7 kt, which was within 10% of the 2016 level. Ninespine stickleback biomass in 2017 was at a near record low level (0.002 kt). Burbot lake-wide biomass (0.1 kt in 2017) has remained below 3 kt since 2001. No age-0 yellow perch were caught in 2017, indicating a weak year-class. Overall, the total lake-wide prey fish biomass estimate (sum of alewife, bloater, rainbow smelt, deepwater sculpin, slimy sculpin, round goby, and ninespine stickleback) in 2017 was 13.3 kt, roughly a 20% increase over the 2016 total but still the fourth lowest estimate in the 45-year time series. In 2017, bloater and deepwater sculpin, two native fishes, constituted nearly 90% of this total.

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[1] Presented at Great Lakes Fishery Commission, Lake Michigan Committee Meeting, Sault Ste. Marie, ON on March 22, 2018.

[2] The data associated with this report are available at: U.S. Geological Survey, Great Lakes Science Center, 2018, Great Lakes Research Vessel Operations 1958-2017 (ver. 2.0, March 2018): U.S. Geological Survey Data Release, https://doi.org/10.5066/F75M63X0.

[3] All GLSC sampling and handling of fish during research are carried out in accordance with guidelines for the care and use of fishes by the American Fisheries Society (http://fisheries.org/docs/wp/Guidelines-for-Use-of-Fishes.pdf).

The U.S. Geological Survey Great Lakes Science Center (GLSC) has conducted daytime bottom trawl surveys in Lake Michigan during the fall annually since 1973. Estimates from the 1998 survey are not reported because the trawls were towed at non-standard speeds. From these surveys, the relative abundances of the prey fish populations are measured, and estimates of lake-wide biomass available to the bottom trawls (for the region of the main basin between the 5-m and 114-m depth contours) can be generated (Hatch et al. 1981; Brown and Stedman 1995). Such estimates are critical to fisheries managers making decisions on stocking and harvest rates of salmonines and allowable harvests of fish by commercial fishing operations.

The basic unit of sampling in our surveys is a 10-minute tow using a bottom trawl (12-m headrope, 25 to 45-mm bar mesh in net body, 6.4-mm bar mesh in cod end) dragged on contour at 9-m (5 fathom) depth increments. At most survey transects, towing depths range from 9 or 18 m to 110 m. In 2013, we began adding tows at deeper depths (i.e., 128 m) to assess the extent to which populations of deepwater sculpins and bloater have migrated outside of our traditional survey range. Since then, we have sampled deeper depths offshore of all ports except Waukegan, for a total of 23 "deep" tows. To maintain time series consistency, these tows are not included in our time series results but are specifically noted for some species.

Ages were estimated for alewives (*Alosa pseudoharengus*, using otoliths) and bloaters (*Coregonus hoyi*, using scales) from our bottom trawl catches (Madenjian et al. 2003; Bunnell et al. 2006a). Although our surveys have included as many as nine index transects in any given year, we have consistently conducted the surveys at seven transects, and data from those seven transects are reported herein. These transects are situated off Manistique, Frankfort, Ludington, and Saugatuck, Michigan; Waukegan, Illinois; and Port Washington and Sturgeon Bay, Wisconsin (Figure 1). All seven transects were completed in 2017.

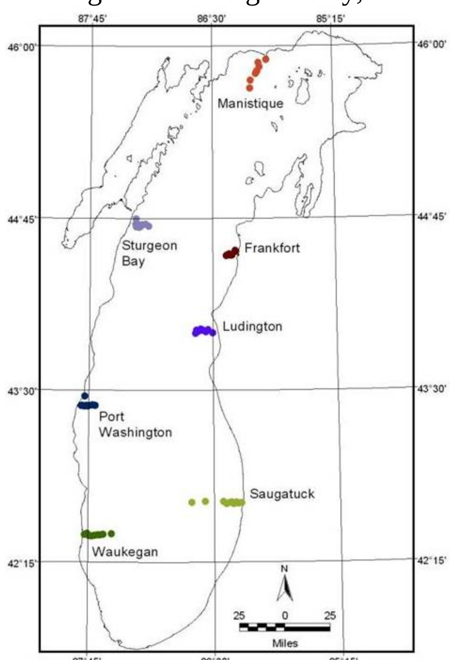

Figure 1. Established sampling locations for GLSC bottom trawls in Lake Michigan.

Indices of lake-wide biomass of fishes vulnerable to the bottom trawl require accurate measures of (1) the surface areas that represent the depths sampled and (2) bottom area swept by the trawl. A complete Geographical Information System (GIS) based on depth soundings at 2-km intervals in Lake Michigan was developed as part of the acoustics study performed by Argyle et al. (1998). This GIS database was used to estimate the surface area for each individual depth zone surveyed by the bottom trawls. In June 2009, we used trawl mensuration gear to monitor net configuration during deployment. It provided specific correction factors for width of the net and actual time on bottom when sampling at 2.1 mph (Madenjian et al. 2010a) that were applied to all years through 2015. The R/V Arcticus replaced the previously used R/V Grayling in 2015. In June 2016, we again used trawl mensuration gear to estimate width of the net during deployment from the R/V Arcticus, which has a wider beam than the R/V Grayling. A regression relationship between bottom depth and width of net was developed that was used to correct for net width during the 2016 survey (Bunnell et al. 2017), and this relationship will continue to be used as long as the survey is conducted using the R/V Arcticus. In addition, in 2016, we began directly estimating time on bottom for each tow with an RBR sensor that is attached to the head rope, and which estimates sensor depth every second. Thus, since 2016, both the RBR estimate of time on bottom and the above-mentioned regression relationship for estimating net width are used to estimate bottom area swept by the bottom trawl during each tow.

We estimate both numeric (fish per hectare [ha]) and biomass (kg per ha) density, although we display graphical trends mostly in biomass for brevity. A weighted mean density over the entire range of depths sampled (within the 5-m to 114-m depth contours) was estimated by first calculating mean density for each depth zone, and then weighting mean density for each depth zone by the proportion of lake surface area assigned to that depth zone. Standard error (SE) of mean density was estimated by weighting the variances of fish density in each of the depth zones by the appropriate weight (squared proportion of surface area in the depth zone), averaging the weighted variances over all depth zones, and taking the square root of the result.

NUMERIC AND BIOMASS DENSITY BY SPECIES

By convention, we classify "adult" prey fish as age 1 or older, based on total length (TL): alewives ≥ 100 mm, rainbow smelt (*Osmerus mordax*) ≥ 90 mm, bloaters ≥ 120 mm, and yellow perch (*Perca flavescens*) ≥ 100 mm. We assume all fish smaller than the above length cut-offs are age-0; length cut-offs are also aided by aging of alewife (by otoliths) and bloater (by scales). Catches of age-0 alewife are not reliable indicators of future year-class strength (Madenjian et al. 2005a), because their position in the water column makes them less vulnerable to bottom trawls. Catches of age-0 bloater, though biased low, can be used as an index of relative abundance given the positive correlation between density of age-0 bloater and density of age-3 bloater (the age at which catch curves reveal full recruitment to our gear, Bunnell et al. 2006a, 2010). Catch of age-0 (< 100 mm TL) yellow perch is likely a good indicator of year-class strength, given that large catches in the bottom trawl during the 1980s corresponded to the strong yellow perch fishery. At the end of this report, we also present densities of age-0 yellow perch and other bottom-dwelling species such as burbot (*Lota lota*) that are not necessarily "prey fish" but are caught in sufficient numbers to index. Unfortunately lake whitefish (*Coregonus clupeaformis*) are only rarely sampled in our trawl and the resultant trends are not meaningful. Since 1999, dreissenid mussels sampled in the trawl have also been sorted and weighed (but not counted), and their biomass is reported in the Appendix.

<u>Alewife</u> – Since its establishment in the 1950s, the alewife has become a key member of the fish community. As a predator on larval fish, adult alewife can depress recruitment of native fishes, including burbot, deepwater sculpin (*Myoxocephalus thompsonii*), emerald shiner (*Notropis atherinoides*), lake trout (*Salvelinus namaycush*), and yellow perch (Smith 1970; Wells and McLain 1973; Madenjian et al. 2005b, 2008; Bunnell et al. 2006b). Additionally, alewife has remained the most important constituent of salmonine diet in Lake Michigan for the last 45 years (Jude et al. 1987; Stewart and Ibarra 1991; Warner et al. 2008; Jacobs et al. 2013). Most of the alewives consumed by salmonines in Lake Michigan are eaten by Chinook salmon (*Oncorhynchus tshawytscha*, Madenjian et al. 2002; Tsehaye et al. 2014). A commercial harvest was established in Wisconsin waters of Lake Michigan in the 1960s to make use of the then extremely abundant alewife that had become a nuisance and health hazard along the lakeshore. In 1986, a quota was implemented, and as a result of these restrictions, the estimated annual alewife harvest declined from about 7,600 metric tons in 1985 to an incidental harvest of only 12 metric tons after 1990 (Mike Toneys, Wisconsin Department of Natural Resources, Sturgeon Bay, personal communication). Lake Michigan currently has no commercial fishery for alewives.

According to the bottom trawl survey results, adult alewife biomass density equaled 0.02 kg per ha in 2017, a record low (Figure 2a). Likewise, adult alewife numeric density in 2017 equaled a record-low estimate of 0.9 fish per ha (Figure 2b). Alewives were caught at all ports other than Saugatuck during 2017, but estimates of biomass density did not exceed 0.5 kg per ha for any of the bottom trawls (Figure 3). Since 2013, alewives have been sampled in 13 of 23 deep tows. However, mean alewife biomass density at 128 m was between 2 and 3 times lower than those at 9 m and 18 m, and about 2 times lower than that at 110

m. Thus, apparently a relatively low proportion of the alewife population was situated in waters deeper than 110 m at the time of our survey during 2013-2017.

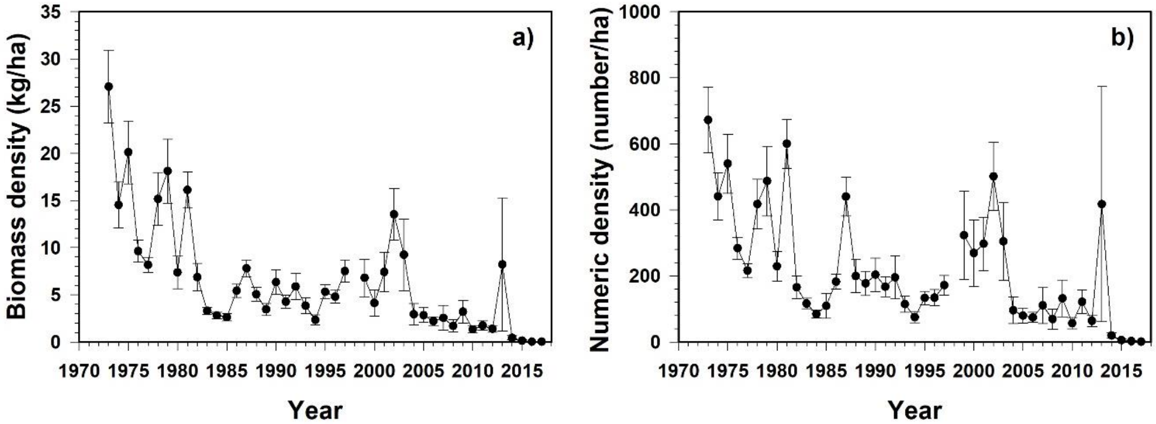

Figure 2. Density of adult alewives as biomass (a) and number (b) per ha (+/- standard error) in Lake Michigan, 1973-2017.

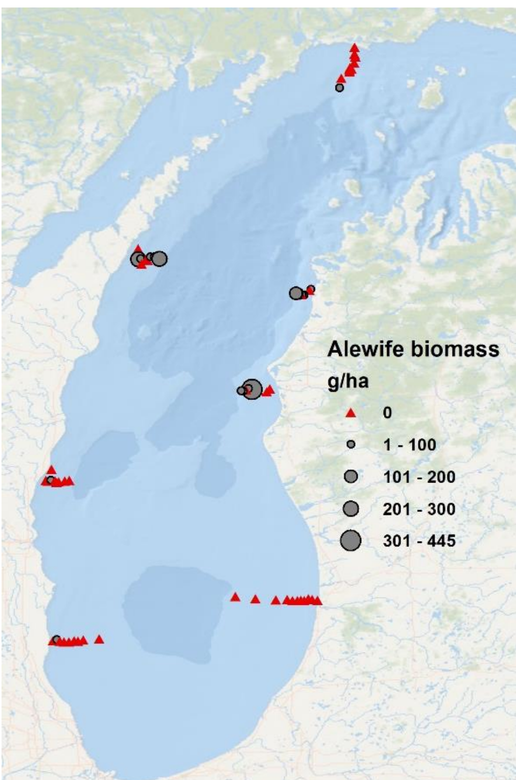

Figure 3. Scaled-symbol plot showing the biomass of alewife sampled at each of the 2017 bottom trawl sites.

The long-term temporal trends in adult alewife biomass, as well as in alewife recruitment to age 3, in Lake Michigan are attributable to consumption of alewives by salmonines (Madenjian et al. 2002, 2005a; Tsehaye et al. 2014). Several factors have likely maintained this high predation pressure in the 2000s including: a relatively high abundance of wild Chinook salmon in Lake Michigan (Williams 2012; Tsehaye et al. 2014), increased migration of Chinook salmon from Lake Huron in search of alewives (Adlerstein et al. 2007; Clark et al. 2017), increased importance of alewives in the diet of Chinook salmon in Lake Michigan (Jacobs et al. 2013), a decrease in the energy density of adult alewives (Madenjian et al. 2006), and increases in lake trout abundance due to increased rates of stocking and natural reproduction (FWS/GLFC 2017; Lake Michigan LTWG 2017).

In 2017, the bottom trawl survey captured only 41 "adult" (i.e., $\geq$100 TL) alewives for which we typically construct an age-length distribution. The age composition of these fish was dominated by age-1 (42%, 2016 year-class) and age-2 (46%, 2015 year-class) fish. Age-4 (2013 year-class), and age-5 (2012 year-class) fish represented 5% and 7%, respectively, of the remaining adults, and no age-3 fish were caught in the survey (Figure 4). No alewives older than age 5 were caught in the survey; thus, the recent trend of age truncation in the alewife population continued through 2017. Likewise, no alewives older than age 5 were caught in the acoustics survey in 2017. Prior to 2009, age-8 alewives were routinely captured in the bottom trawl survey. In contrast to 2017, in most years the age composition of the alewife population is based on aging at least 200 alewives caught from the bottom trawl survey each year.

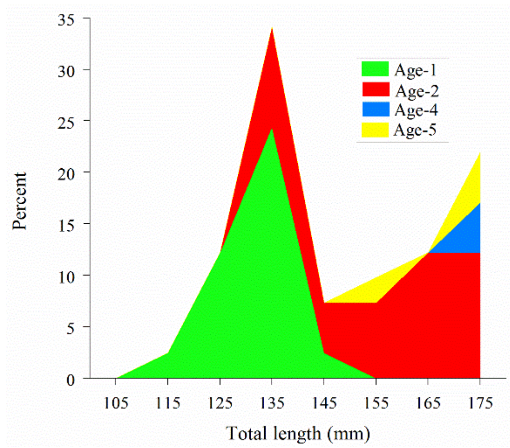

Figure 4. Age-length distribution of alewives ≥ 100 mm total length caught in bottom trawls in Lake Michigan, 2017.

Both the acoustic and bottom trawl survey time series for total alewife biomass are in general agreement, indicating that biomass during 2004-2017 was relatively low compared with biomass during 1994-1996 (Warner et al. 2018). Across the 22 years, however, the acoustic estimate has been higher than the bottom trawl survey estimate 82% of the time. The discrepancy between the two estimates has increased between 2014 and 2017, with the acoustic estimate ranging from 10 to nearly 200 times higher during this 4-year period. The acoustic survey likely provides a less biased estimate of younger (age 3 and younger) alewives, owing to their pelagic orientation. Thus, this recent higher discrepancy between the two surveys may have been partly due to the alewife population in the lake becoming younger in recent years, but other factors were also likely involved. The acoustic survey assessed a 13% increase in total alewife biomass between 2016 and 2017, whereas the bottom trawl survey assessed a 75% decrease in total alewife biomass between these two years.

Bloater - Bloaters are eaten by salmonines in Lake Michigan, but are far less prevalent in salmonine diets than alewives (Warner et al. 2008; Jacobs et al. 2010, 2013). For large (≥ 600 mm) lake trout, over 30% of the diets offshore of Saugatuck and on Sheboygan Reef were composed of adult bloaters during 1994-1995, although adult bloaters were a minor component of lake trout diet at Sturgeon Bay (Madenjian et al. 1998). For Chinook salmon, the importance of bloater (by wet weight) in the diets has declined between 1994-1995 and 2009-2010. For small (< 500 mm) Chinook salmon the proportion declined from 9% to 6% and for large Chinook salmon the proportion declined from 14% to <1% (Jacobs et al. 2013). The bloater population in Lake Michigan also supports a valuable commercial fishery, although its yield has declined sharply since the late 1990s.

Adult bloater biomass density in our survey has been < 10 kg per ha since 1999 (Figure 5a). Nevertheless, adult bloater biomass nearly tripled between 2016 and 2017, when it reached a level of 2 kg per ha. This

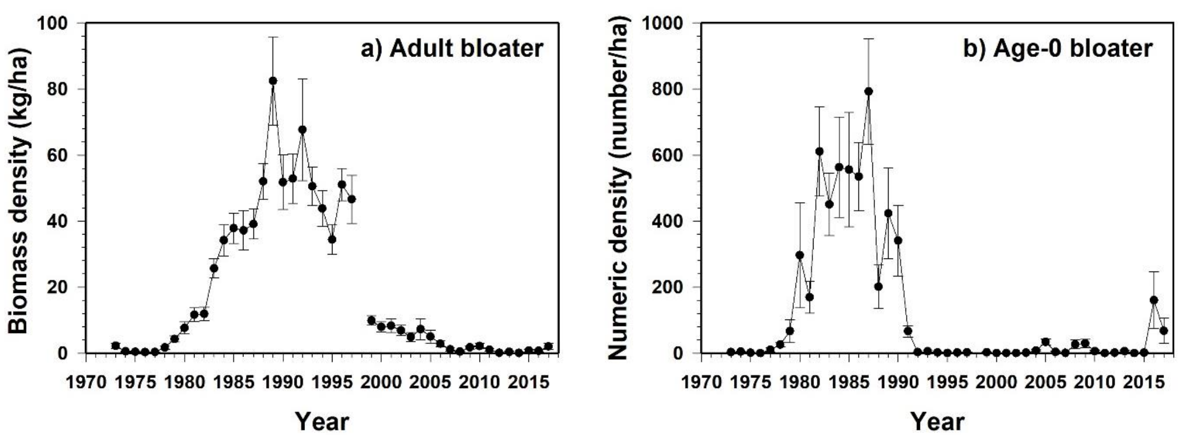

Figure 5. Panel (a) depicts biomass density (+/- standard error) of adult bloater in Lake Michigan, 1973-2017. Panel (b) depicts numeric density (+/- standard error) of age-0 bloater in Lake Michigan, 1973-2017.

substantial increase in adult bloater biomass was attributable to the relatively strong 2016 year-class recruiting to the age-1 and older population in 2017 (Figure 5). Moreover, numeric density of age-0 bloaters

(< 120 mm TL) in 2017 was 68 fish per ha, which the second highest estimate since 1990 (Figure 5b). Thus, bloater recruitment during the past two years has been much higher than bloater recruitment during other years since 1992, based on the bottom trawl survey results. Bloaters were sampled in all seven ports in 2017 (Figure 6), with the highest mean biomass densities at Ludington, Saugatuck, and Frankfort. Since 2013, bloaters have been sampled in 8 of 23 deep tows. Mean biomass density at 128 m was more than an order of magnitude lower than mean biomass densities at some of the shallower depths. Thus, according to the bottom trawl survey results, a relatively low proportion of the bloater population occurred in waters deeper than 110 m at the time of our survey during 2013-2017.

The exact mechanisms underlying the apparently poor bloater recruitment for most of the 1992-2017 period (Figure 5b), and the low biomass of adult bloater since 2007 (Figure 5a), remain unknown. Madenjian et al. (2002) proposed that the Lake Michigan bloater population may be cycling in abundance, with a period of about 30 years, although the exact mechanism by which recruitment is regulated remains unknown. Of the mechanisms that have been recently evaluated, reductions in fecundity associated with poorer condition (Bunnell et al. 2009) and egg predation by slimy and deepwater sculpins (Bunnell et al. 2014a) may be contributing to the reduced bloater recruitment, but neither one is the primary regulating factor.

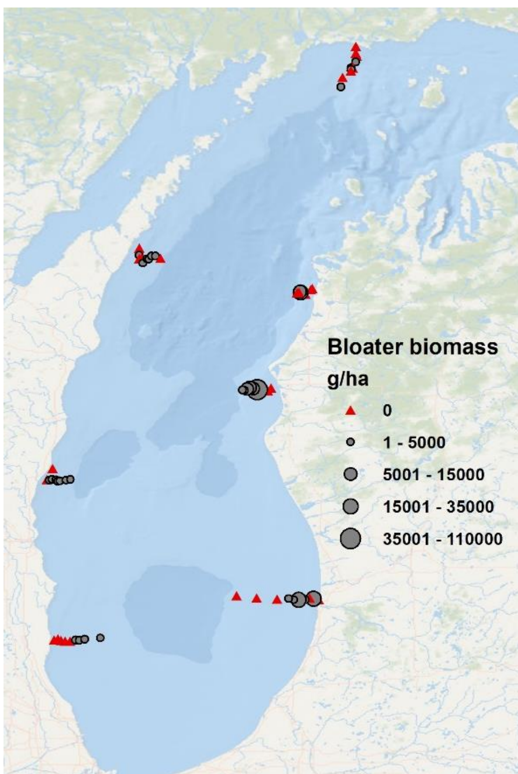

Figure 6. Scaled-symbol plot showing the biomass of bloater sampled at each of the 2017 bottom trawl sites.

An important consideration when interpreting the bottom trawl survey results is that bloater catchability may have decreased in recent years, in response to the proliferation of quagga mussels and the associated increased water clarity and decreased *Diporeia* spp. densities, which could be responsible for a shift to the more pelagic calanoid copepods in their diets (Bunnell et al. 2015). Hence, one hypothesis is that bloaters are less vulnerable to our daytime bottom trawls either owing to behavioral changes (more pelagic during the day) or increased ability to avoid the net while on the bottom (due to clearer water). Further, vulnerability of bloaters to our bottom trawl survey may have decreased more for large bloaters than for small bloaters. In recent years, nearly all of the bloaters captured by our bottom trawls were less than 240 mm in TL, whereas commercial fishers using gill nets continue to harvest bloaters well over 300 mm in TL. Perhaps, in recent years, bloaters have become more pelagic and/or better able to avoid the net as they grow.

Both the acoustic and bottom trawl survey have assessed that bloater biomass was more than an order of magnitude higher during 1992-1996 than during 2001-2017. A comparison of the two surveys during 1992-2006 revealed that the biomass estimate from the bottom trawl survey was always higher (about 3 times higher, on average) than the acoustic survey estimate. Since 2007, either survey was just as likely to yield the higher estimate as the other survey. In 2017, total biomass density estimated for bloater from the bottom trawl survey (2.59 kg per ha) was very similar to that from the acoustic survey (2.52 kg per ha). Age-0 bloater trends also have revealed relative differences between surveys varying through time. During 1992-1996, both surveys documented age-0 bloater numeric density to range between 0.3 and 6.2 fish per ha. Since 2001, however, the acoustic survey has documented a mean numeric density of age-0 bloater of 192 fish per ha, while mean numeric density of age-0 bloater from the bottom trawl survey was only 20 fish per ha since 2001. One potential explanation for these inconsistent relative differences in survey results over time is that catchability of age-0 bloater with the bottom trawl decreased sometime during the 2000s.

Rainbow smelt – Adult rainbow smelt have been an important part of the diet for intermediate-sized (400 to 600 mm) lake trout in the nearshore waters of Lake Michigan (Stewart et al. 1983; Madenjian et al. 1998; Jacobs et al. 2010). For Chinook salmon, rainbow smelt comprised as much as 18% in the diets of small individuals in 1994-1996, but that dropped precipitously to 2% in 2009-2010. Rainbow smelt has been consistently rare in the diets of larger Chinook salmon since 1994 (Jacobs et al. 2013). The rainbow smelt population has traditionally supported commercial fisheries in Wisconsin and Michigan waters (e.g., Belonger et al. 1998), but its yields have also declined through time. Between 1971 and 1999, more than 1.3 million pounds were annually harvested on average. Between 2000 and 2011, the annual average dropped to about 375,000 pounds. Since 2013, less than 2,000 pounds have been harvested per year.

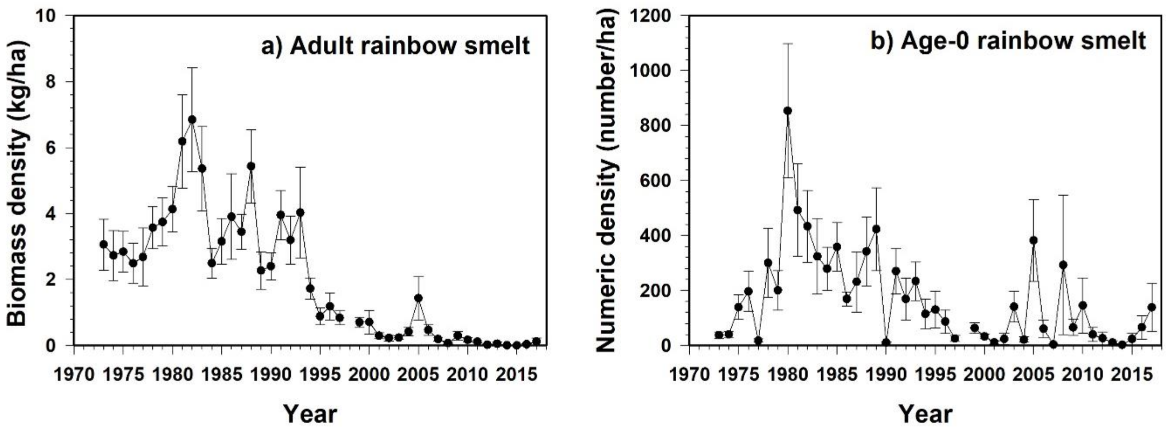

Figure 7. Panel (a) depicts biomass density (+/- standard error) of adult rainbow smelt in Lake Michigan, 1973-2017. Panel (b) depicts numeric density (+/- standard error) of age-0 rainbow smelt in Lake Michigan, 1973-2017.

Similar to the commercial yields, adult rainbow smelt biomass density in the bottom trawl has remained at low levels since 2001, aside from a relatively high estimate in 2005 (Figure 7a). Biomass density in 2017 was 0.12 kg per ha. Age-0 rainbow smelt numeric density has been highly variable since 1999 (Figure 7b), and equaled 138 fish per ha in 2017, marking the first time this density exceeded 100 fish per ha since 2010. Rainbow smelt were sampled at all seven ports in 2017 (Figure 8), with the highest mean biomass densities at Saugatuck, Ludington, and Manistique. Causes for the general decline in rainbow smelt biomass since 1993 remain unclear. Consumption of rainbow smelt by salmonines was higher in the mid-1980s than during the 1990s (Madenjian et al. 2002), yet adult and age-0 (< 90 mm TL) rainbow smelt abundance remained high during the 1980s (Figure 7b). Results from a recent population modeling exercise suggested that predation by salmonines was not the primary driver of long-term temporal trends in Lake Michigan rainbow smelt abundance (Tsehaye et al. 2014). Furthermore, a recent analysis of our time series suggested that the productivity of the population has actually increased since 2000 (relative to 1982-1999), yet those recruits do not appear to be surviving to the adult population (Feiner et al. 2015).

The bottom trawl and acoustic surveys detected similar temporal trends, with total (age-0 and adult pooled) rainbow smelt biomass densities more than 7 times higher, on average, during 1992-1996 than during 2001-2017. A comparison of the two survey estimates revealed that the acoustic survey estimate always exceeds that of the bottom trawl survey, on average by a factor of about 6. This difference is not surprising given that rainbow smelt tend to be more pelagic than other prey species during the day. In 2017, the total biomass

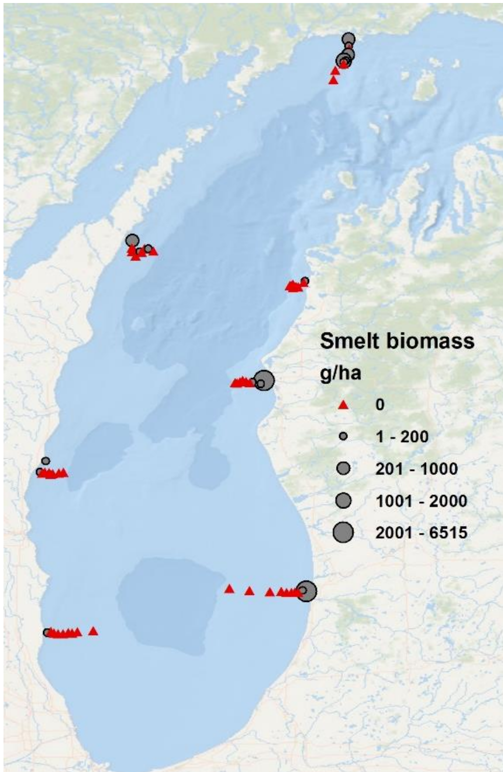

Figure 8. Scaled-symbol plot showing the biomass of rainbow smelt sampled at each of the 2017 bottom trawl sites.

estimate for all rainbow smelt was 1.03 kg per ha for the acoustic survey (Warner et al. 2018), which was about 6 times greater than the bottom trawl survey estimate (0.18 kg/ha).

Sculpins – From a biomass perspective, the cottid populations in Lake Michigan have been dominated by deepwater sculpins, and to a lesser degree, slimy sculpins (*Cottus cognatus*). Spoonhead sculpins (*Cottus ricei*), once fairly common, suffered declines to become rare to absent by the mid-1970s (Eck and Wells 1987). Spoonhead sculpins were encountered in small numbers in our survey between 1990 and 1999 (e.g., Potter and Fleischer 1992), but have not been sampled since 1999.

Slimy sculpin is a favored prey of juvenile lake trout in Lake Michigan (Stewart et al. 1983; Madenjian et al. 1998), but is only a minor part of adult lake trout diets. When abundant, deepwater sculpin can be an important diet constituent for burbot in Lake Michigan, especially in deeper waters (Van Oosten and Deason 1938; Brown and Stedman 1995; Fratt et al. 1997). Deepwater sculpin biomass density in 2017 was 0.78 kg per ha, which was only 8% lower than the estimate of 0.85 kg per ha for 2016 (Figure 9a). Previous analysis of the time series indicated deepwater sculpin density is negatively influenced by alewife (predation on sculpin larvae) and burbot (predation on juvenile and adult sculpin, Madenjian et al. 2005b). Based on bottom trawl survey results, neither alewife nor burbot significantly increased in abundance during 2007-2017 to account for this decline in deepwater sculpins. Following no clear trend between 1990 and 2005, the biomass of deepwater sculpin sampled in the bottom trawl has declined since 2005. Madenjian and Bunnell (2008) demonstrated that deepwater sculpins have been captured at increasingly greater depths since the 1980s. Therefore, one potential explanation for the recent decline in deepwater sculpin densities is that an increasing proportion of the population is now occupying depths deeper than those sampled by our survey (i.e., 9-110 m), perhaps in response to the decline of *Diporeia* and proliferation of dreissenid mussels.

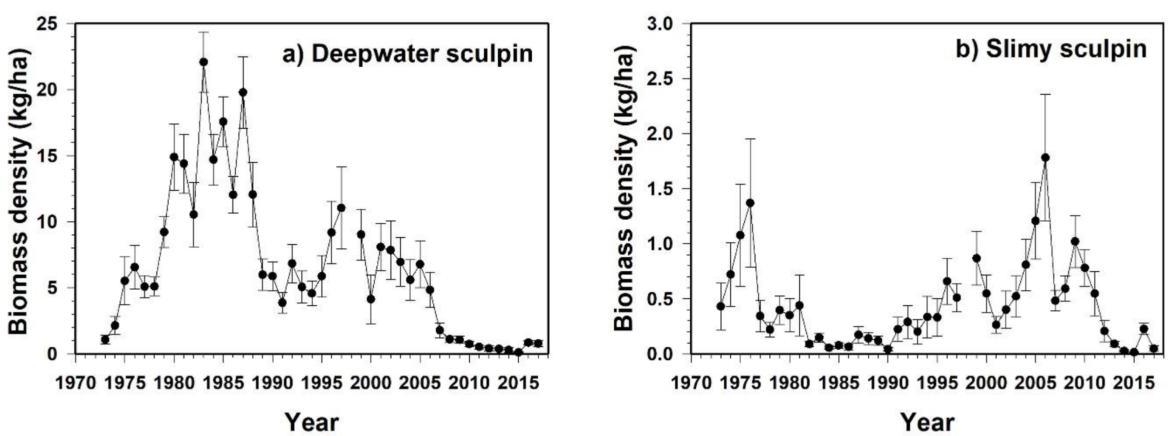

Figure 9. Biomass density (+/- standard error) for deepwater sculpin (a) and slimy sculpin (b) in Lake Michigan, 1973-2017.

Furthermore, because the deepwater sculpin has historically occupied deeper depths than any of the other prey fishes of Lake Michigan, a shift to waters deeper than 110 m would seem to be a reasonable explanation for the recent declines in deepwater sculpin densities. Our sampling at deeper depths has been supportive of this hypothesis. Since 2013, deepwater sculpins have been sampled in all 23 deep tows. Moreover, mean biomass densities at 73, 82, 91, 110, and 128 m were 0.16, 0.26, 0.61, 2.52, and 4.45 kg per ha, respectively, suggesting that the bulk of the deepwater sculpin population in Lake Michigan now occupies waters deeper than 110 m.

Slimy sculpin biomass density in 2017 was 0.05 kg per ha, which was nearly 5 times lower than the 2016 density. Overall, slimy sculpin biomass density has substantially declined since 2009 (Figure 9b). Slimy sculpin abundance in Lake Michigan is regulated, at least in part, by predation from juvenile lake trout (Madenjian et al. 2005b). We attribute the slimy sculpin recovery that occurred during the 1990s to, in part, the 1986 decision to emphasize stocking lake trout on offshore reefs (as opposed to the areas closer to shore where our survey samples, Madenjian et al. 2002). Likewise, the slimy sculpin decline that began in 2009 coincided with a substantial increase in the rate of stocking juvenile lake trout into Lake Michigan and an increase in natural reproduction by lake trout (FWS/GLFC 2017; Lake Michigan LTWG 2017). Since 2013, slimy sculpins have been sampled in 12 out of 23 deep tows. However, mean biomass density of slimy sculpins at 128 m was about 7 times lower than the peak mean biomass density at 82 m, and mean biomass densities at 73, 91, and 110 m were at least 5 times higher than that at 128 m. These results suggested that a relatively small proportion of the population resided in waters deeper than 110 m.

Round goby – The round goby (*Neogobius melanostomus*) is an invader from the Black and Caspian Seas. Round gobies have been observed in bays and harbors of Lake Michigan since 1993, and were captured in

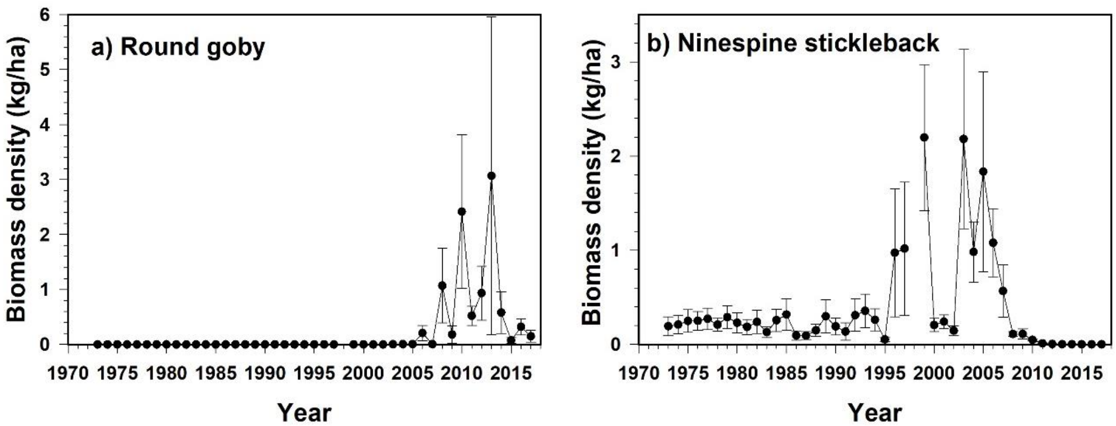

Figure 10. Biomass density (+/- standard error) of round goby (a) and ninespine stickleback (b) in Lake Michigan, 1973-2017.

the southern main basin of the lake as early as 1997 (Clapp et al. 2001). Round gobies were not captured in the GLSC bottom trawl survey until 2003; our survey likely markedly underestimates round goby abundance given their preferred habitat includes rocky and inshore (i.e., < 9 m bottom depth) areas that we do not sample. By 2002, round gobies had become an integral component of yellow perch diets at nearshore sites (i.e., < 15 m depth) in southern Lake Michigan. Recent studies have revealed round gobies are an important constituent of the diets of Lake Michigan burbot (Hensler et al. 2008; Jacobs et al. 2010), yellow perch (Truemper et al. 2006), smallmouth bass (*Micropterus dolomieu*, T. Galarowicz, Central Michigan University, personal communication), lake trout (Happel et al. 2018), and even lake whitefish (S. Hansen, Wisconsin DNR, personal communication).

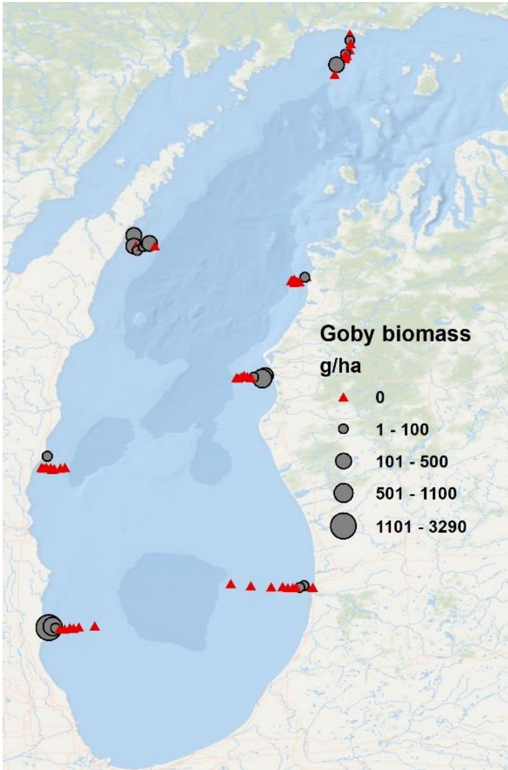

Figure 11. Scaled-symbol plot showing the biomass of round goby sampled at each of the 2017 bottom trawl sites.

Round goby biomass density equaled 0.15 kg per ha in 2017 (Figure 10a). Since 2011, round goby biomass density has ranged between 0.15 and 1.0 kg per ha in every year except for 2013 (due to a few extraordinarily large catches inflating the mean and causing high uncertainty) and 2015 (due to consistently low catches). Round goby were sampled at all seven ports in 2017 (Figure 11), with the highest mean biomass densities at the 9-m and 18-m bottom depths at Waukegan. We hypothesize that round goby abundance in Lake Michigan is now being controlled by predation. This hypothesis was supported by recent estimates of annual mortality rates of between 79 and 84% (Huo et al. 2014), which are comparable to the mortality rates currently experienced by Lake Michigan adult alewives (Tsehaye et al. 2014).

Ninespine stickleback – Two stickleback species occur in Lake Michigan. Ninespine stickleback (*Pungitius pungitius*) is native, whereas threespine stickleback (*Gasterosteus aculeatus*) is non-native and was first collected in the GLSC bottom trawl survey during 1984 (Stedman and Bowen 1985), but has been extremely rare in recent sampling years. Biomass density of ninespine stickleback in 2017 was only 0.7 g per ha, the second lowest estimate ever recorded (Figure 10b). Biomass of ninespine stickleback remained fairly low from 1973-1995 and then increased dramatically through 2007, perhaps attributable to dreissenid mussels enhancing ninespine stickleback spawning and nursery habitat through proliferation of *Cladophora* (Madenjian et al. 2010b). Since 2011, however, biomass has been maintained at or near record-low levels. One plausible explanation for the low ninespine stickleback abundance during 2008-2017 is that piscivores began to incorporate ninespine sticklebacks into their diets as the abundance of alewives has remained at a low level. For example, Jacobs et al. (2013) found ninespine sticklebacks in large Chinook salmon diets (i.e., 2% occurrence) during 2009-2010 after 0% occurrence in 1994-1996.

LAKE-WIDE BIOMASS

We estimated a total lake-wide biomass of prey fish available to the bottom trawl in 2017 of 13.3 kilotonnes (kt) (1 kt = 1000 metric tons) (Figure 12a, Appendix 1). Total prey fish biomass was the sum of the population biomass estimates for alewife, bloater, rainbow smelt, deepwater sculpin, slimy sculpin, ninespine stickleback, and round goby. Total prey fish biomass in Lake Michigan has trended downward since 1989, primarily due to a dramatic decrease in bloater biomass (Figure 12a). Total biomass first dropped below 30 kt in 2007, and has since remained below that level with the exception of 2013 (when the biomass estimates for alewife and round goby were highly uncertain).

As Figure 12b depicts, the 2017 prey fish biomass was apportioned as: bloater 68.8% (9.13 kt), deepwater sculpin 20.7% (2.75 kt), rainbow smelt 4.7% (0.62 kt), round goby 3.9% (0.52 kt), slimy sculpin 1.3% (0.17 kt), alewife 0.6% (0.09 kt), and ninespine stickleback 0.02% (0.002 kt).

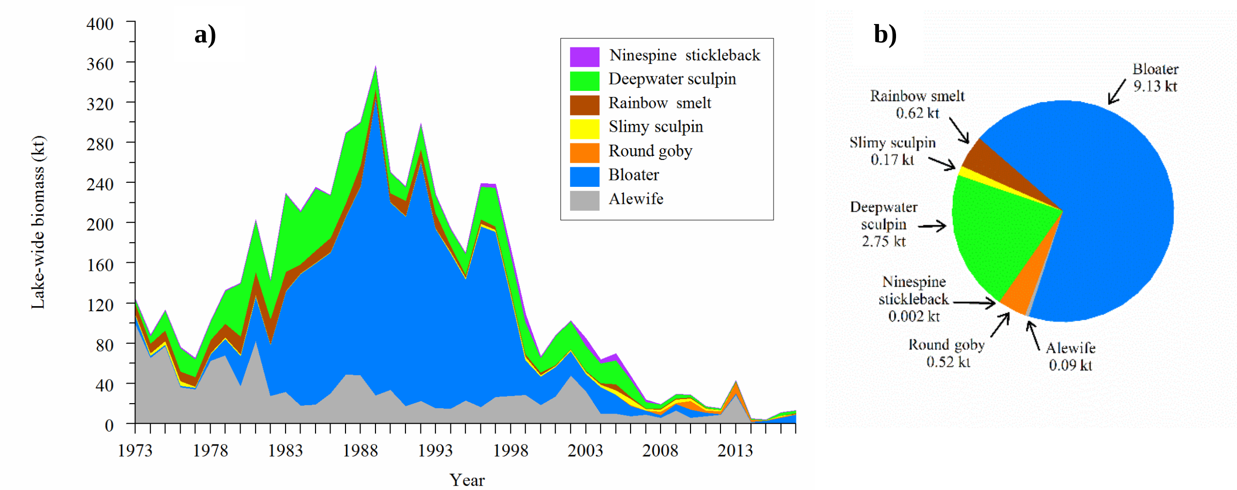

Figure 12. Estimated lake-wide (i.e., 5-114 m depth region) biomass of prey fishes in Lake Michigan, 1973-2017 (a) and species composition in 2017 (b).

OTHER SPECIES OF INTEREST

Burbot – Burbot and lake trout represent the native top predators in Lake Michigan. The decline in burbot abundance in Lake Michigan during the 1950s has been attributed to sea lamprey predation (Wells and McLain 1973). Sea lamprey control was a necessary condition for recovery of the burbot population in Lake Michigan, however Eshenroder and Burnham-Curtis (1999) proposed that a reduction in alewife abundance was an additional prerequisite for burbot recovery.

Burbot collected in the bottom trawls are typically large individuals (>350 mm TL); juvenile burbot apparently inhabit areas not usually covered by the bottom trawl survey. Burbot biomass density was 0.03 kg per ha in 2017, the lowest estimate since 1983 when none were captured. After a period of low biomass density in the 1970s, burbot showed a strong recovery in the 1980s (Figure 13a). Densities increased

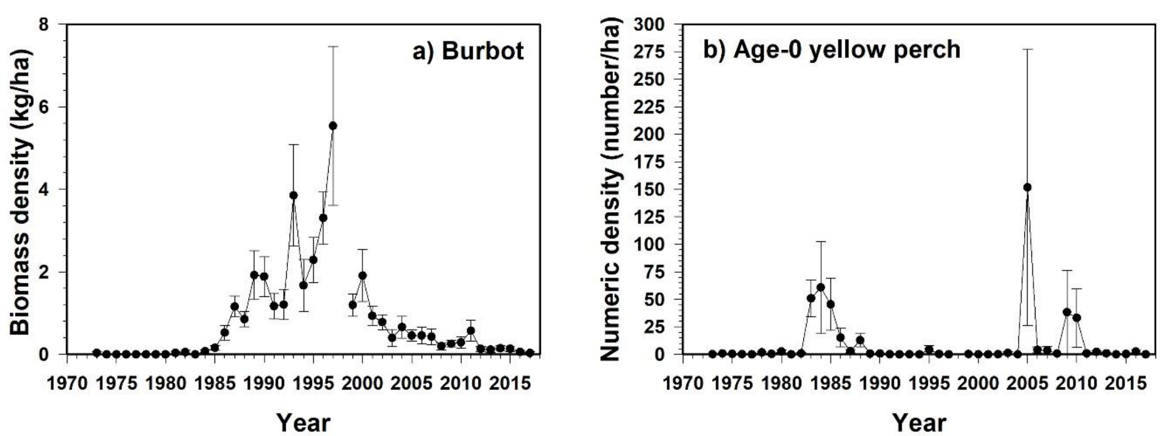

Figure 13. Biomass density (+/- standard error) of burbot (a) and numeric density (+/- standard error) of age-0 yellow perch (b) in Lake Michigan, 1973-2017.

through 1997, but declined thereafter. It is unclear why burbot catches in the bottom trawl survey have declined in the face of relatively low alewife densities. The continued burbot decline in the past 10 years may have been due to movement of a portion of the population to waters deeper than 110 m, as the mean biomass density at 128 m was comparable to the mean biomass density at shallower depths.

<u>Age-0 yellow perch</u> – The yellow perch population in Lake Michigan has supported valuable recreational and commercial fisheries (Wells 1977). GLSC bottom trawl surveys provide an index of age-0 yellow perch numeric density, which serves as an indication of yellow perch recruitment success. The 2005 year-class of yellow perch was the largest ever recorded (Figure 13b) and the 2009 and 2010 year-classes also were higher than average. In 2017, no age-0 yellow perch were caught, indicating a weak year-class.

CONCLUSIONS

In 2017, total prey fish biomass was estimated to be 13.3 kt, a 17% increase over 2016. The bulk of this increase was driven by the increasing biomass of the bloater population. The increase in rainbow smelt biomass also contributed to this increase in total prey fish biomass. Relative to previous years in the time series, however, total prey fish biomass for 2017 was still relatively low- the fourth lowest estimate ever.

This low level of prey fish biomass can be attributable to a suite of factors, two of which can be clearly identified: (1) a prolonged period of poor bloater recruitment for most of the years during 1992-2017 and (2) intensified predation on alewives by salmonines during the 2000s and 2010s. Adult alewife density has been maintained at a relatively low level over the last 14 years and the age distribution of the adult alewife population has become especially truncated in recent years. As recent as 2007, alewives as old as age 9 were sampled in this survey, whereas the oldest alewife sampled in 2013, 2014, and 2017 was age 5.

We also note that the striking decrease in deepwater sculpin biomass after 2006 appears to have been due, at least in part, to a substantial portion of the population moving to waters deeper than 110 m. Results from the deep tows that we have conducted since 2013 corroborate the contention that the bulk of the deepwater sculpin population in Lake Michigan now inhabits waters deeper than 110 m.

In addition to the importance of top-down forces, prey fishes also may be negatively influenced by reduced prey resources (i.e., “bottom-up” effects). For example, several data sets are indicating a reduction in the base of the food web, particularly for offshore total phosphorus and phytoplankton, as a consequence of long-term declines in phosphorus inputs and the proliferation of dreissenid mussels (Evans et al. 2011; Bunnell et al. 2014b). Grazing of phytoplankton by dreissenid mussels and reduced availability of phosphorus in offshore waters appeared to be the primary drivers of the 35% decline in primary production in offshore waters between the 1983-1987 and 2007-2011 periods (Madenjian et al. 2015; Rowe et al. 2017). The quagga mussel expansion into deeper waters may have been partly responsible for this reduced availability of phosphorus in offshore waters. The evidence for declines in “fish food” (e.g., zooplankton, benthic invertebrates) in offshore waters of Lake Michigan is somewhat less clear. *Diporeia* has undoubtedly declined in abundance (Nalepa et al. 2014), but whether or not crustacean zooplankton and mysids have declined depends on which data set is examined (e.g., Pothoven et al. 2010; Bunnell et al. 2014b; Madenjian et al. 2015). Crustacean zooplankton biomass density in nearshore waters appeared to decrease during 1998-2010, likely due to a reduction in primary production mainly stemming from grazing of phytoplankton by dreissenid mussels. The above-mentioned decline in *Diporeia* abundance appeared to have led to reductions in growth, condition, and/or energy density of lake whitefish, alewives, bloaters, and deepwater sculpins during the 1990s and 2000s (Pothoven et al. 2011, 2012; Madenjian et al. 2015). Of course, decreases in growth, condition, and energy density do not necessarily cause declines in fish abundance. The challenge remains to quantify bottom-up effects on prey fish abundances and biomasses in Lake Michigan. Given the complexities of the food web, disentangling the effects of the dreissenid mussel invasions and the reduction in nutrient loadings from other factors influencing the Lake Michigan food web will require a substantial amount of ecological detective work.

An emerging issue for Lake Michigan's prey fish base is whether the apparent recent increase in bloater recruitment will eventually translate into a long-term sustained increase in adult bloater biomass. Failure of these apparently large year-classes to recruit to the adult population could suggest that survival of age-1, age-2, and age-3 bloaters is sufficiently low to prevent buildup of the adult population, and this poor survival could be due to top-down or bottom-up forces, as well as other factors. Alternatively, failure to recruit to the adult population could reflect reduced catchabilities of large bloaters for both surveys.

ACKNOWLEDGMENTS

We thank Capt. Shawn Parsons and Engineers Erin Grivicich and Deirdre Jordan for their seamanship on our 2017 survey. We also greatly appreciate Deirdre's assistance in the wet laboratory. Reviews provided by Brad Eggold and Dan O'Keefe improved this report. We also thank Tim O'Brien and Lynn Ogilvie for assisting with the aging of the alewives.

REFERENCES

Adlerstein, S. A., E. S. Rutherford, D. Clapp, J. A. Clevenger, and J. E. Johnson. 2007. Estimating seasonal movements of Chinook salmon in Lake Huron from efficiency analysis of coded wire tag recoveries in recreational fisheries. N. Am. J. Fish. Manage. 27:792-803.

Argyle, R. L., G. W. Fleischer, G. L. Curtis, J. V. Adams, and R. G. Stickel. 1998. An Integrated Acoustic and Trawl Based Prey Fish Assessment Strategy for Lake Michigan. A report to the Illinois Department of Natural Resources, Indiana Department of Natural Resources, Michigan Department of Natural Resources, and Wisconsin Department of Natural Resources. U. S. Geological Survey, Biological Resources Division, Great Lakes Science Center, 1451 Green Road, Ann Arbor, MI USA.

Belonger, B. B. T. Eggold, P. Hirethota, S. Hogler, B. Horns, T. Kroeff, T. Lychwick, S. Marcquenski, P. Peters, S. Surendonk, and M. Toneys. 1998. Lake Michigan Management Reports, Wisconsin Department of Natural Resources. Lake Michigan Committee Meetings, Great Lakes Fishery Commission, Thunder Bay, Ontario, March 16-17, 1998.

Brown, E. H., Jr., and R. M. Stedman. 1995. Status of forage fish stocks in Lake Michigan, 1994. Pages 81-88 in Minutes of Great Lakes Fishery Commission, Lake Michigan Committee Meeting, Milwaukee, Wisconsin, March 29-30, 1995.

Bunnell, D. B., C. P. Madenjian, and T. E. Croley II. 2006a. Long-term trends of bloater recruitment in Lake Michigan: evidence for the effect of sex ratio. Can. J. Fish. Aquat. Sci. 63:832-844.

Bunnell, D. B., C. P. Madenjian, and R. M. Claramunt. 2006b. Long-term changes of the Lake Michigan fish community following the reduction of exotic alewife (*Alosa pseudoharengus*). Can. J. Fish. Aquat. Sci. 63:2434-2446.

Bunnell, D. B., S. R. David, and C. P. Madenjian. 2009. Decline in bloater fecundity in southern Lake Michigan after decline of *Diporeia*. J. Great Lakes Res. 35:45-49.

Bunnell, D. B., J. V. Adams, O. T. Gorman, C. P. Madenjian, S. C. Riley, E. F. Roseman, and J. S. Schaeffer. 2010. Population synchrony of a native fish across three Laurentian Great Lakes: evaluating the effects of dispersal and climate. Oecologia
162:641-651.

Bunnell, D. B., J. G. Mychek-Londer, and C. P. Madenjian. 2014a. Population-level effects of egg predation on a native planktivore in a large freshwater lake. Ecol. Freshw. Fish 23: 604-614.

Bunnell, D. B., R. P. Barbiero, S. A. Ludsin, C. P. Madenjian, G. J. Warren, D. M. Dolan, T.O. Brenden, R. Briland, O.T. Gorman, J. X. He, T. H. Johengen, B. F. Lantry, T. F. Nalepa, S. C. Riley, C. M. Riseng, T. J. Treska, I. Tsehaye, M. G. Walsh, D. M. Warner, and B. C. Weidel. 2014b. Changing ecosystem dynamics in the Laurentian Great Lakes: bottom-up and top-down regulation. BioScience 64:26-39.

Bunnell, D. B., B. M. Davis, M. A. Chriscinske, K. M. Keeler, and J. G. Mychek-Londer. 2015. Diet shifts by planktivorous and benthivorous fishes in northern Lake Michigan in response to ecosystem changes. Journal of Great Lakes Research 41(Suppl. 3): 161-171.

Bunnell, D. B., C. P. Madenjian, T. J. Desorcie, M. J. Kostich, P. Armenio, and J. V. Adams. 2017. Status and trends of prey fish populations in Lake Michigan, 2016. A report to the Great Lakes Fishery Commission, Lake Michigan Committee, Ypsilanti, MI, March 20, 2017.

Clapp, D. F., P. J. Schneeberger, D. J. Jude, G. Madison, and C. Pistis. 2001. Monitoring round goby (*Neogobius melanostomus*) population expansion in eastern and northern Lake Michigan. J. Great Lakes Res. 27:335-341.

Clark, R. D., Jr., J. R. Bence, R. M. Claramunt, J. A. Clevenger, M. S. Kornis, C. R. Bronte, C. P. Madenjian, and E. F. Roseman. 2017. Changes in movements of Chinook Salmon between Lakes Huron and Michigan after Alewife population collapse. N. Am J. Fish. Manage. 37:1311-1331.

Eck, G. W., and L. Wells. 1987. Recent changes in Lake Michigan's fish community and their probable causes, with emphasis on the role of the alewife *Alosa pseudoharengus* . Can. J. Fish. Aquat. Sci. 44(Suppl. 2):53-50.

Eshenroder, R. L. and M. K. Burnham-Curtis. 1999. Species succession and sustainability of the Great Lakes fish community. Pages 145-184 in W. W. Taylor and C. P. Ferreri (ed) Great Lakes Fisheries Policy and Management: A Binational Perspective. Michigan State University Press, East Lansing, MI.

Evans, M. A., G. Fahnenstiel, and D. Scavia. 2011. Incidental oligotrophication of North American Great Lakes. Environ. Sci. Technol. 45: 3297–3303.

Feiner, Z. S., D. B. Bunnell, T. O. Höök, C. P. Madenjian, D. M. Warner, and P. D. Collingsworth. 2015. Non-stationary recruitment dynamics of rainbow smelt: the influence of environmental variables and variation in size structure and length-at-maturation. J. Great Lakes Res. 41:246-258.

Fratt, T. W., D. W. Coble, F. Copes, and R. E. Brusewitz. 1997. Diet of burbot in Green Bay and western Lake Michigan with comparison to other waters. J. Great Lakes Res. 23:1-10.

FWS/GLFC. 2017. Great Lakes Fish Stocking database. U. S. Fish and Wildlife Service, Region 3 Fisheries Program, and Great Lakes Fishery Commission.

Happel, A., J. L. Jonas, P. R. McKenna, J. Rinchard, J. X. He, and S. J. Czesny. 2018. Spatial variability of lake trout diets in Lakes Huron and Michigan revealed by stomach content and fatty acid profiles. Can. J. Fish. Aquat. Sci. 75:95-105.

Hatch, R. W., P. M. Haack, and E. H. Brown, Jr. 1981. Estimation of alewife biomass in Lake Michigan, 1967-1978. Trans. Am. Fish. Soc. 110:575-584.

Hensler, S. R., D. J. Jude, and J. He. 2008. Burbot growth and diet in Lakes Michigan and Huron: an ongoing shift from native species to round gobies. Pages 91-107 in V. L. Paragamian and D. H. Bennett (ed) Burbot: Ecology, Management, and Culture. American Fisheries Society, Symposium 59, Bethesda, MD.

Huo, B., C. P. Madenjian, C. Xie, Y. Zhao, T. P. O'Brien, and S. J. Czesny. 2014. Age and growth of round gobies in Lake Michigan, with preliminary mortality estimation. J. Great Lakes Res. 40:712-720.

Jacobs, G. R., C. P. Madenjian, D. B. Bunnell, and J. D. Holuszko. 2010. Diet of lake trout and burbot in northern Lake Michigan during spring: evidence of ecological interaction. J. Great Lakes Res. 36:312-317.

Jacobs, G. R., C. P. Madenjian, D. B. Bunnell, D. M. Warner, and R. M. Claramunt. 2013. Chinook salmon foraging patterns in a changing Lake Michigan. Trans. Am. Fish. Soc. 142:362-372.

Jude, D. J., F. J. Tesar, S. F. DeBoe, and T. J. Miller. 1987. Diet and selection of major prey species by Lake Michigan salmonines, 1973-1982. Trans. Am. Fish. Soc. 116:677-691.

Lake Michigan LTWG. 2017. 2016 Lake Michigan Lake Trout Working Group Report. A report to the Great Lakes Fishery Commission, Lake Michigan Committee, Ypsilanti, MI, March 20, 2017.

Madenjian, C. P., and D. B. Bunnell. 2008. Depth distribution dynamics of the sculpin community in Lake Michigan. Trans. Am. Fish. Soc. 137:1346-1357.

Madenjian, C. P., T. J. DeSorcie, and R. M. Stedman. 1998. Ontogenic and spatial patterns in diet and growth of lake trout from Lake Michigan. Trans. Am. Fish. Soc. 127: 236-252.

Madenjian, C. P., G. L. Fahnenstiel, T. H. Johengen, T. F. Nalepa, H. A. Vanderploeg, G. W. Fleischer, P. J. Schneeberger, D. M. Benjamin, E. B. Smith, J. R. Bence, E. S. Rutherford, D. S. Lavis, D. M. Robertson, D. J. Jude, and M. P. Ebener. 2002. Dynamics of the Lake Michigan food web, 1970-2000. Can. J. Fish. Aquat. Sci. 60:736-753.

Madenjian, C. P., J. D. Holuszko, and T. J. Desorcie. 2003. Growth and condition of alewives in Lake Michigan, 1998-2001. Trans. Am. Fish. Soc. 132:1104-1116.

Madenjian, C. P., T. O. Höök, E. S. Rutherford, D. M. Mason, T. E. Croley II, E. B. Szalai, and J. R. Bence. 2005a. Recruitment variability of alewives in Lake Michigan. Trans. Am. Fish. Soc. 134:218-230.

Madenjian, C. P., D. W. Hondorp, T. J. Desorcie, and J. D. Holuszko. 2005b. Sculpin community dynamics in Lake Michigan. J. Great Lakes Res. 31:267-276.

Madenjian, C. P., S. A. Pothoven, J. M. Dettmers, and J. D. Holuszko. 2006. Changes in seasonal energy dynamics of alewife (*Alosa pseudoharengus*) in Lake Michigan after invasion of dreissenid mussels. Can. J. Fish. Aquat. Sci. 63:891-902.

Madenjian, C. P., R. O'Gorman, D. B. Bunnell, R. L. Argyle, E. F. Roseman, D. M. Warner, J. D. Stockwell, and M. A. Stapanian. 2008. Adverse effects of alewives on Laurentian Great Lakes fish communities. N. Am. J. Fish. Manage. 28:263-282.

Madenjian, C. P., D. B. Bunnell, J. D. Holuszko, T. J. Desorcie, and J. V. Adams. 2010a. Status and trends of prey fish populations in Lake Michigan, 2009. A report to the Great Lakes Fishery Commission, Lake Michigan Committee, Windsor, Ontario, March 23, 2010.

Madenjian, C. P., D. B. Bunnell, and O. T. Gorman. 2010b. Ninespine stickleback abundance in Lake Michigan increases after invasion of dreissenid mussels. Trans. Am. Fish. Soc. 139:11-20.

Madenjian, C. P., D. B. Bunnell, D. M. Warner, S. A. Pothoven, G. L. Fahnenstiel, T. F. Nalepa, H. A. Vanderploeg, I. Tsehaye, R. M. Claramunt, and R. D. Clark, Jr. 2015. Changes in the Lake Michigan food web following dreissenid mussel invasions: a synthesis. J. Great Lakes Res. 41(Suppl. 3):217-231.

Nalepa, T. F., D. L. Fanslow, G. A. Lang, K. Mabrey, and M. Rowe. 2014. Lake-wide benthic surveys in Lake Michigan in 1994-1995, 2005, and 2010: abundances of the amphipod Diporeia spp. and abundances and biomass of the mussels Dreissena polymorpha and Dreissena rostriformes bugensis. NOAA Technical Memorandum GLERL-164.

Pothoven, S. A., G. L. Fahnenstiel, H. A. Vanderploeg. 2010. Temporal trends in Mysis relicta abundance, production, and life-history characteristics in southeastern Lake Michigan. J. Great Lakes Res. 36(Suppl. 3):60-64.

Pothoven, S. A., D. W. Hondorp, T. F. Nalepa. 2011. Declines in deepwater sculpin Myoxocephalus thompsonii energy density associated with the disappearance of Diporeia spp. in lakes Huron and Michigan. Ecol. Freshw. Fish 20: 14-22.

Pothoven, S. A., D. B. Bunnell, C. P. Madenjian, O. T. Gorman, E. F. Roseman. 2012. Energy density of bloaters in the upper Great Lakes. Trans. Am. Fish. Soc. 141: 772-780.

Potter, R. L. and G. W. Fleischer. 1992. Reappearance of spoonhead sculpins (Cottus ricei) in Lake Michigan. J. Great Lakes Res. 18:755-758.

Rowe, M. D., E. J. Anderson, H. A. Vanderploeg, S. A. Pothoven, A. K. Elgin, J. Wang, and F. Yousef. 2017. Influence of invasive quagga mussels, phosphorus loads, and climate on spatial and temporal patterns of productivity in Lake Michigan: A biophysical modeling study. Limnol. Oceanogr. 62:2629-2649.

Smith, S. H. 1970. Species interactions of the alewife in the Great Lakes. Trans. Am. Fish. Soc. 99:754-765.

Stedman, R. M., and Bowen, C. A. 1985. Introduction and spread of the threespine stickleback (Gasterosteus aculeatus) in lakes Huron and Michigan. J. Great Lakes Res. 11:508-511.

Stewart, D. J., and M. Ibarra. 1991. Predation and production by salmonine fishes in Lake Michigan, 1978-88. Can. J. Fish. Aquat. Sci. 48:909-922.

Stewart, D. J., D. Weininger, D. V. Rottiers, and T. A. Edsall. 1983. An energetics model for lake trout, Salvelinus namaycush: application to the Lake Michigan population. Can. J. Fish. Aquat. Sci. 40:681-698.

Truemper, H. A., T. E. Lauer, T. S. McComish, and R. A. Edgell. 2006. Response of yellow perch diet to a changing forage base in southern Lake Michigan, 1984-2002. J. Great Lakes Res. 32:806-816.

Tsehaye, I., M. L. Jones, J. R. Bence, T. O. Brenden, C. P. Madenjian, and D. M. Warner. 2014. A multispecies statistical age-structured model to assess predator-prey balance: application to an intensively managed Lake Michigan pelagic fish community.Can. J. Fish. Aquat. Sci. 71:627-644.

Van Oosten, J., and H. J. Deason. 1938. The food of the lake trout (Cristivomer namaycush) and of the lawyer (Lota maculosa) of Lake Michigan. Trans. Am. Fish. Soc. 67:155-177.

Warner, D. M., C. S. Kiley, R. M. Claramunt, and D. F. Clapp. 2008. The influence of alewife year-class strength on prey selection and abundance of age-1 Chinook salmon in Lake Michigan. Trans. Am. Fish. Soc. 137:1683-1700.

Warner, D. M., B. Turschak, D. Hanson, P. Armenio, J. Smith, S. Farha, and K. Phillips. 2018. Status of pelagic prey fishes in Lake Michigan, 2017. A report to the Great Lakes Fishery Commission, Lake Michigan Committee, Sault Ste. Marie, Ontario, March 22, 2018.

Wells, L. 1977. Changes in yellow perch (Perca flavescens) populations of Lake Michigan, 1954-75. J. Fish. Res. Board Can. 34:1821-1829.

Wells, L., and A. L. McLain. 1973. Lake Michigan: man's effects on native fish stocks and other biota. Great Lakes Fishery Commission. Technical Report 20. 56 p.

Williams, M. C. 2012. Spatial, temporal, and cohort-related patterns in the contribution of wild Chinook salmon (Oncorhynchus tshawytscha) to total Chinook harvest in Lake Michigan. M.S. Thesis. Michigan State University, East Lansing, Michigan.

Appendix 1. Mean numeric and biomass density, as well as lake-wide biomass (defined as biomass available to the bottom trawls for the region of the main basin between the 5-m and 114-m depth contours) estimates for various fishes and dreissenid mussels in Lake Michigan during 2017. Estimates are based on the bottom trawl survey. Standard error enclosed in parentheses. NA denotes that estimate is not available.

Taxon	Numeric density (fish per ha)	Biomass density (kg per ha)	Lake-wide biomass (kt)
age-0 alewife	0.05 (0.05)	0.0001 (0.0001)	0.0002 (0.0002)
adult alewife	0.93 (0.27)	0.024 (0.008)	0.085 (0.027)
age-0 bloater	67.86 (38.77)	0.563 (0.320)	1.982 (1.126)
adult bloater	117.22 (64.65)	2.028 (0.914)	7.144 (3.217)
age-0 rainbow smelt	138.32 (87.65)	0.057 (0.039)	0.199 (0.137)
adult rainbow smelt	10.26 (7.84)	0.121 (0.103)	0.425 (0.364)
deepwater sculpin	89.34 (18.51)	0.780 (0.245)	2.745 (0.861)
slimy sculpin	7.37 (3.65)	0.048 (0.025)	0.169 (0.089)
ninespine stickleback	0.32 (0.16)	0.0007 (0.0004)	0.002 (0.001)
burbot	0.01 (0.01)	0.031 (0.031)	0.109 (0.109)
age-0 yellow perch	0 (0)	0 (0)	0 (0)
round goby	15.18 (8.59)	0.147 (0.107)	0.517 (0.377)
dreissenid mussels	NA	22.319 (21.063)	78.598 (74.176)

Status of Pelagic Prey Fishes in Lake Michigan, 2017[1]

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ABSTRACT
Acoustic surveys were conducted in late summer/early fall during the years 1992-1996 and 2001-2017 to estimate pelagic prey fish biomass in Lake Michigan. Midwater trawling during the surveys as well as target strength provided a measure of species and size composition of the fish community for use in scaling acoustic data and providing species-specific abundance estimates. The 2017 survey consisted of 29 acoustic transects [711 km total (442 miles)] and 40 midwater trawl tows. Mean prey fish biomass was 7.99 kg/ha [38.9 kilotonnes (kt = 1,000 metric tons)], which was 46% higher than in 2016 and 35% of the long-term (22 years) mean. The numeric density of the 2017 alewife year-class was 27% of the time series average and 60% times the 2016 density. This year-class contributed 15% of total alewife biomass (4.4 kg/ha). In 2017, alewife comprised 55% of total prey fish biomass, while rainbow smelt and bloater were 32% and 14 % of total biomass, respectively. Rainbow smelt biomass in 2017 (1.0 kg/ha) was 29% of the long-term mean and increased for the second time since 2008. Bloater biomass in 2017 was 2.5 kg/ha and 32% of the long-term mean. Mean density of small bloater in 2017 (120 fish/ha) was 80% of the long-term mean. Biomass density of large bloater increased to 2.2 kg/ha in 2017. This remains much lower than in the 1990s but likely shows evidence of recruitment of small fish observed in the past 5 years. Although prey fish biomass remains low relative to the 1990s, it did increase in 2017.

[1]Presented at Great Lakes Fishery Commission, Lake Michigan Committee Meeting, Sault Ste. Marie, ON on March 22, 2018.

INTRODUCTION

Annual evaluation of long-term data on prey fish dynamics is critical in light of changes to the Lake Michigan food web during the last 40 years (Madenjian et al. 2002) and continued restructuring due to exotic species, pollution, fishing, and fish stocking. Alewives are the primary prey in Lake Michigan and of especial importance to introduced salmonines in the Great Lakes (Elliott 1993; Rybicki and Clapp 1996; Warner et al. 2008; Jacobs et al. 2013), however they are also predators of larval fish and are tied to thiamine deficiencies that contribute to recruitment bottlenecks in native fishes including lake trout (*Salvelinus namaycush*). As such, alewives constitute an important component of the food-web. The traditional Great Lakes Science Center (GLSC) prey fish monitoring method (bottom trawl) is inadequate for fish located off bottom (Fabrizio et al. 1997). In particular, bottom trawls provide particularly biased estimates for age-0 alewives (*Alosa pseudoharengus*) based on catchability estimates from stock assessment modeling (Tsehaye et al. 2014). Much of the alewife biomass will not be recruited to bottom trawls until age-3 (Madenjian et al. 2005), but significant predation by salmonines may occur on alewives ≤ age-2 (Warner et al. 2008). Alewife abundance patterns are largely driven by the age-classes that are not effectively sampled by bottom trawls; total alewife density is highly correlated with the density of alewife ≤ age-2 (Warner et al. 2008). Because of the ability of acoustic equipment to count organisms far above bottom, this type of sampling is ideal for highly pelagic fish like age-0 alewives, rainbow smelt (*Osmerus mordax*), and bloater (*Coregonus hoyi*) and is a valuable complement to bottom trawl sampling. Further, these two long-term surveys have enabled the development of a stock assessment model for alewife (Tsehaye et al. 2014).

METHODS

Sampling Design

The initial Lake Michigan survey adopted by the Lake Michigan Technical Committee (Fleischer et al. 2001) was a stratified quasi-random design with three strata (north, south-central, and west) and unequal effort allocated among strata. The location of strata and number of transects within each stratum was determined from a study of geographic distribution of species and the variability of fish abundance within strata (Adams et al. 2006). A modified design was developed in 2004 (Warner et al. 2005), which included two additional strata (north and south offshore). The initial three strata were retained, but their size was modified based on data collected in 2003 as well as NOAA Coast Watch Great Lakes node maps of sea surface temperature from 2001-2003. In 2007-2016, the number of transects in each stratum was optimized based on stratum area and standard deviation of biomass using methods in Adams et al. (2006). The collection and analytical approach for 2017 acoustic and midwater trawl data was similar to that in 2004-2016. For a detailed description of the methods see Warner et al. (2009) and Warner et al. (2014). In short, each survey vessel samples along transects using scientific echosounders for estimation of total fish density. While sampling those transects, we use midwater trawls to collect fish, which enables us to determine species, size, and (in the case of alewife), age composition. We used ages estimated for fish from both the acoustic survey and bottom trawl survey to create an age-length key. Prior to 2005 ages were only available from the bottom trawl survey. The age-length key was used to estimate the age composition of the catch for each midwater tow based on the length composition of alewife in each tow. The numeric density of fish [fish per hectare (ha)] is split among the species captured in the trawls except in water >40 m below the surface, where species are determined using target strength

RESULTS

The 2017 acoustic survey of Lake Michigan was conducted by the United States Geological Survey (USGS), the United States Fish and Wildlife Service (USFWS), the Michigan Department of Natural Resources (MDNR), and the Little Traverse Bay Band of Odawa Indians (LTTBOI). The main basin sampling consisted of 40 midwater trawl tows and 29 transects for a total transect distance of 711 km, which was similar to the distance sampled in 2016. The bottom range over which acoustic data were collected was 12-231 m (39-758 ft). Survey locations are shown in Figure 1.

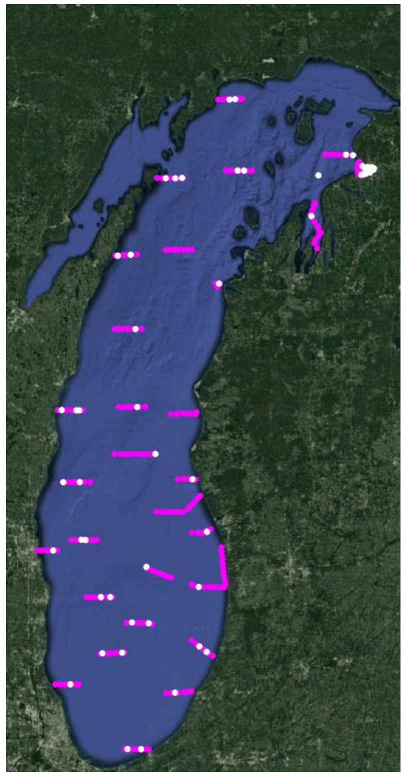

Figure 1. Location of acoustic (magenta symbols) and midwater trawl (white symbols) samples in the 2017 acoustic survey of Lake Michigan.

<u>Alewife</u> – Ages were estimated for 367 alewife ranging from 60-202 mm total length. These fish were captured during both the acoustic survey and bottom trawl survey. Ages in this sample ranged from 0-6 years old. The age-6 fish made up only 0.3% of all aged fish and came from non-standard deep bottom tows not included in the bottom trawl reporting and were very large (around 200 mm) relative to any of the alewife caught in the midwater trawling during the acoustic survey. The length composition of alewife in the acoustic survey were such that none were older than age-5. No alewife <85 mm was older than age-0. Fish older than age-2 made up <3% of the population numerically, which means very few of the alewife in the population are of reproductive age.

The numeric density of the 2017 alewife year-class in 2017 was 60% the density of age-0 alewife in 2016 and was identical to the density observed in 2015. At 277 fish/ha, the 2017 estimate was 27% of the long-term mean. The biomass density of age-1 or older alewife was 3.8 kg/ha (Figure 2), which was 41% of the long-term mean and 18% higher than in 2016. The biomass of alewife ≥ age-1 was predominantly the 2016 (63%) and 2015 (32%) year classes. The acoustic biomass density estimate for all alewife was approximately 182 times the bottom trawl estimate in 2017 (Madenjian et al. 2018) and over the time series (years in which both surveys took place), the acoustic estimates have been greater than the bottom trawl estimates 82% of the time (18 of 22 years). The bottom trawl alewife biomass has been 66% of the acoustic estimate on average but the difference has become much larger in 2014-2017. Although we observed lower than average density of alewife in Lake Michigan, the density is still much higher than the density of alewife in Lake Huron as no alewife were caught during the Lake Huron acoustic survey (O'Brien et al. 2018).

Spatial patterns in YOY and YAO alewife indicate that these fish have a patchy distribution (Figure 3). Highest numeric densities of YOY alewife were observed in the southern third of the lake with the maximum observed near Michigan City, Indiana.

Densities were much lower in the northern 2/3 of the lake with the exception of the areas near Ludington, Point Betsie, and Little Traverse Bay in Michigan. Densities of YAO alewife were highest in the southeastern portion of the lake in areas closer to shore, followed by the northern ¼ of the lake and Grand Traverse Bay, Michigan.

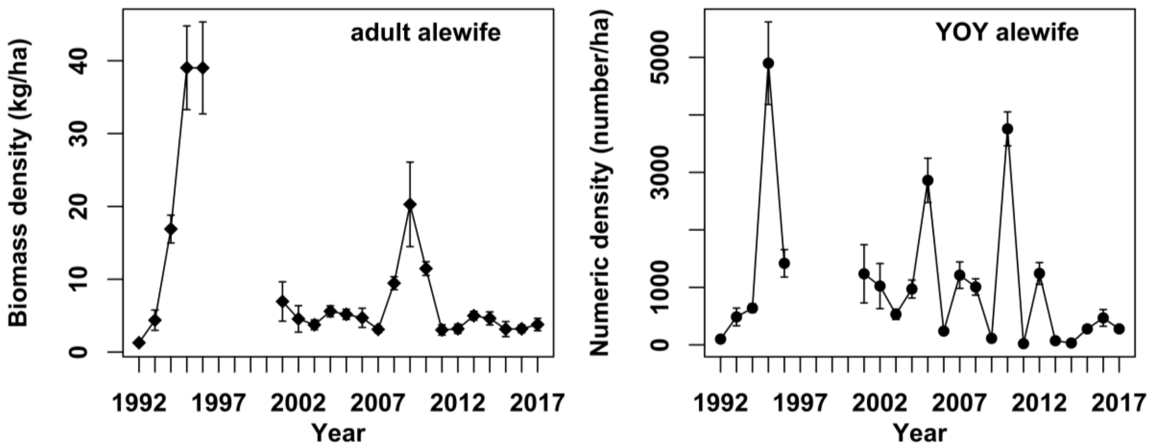

Figure 2. Biomass density of age-1 or older alewife (left panel) and Numeric density of age-0 alewife (right panel) in Lake Michigan during 1992-1996 and 2001-2017 (no sampling in 1997-2000). Error bars show one standard error.

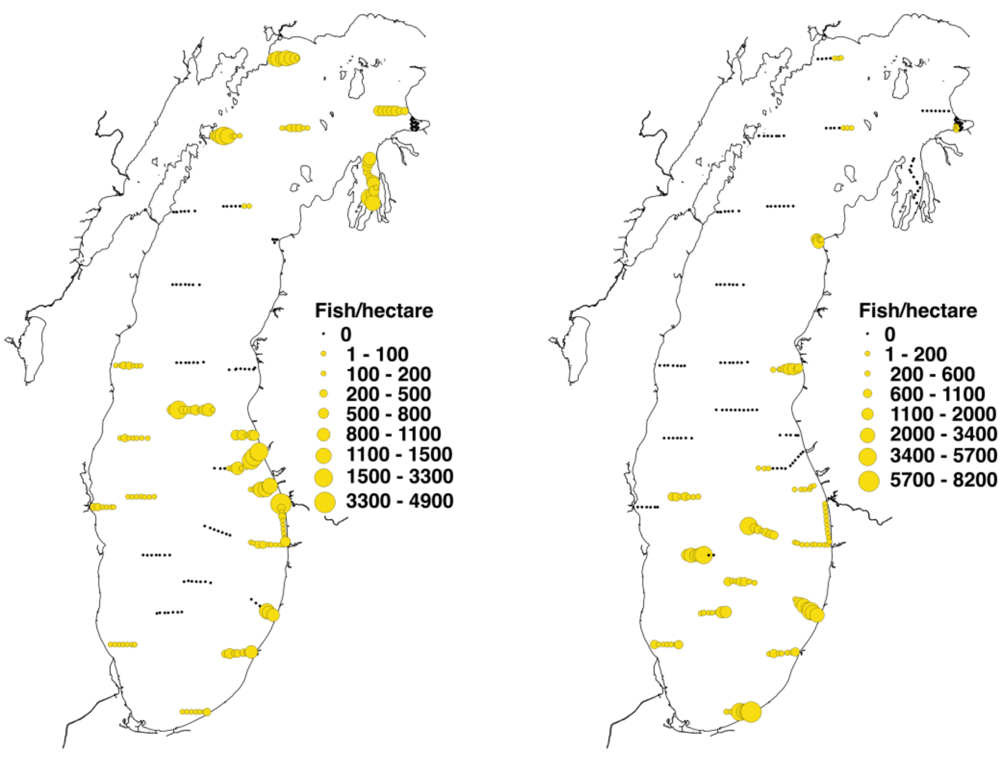

Figure 3. Map of numeric density of YAO alewife (left map) and YOY alewife (right map) during August 2017. Symbol size corresponds to the acoustic estimate of density. Black symbols represent zero values.

<u>Rainbow smelt</u> –At 209 fish/ha, numeric density of small rainbow smelt (<90 mm) in 2017 (Figure 4) was slightly higher than that observed 2016. This density was almost identical to the time series mean of 204 fish/ha. Similarly, at 0.95 kg/ha, biomass density of large rainbow smelt (≥90 mm) increased from that observed in 2016. This was the third consecutive year of increase for small rainbow smelt and the second for large rainbow smelt. Even though acoustic biomass density estimates of large smelt have always exceeded bottom trawl estimates, both surveys show there was an order of magnitude decrease from 1992-1996 to 2001-2014 (Bunnell et al. 2015).

Recent low biomass is in stark contrast to observations from the late 1980s (Argyle 1992) but are consistent with the findings of Warner et al. (2012), who reported a shift in the pelagic fish community away from rainbow smelt numeric dominance in the mid-1990s following this period of dominance in the late 1980s.

Spatial patterns in rainbow smelt density differed from alewife. Small rainbow smelt were distributed throughout much of the lake at low density but were absent from several parts of the lake (Figure 5). Large rainbow smelt were much more limited in their distribution, with none observed in approximately the southern half of the lake.

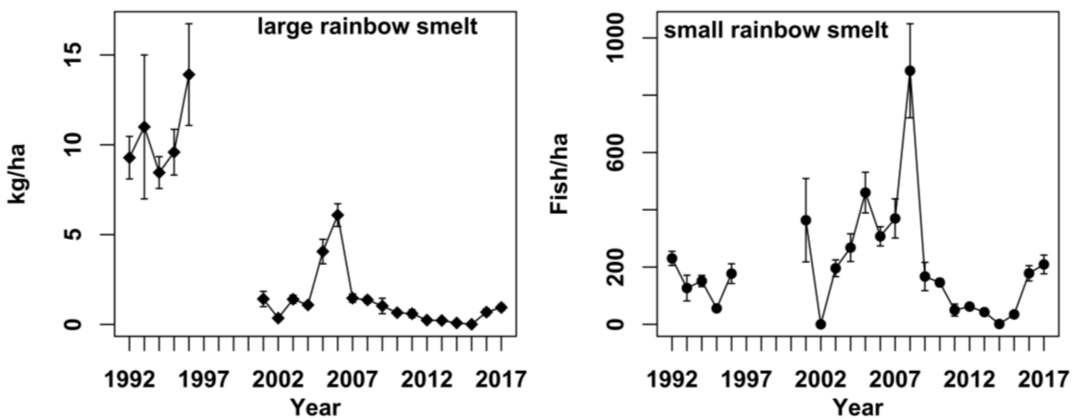

Figure 4. Biomass density of large rainbow smelt (≥90 mm, left panel) and numeric density of small rainbow smelt (<90 mm, right panel) in Lake Michigan during 1992-1996 and 2001-2017 (no sampling in 1997-2000). Error bars show one standard error.

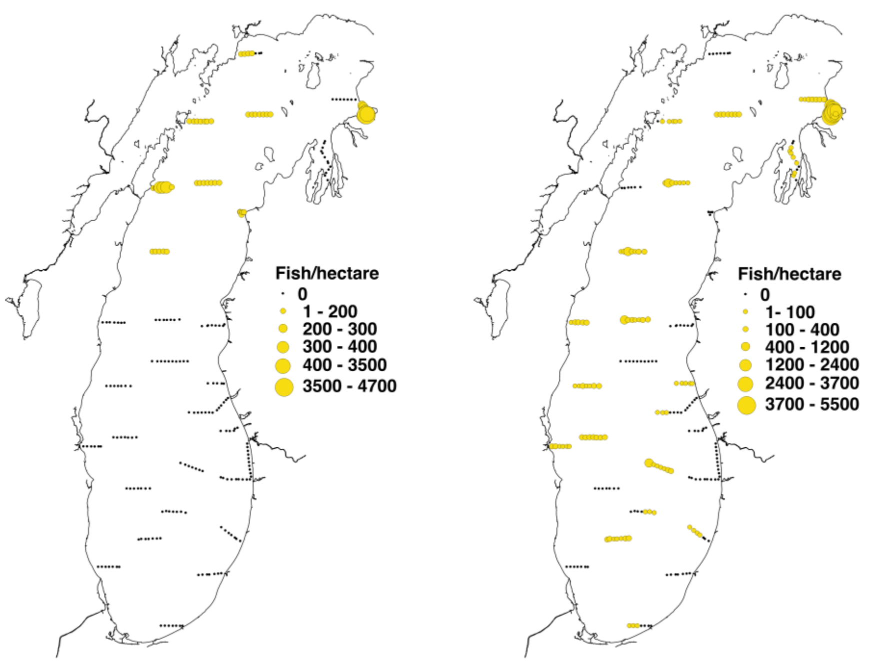

Figure 5. Map of numeric density of large rainbow smelt (>90 mm total length, left map) and small rainbow smelt (right map) during August 2017. Yellow symbol size corresponds to the acoustic estimate of density. Black symbols represent zero values.

Bloater –Densities of both small and large bloater have been variable in 2001-2017. Mean numeric density of small bloater in 2017 (120 fish/ha) was 81% the time series mean (Figure 6). Biomass density of large bloater in 2017 was 2.2 kg/ha, which was 27% of the time series mean, and 7% of the mean in 1992-1996. Bloater biomass has been only 16% of total prey fish biomass density in 2001-2017, on average. This is in contrast to the 1992-1996 period, when bloater made up 48% of total prey fish biomass density. For 13 of 22 years acoustic estimates of biomass density of large bloater were lower than bottom trawl estimates (Madenjian et al. 2018). In the 1992-2006 period the acoustic estimates averaged 43% of the bottom trawl estimates but in the 2007-2017 period acoustic estimates have been on average 3.7 times bottom trawl estimates. However, in 2017, the estimates were similar at 2.5 kg/ha for the acoustic survey and 2.6 kg/ha for the bottom trawl survey (Madenjian et al. 2018).

Spatial patterns in bloater indicated different distributions for small and large bloater (Figure 7). High densities of small bloater were generally in the southern half of the lake, with highest values in the southeastern part of the lake. Large bloater were less restricted in distribution but had highest densities in the eastern portion of the central lake.

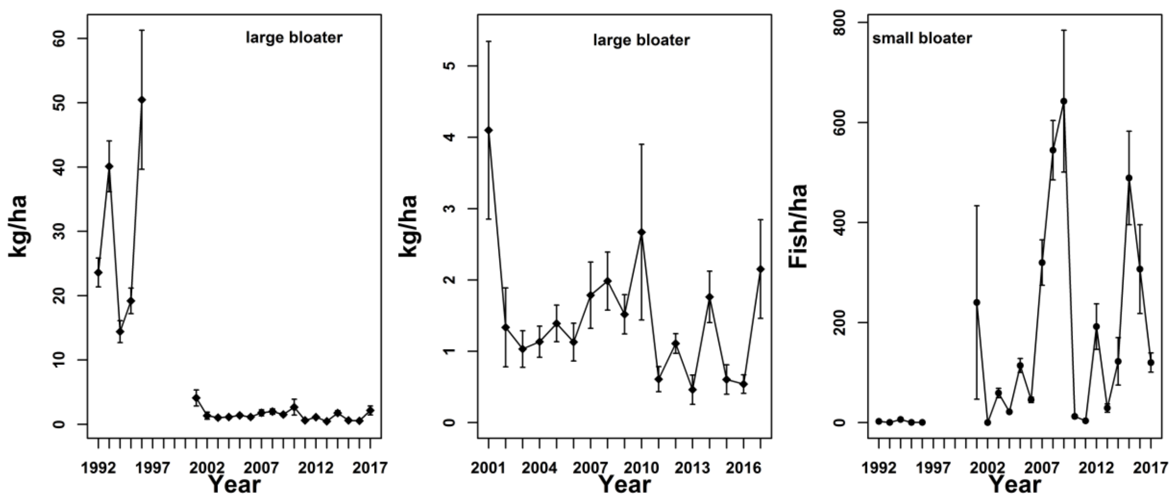

Figure 6. Biomass density of large bloater (≥120 mm, left panel) from 1992-2017 (no sampling in 1997-2000, left panel), biomass density of large bloater for the years 2001-2017 (middle panel), and numeric density of small bloater (<120 mm, right panel) from 1992-2017 in Lake Michigan. Error bars show one standard error.

ASSUMPTIONS

As with any survey, it is important to note that bottom trawl or acoustic estimates of fish density are potentially biased and, when possible, we should describe the effects of any bias when interpreting results. With acoustic sampling, areas near the surface (upper blind zone 0-4 m) or near the bottom (bottom dead zone, bottom 0.3-1 m) are not sampled well or at all. The density of fish in these areas therefore is unknown. Recent technological advances allow for acoustic sampling of the upper blind zone over large spatial areas but the cost of this technology has been prohibitive. While our highest alewife and rainbow smelt catches and catch-per-unit-effort with midwater tows generally occur near the thermocline in Lake Michigan (Warner et al. 2008; Warner et al. 2012), it is possible that some are located in the top 4 m and can't be captured with trawls because the ship displaces this water and the fish.

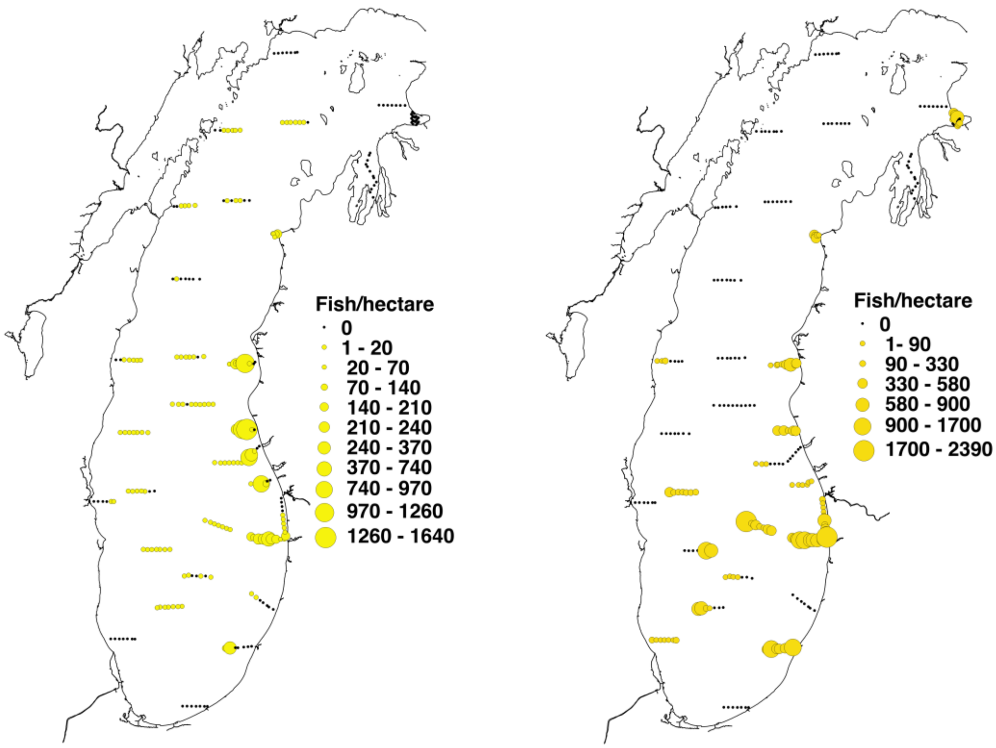

Figure 7. Map of numeric density of large bloater bloater (>120 mm total length, left map) and small bloater (right map) during August 2017. Symbol size corresponds to the acoustic estimate of density. Black symbols represent zero values.

We are less concerned with bias in alewife and rainbow smelt densities attributable to ineffective acoustic sampling of the bottom because of their pelagic distribution at night, when our sampling occurs. In Lake Michigan, day-night bottom trawling was conducted at numerous locations and depths in 1987 (Argyle 1992), with day and night tows occurring on the same day. These data indicate that night bottom trawl estimates of alewife density in August/September 1987 were only 6% of day estimates (https://doi.org/10.5066/F75M63X0). Similarly, night bottom trawl estimates of rainbow smelt density were ≈ 6% of day estimates. Disparities between day and night bottom trawl data demonstrate that alewife and rainbow smelt make an upward diel vertical migration at night in Lake Michigan which facilitates accurate sampling using acoustics and midwater trawling. However, bloaters tend to be more demersal; in Lake Superior, night acoustic/midwater trawl sampling may detect only 60% of bloater present (Yule et al. 2007). The day-night bottom trawl data from Lake Michigan in 1987 suggested that the availability of bloater to acoustic sampling at night was somewhat higher (mean = 76%, D. M. Warner, unpublished data). Slimy sculpins (*Cottus cognatus*) and deepwater sculpins (*Myoxocephalus thompsonii*) are poorly sampled acoustically and we must rely on bottom trawl estimates for these species (Yule et al. 2008). We also assumed that our midwater trawling provided accurate estimates of species and size composition. Based on the relationship between trawling effort and uncertainty in species proportions observed by Warner et al. (2012), this assumption was likely reasonable.

We made additional assumptions about acoustic data not described above. For example, we assumed that all targets below 40 m with mean target strength (TS) > -45 dB were bloater. It is possible that this resulted in a slight underestimation of rainbow smelt density. We also assumed that conditions were suitable for use of *in situ* TS to estimate fish density, which could also lead to biased results if conditions are not suitable for measuring TS (Rudstam et al. 2009; Sawada et al. 1993) and biased TS estimates are used. However, we used the Nv index of Sawada et al. (1993) to identify areas where bias was likely. We assumed that noise levels did not contribute significantly to echo integration data and did not preclude detection of key organisms. Detection limits were such that the smallest fish were detectable well below the depths they typically occupy. Finally, we have assumed that the estimates of abundance and biomass are relative and do not represent absolute measures. This assumption is supported by recent estimates of catchability derived from a multispecies age structured stock assessment model (Tsehaye et al. 2014). Even though subject to various biases, our stratified random sampling design and use of standardized data processing techniques allow for comparisons of prey fish abundance estimates between years and throughout the time series.

SUMMARY

The long-term pattern in total preyfish biomass has been a decrease (Figure 8), with the current estimate, 7.99 kg/ha, being much lower than values in the 1990s and only 35% of the survey mean. There has been and continues to be debate about the causes of this decline, with some arguing the cause is bottom-up limitation and others arguing the cause is predation (top-down). The states surrounding Lake Michigan have made several cuts to predator stocking as a result of this pattern in an effort to promote a better balance between the demand for prey and the availability of prey in the system. How this balance plays out in the future remains to be seen. While alewife biomass has stopped declining and even increased slightly from 2015, and both bloater and rainbow smelt biomass have increased, the vast majority of the alewife population in 2017 was not sexually mature, which likely had a negative impact in year class size. This limitation to year potential year class strength is likely to persist as long as the alewife population remains young and small in size.

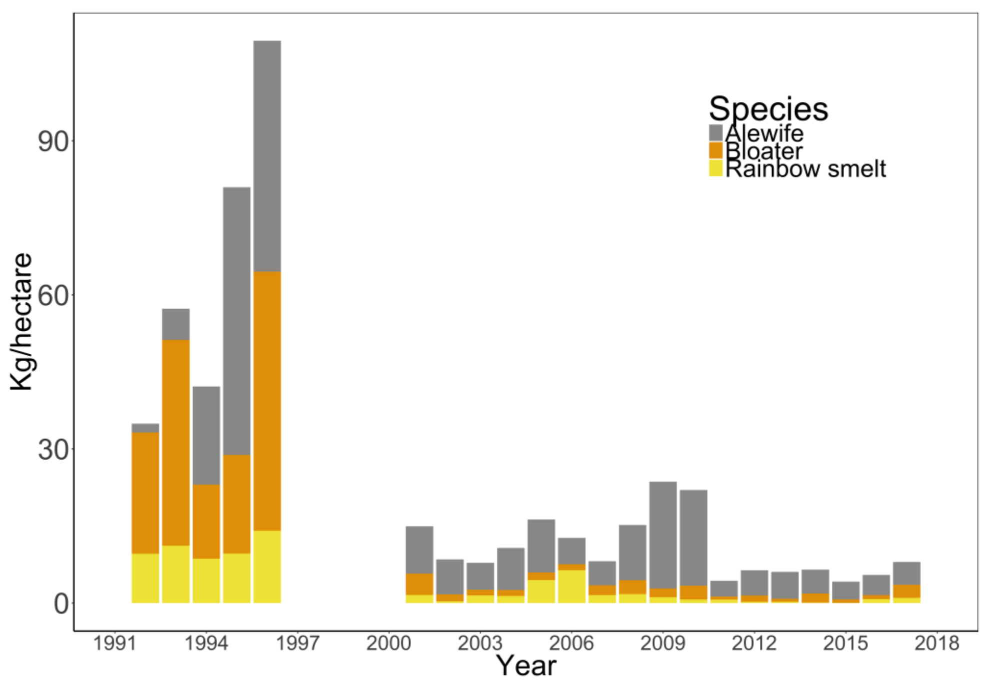

Figure 8. Total preyfish biomass density estimated for the acoustic survey of Lake Michigan, 1992-2017 (no sampling in 1997-2000).

Acknowledgements
We thank the crews of the research vessels M/V Spencer F. Baird, S/V Steelhead, and R/V Sturgeon as well as reviewers for their contributions to this work. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government. A portion of the funding for this work is provided through the Sport Fish Restoration Project #230485.

NOTICE

The acoustic data associated with this report have not received final approval by the U.S. Geological Survey (USGS) and are currently under review. However, the trawl data associated with this report have met final approval by USGS. The Great Lakes Science Center is committed to complying with the Office of Management and Budget data release requirements and providing the public with high quality scientific data. The trawl data associated with this report are available at: U.S. Geological Survey, Great Lakes Science Center, 2018, Great Lakes Research Vessel Operations 1958-2017 (ver. 2.0, March 2018): U.S. Geological Survey Data Release, https://doi.org/10.5066/F75M63X0.

All GLSC sampling and handling of fish during research are carried out in accordance with guidelines for the care and use of fishes by the American Fisheries Society (http://fisheries.org/docs/wp/Guidelines-for-Use-of-Fishes.pdf).

Table 1. Numeric or biomass density, RSE, and 95% CI for age-0, YAO, total alewife, rainbow smelt, and bloater estimated from acoustic and midwater trawl data collected in Lake Michigan in 2017.

Species	Density	RSE (%)	95% CI
Total alewife	4.4 kg/ha	21	(2.8, 6.0)
Age-0 alewife	277 fish/ha	22	(175, 380)
YAO alewife	3.8 kg/ha	22	(2.3, 5.2)
Rainbow smelt	338 fish/ha	16	(248, 428)
Bloater	2.5 kg/ha	27	(1.4, 3.7)
Total	8.0 kg/ha	15	(5.9, 10.1)

REFERENCES

Adams, J.V., R.L. Argyle, G.W. Fleischer, G.L. Curtis, and R.G. Stickel. 2006. Improving the design of acoustic and midwater trawl surveys through stratification, with an application to Lake Michigan prey fishes. North American Journal of Fisheries Management 26:612-621.

Argyle, R.L. 1992. Acoustics as a tool for the assessment of Great Lakes Forage fishes. Fisheries Research 14:179-196.

Elliott, R.F. 1993. Feeding habits of Chinook salmon in eastern Lake Michigan. M.Sc. thesis. Michigan State University, East Lansing, MI.

Fabrizio, M.C., J.V. Adams, and G.L. Curtis. 1997. Assessing prey fish populations in Lake Michigan: comparison of simultaneous acoustic-midwater trawling with bottom trawling. Fisheries Research 33:37-54.

Fleischer, G.W., R.L. Argyle, and G.L. Curtis. 1997. In situ relations of target strength to fish size for Great Lakes pelagic planktivores. Transactions of the American Fisheries Society 126:784-796.

Fleischer, G.W., J. Dettmers, and R.M. Claramunt. 2001. Original acoustics LWAP adopted by the Lake Michigan Technical Committee at the summer 2001 meeting in Sturgeon Bay, Wisconsin.

Jacobs, G.R., C.P. Madenjian, D.B. Bunnell, D.M. Warner, and R.M. Claramunt. 2013. Chinook salmon foraging patterns in a changing Lake Michigan. Transactions of the American Fisheries Society 142:362-372.

Madenjian, C.P., G.L. Fahnenstiel, T.H. Johengen, T.F. Nalepa, H.A. Vanderploeg, G.W. Fleischer, P.J. Schneeberger, D.M. Benjamin, E.B. Smith, J.R. Bence, E.S. Rutherford, D.S. Lavis, D.M. Robertson, D.J. Jude, and M.P. Ebener. 2002. Dynamics of the Lake Michigan food web, 1970-2000. Canadian Journal of Fisheries and Aquatic Sciences 59:736-753.

Madenjian, C.P., T.O. Höök, E.S. Rutherford, D.M. Mason, T.E. Croley II, E.B. Szalai, and J.R. Bence. 2005. Recruitment variability of alewives in Lake Michigan. Transactions of the American Fisheries Society 134:218-230.

Madenjian, C.P., D. B. Bunnell, T.J. Desorcie, P. Armenio, and J.V. Adams. 2018. Status and trends of preyfish populations in Lake Michigan, 2016. A report to the Great Lakes Fishery Commission, Lake Michigan Committee, Sault St. Marie, ON 2018.

O'Brien, T.P, Warner, D.M., Lenart, S. Esselman, P., Ogilvie, L., and Olds, C. 2016. Status and trends of pelagic fish in Lake Huron 2016. A report to the Great Lakes Fishery Commission, Lake Huron Committee Milwaukee, WI, March, 2016

O'Brien, T.P, K. Philips, S. Lenart, D.M. Warner, P. Esselman, C. Olds, C, and. 2018. Status and trends of pelagic fish in Lake Huron 2016. A report to the Great Lakes Fishery Commission, Lake Huron Committee Sault St. Marie, ON 2018.

Rybicki, R.W., and D.F. Clapp. 1996. Diet of Chinook salmon in eastern Lake Michigan, 1991-1993. Michigan Department of Natural Resources, Fisheries Division. Research Report 2027, Ann Arbor, MI.

Sawada, K., M. Furusawa, and N.J. Williamson. 1993. Conditions for the precise measurement of fish target strength in situ. Journal of the Marine Acoustical Society of Japan 20:73–79.

Tsehaye, I., M.L. Jones, J.R. Bence, T.O. Brendan, C.P. Madenjian, and D.M. Warner. 2014. A multispecies statistical age-structured model to assess predator-prey balance: application to an intensively managed Lake Michigan fish community. Canadian Journal of Fisheries and Aquatic Sciences 71:627-644.

Warner, D.M., S. Farha, T.P. O'Brien, L. Ogilvie, R.M. Claramunt, and D. Hanson. 2014. Status of pelagic prey fish in Lake Michigan, 2013. A report to the Great Lakes Fishery Commission, Lake Michigan Committee, Windsor, ON, March , 2014.

Warner, D.M., R.M. Claramunt, J.S. Schaeffer, D.L. Yule, T.R. Hrabik, B. Pientka, L.G. Rudstam, J.D. Holuszko, and T.P. O'Brien. 2012. Relationship between mid-water trawling effort and catch composition uncertainty in two large lakes (Huron and Michigan) dominated by alosines, osmerids, and coregonines. Fisheries Research 123/124:62-69.

Warner, D.M., R.M. Claramunt, D.F. Clapp, and C.S. Kiley. 2008. The influence of alewife year-class strength on prey selection and abundance of age-1 Chinook salmon in Lake Michigan. Transactions of the American Fisheries Society 137:1683-1700.

Warner, D.M., R.M. Claramunt, C. Faul, and T.P. O'Brien. 2005. Status of pelagic prey fish in Lake Michigan, 2001-2004. A report to the Great Lakes Fishery Commission, Lake Michigan Committee, Ypsilanti, MI March , 2005.

Warner, D.M., J.S. Schaeffer, and T.P. O'Brien. 2009. The Lake Huron pelagic fish community: persistent spatial pattern along biomass and species composition gradients. Canadian Journal of Fisheries and Aquatic Sciences 66:1199-1215.

Yule, D.L., J.V. Adams, J.D. Stockwell, and O.T. Gorman. 2008. Factors affecting bottom trawl catches: implications for monitoring the fishes of Lake Superior. North American Journal of Fisheries Management 28:109-123.

Yule, D.L., J.V. Adams, J.D. Stockwell, and O.T. Gorman. 2007. Using multiple gears to assess acoustic detectability and biomass of fish species in Lake Superior. North American Journal of Fisheries Management 27:106-126.

Status and Trends of Pelagic Prey Fish in Lake Huron, 2017[1, 2]

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Abstract

Scientists from the U.S. Geological Survey's Great Lakes Science Center conducted integrated acoustic and mid-water trawl surveys of Lake Huron in 1997 and annually from 2004-2017. The 2017 survey was conducted during September and included transects in Lake Huron's main basin, Georgian Bay, and North Channel. Mean lake-wide pelagic fish density was 1582 fish/ha and mean pelagic fish biomass was 10.5 kg/ha in 2017, which represents 96% and 93% of the long-term mean respectively. Mean lake-wide biomass was 23% higher in 2017 as compared to 2016. The total estimated lake-wide standing stock biomass of pelagic fish species, excluding cisco, was ~49 kt (± 10.4 kt), consisting almost entirely of bloater (26.8 kt; 55%) and rainbow smelt (22 kt; 45%), with small contributions from sticklebacks (0.13 kt; 0.26 %), emerald shiner (0.09 kt; 0.18%), and alewife (0.004kt; <0.005%). Age-0 rainbow smelt abundance increased from 155 fish/ha in 2016 to 598 fish/ha in 2017. Biomass of age-1+ rainbow smelt increased from 2.5 kg/ha in 2016 to 4.1 kg/ha in 2017. Age-0 bloater abundance increased from 94 fish/ha in 2016 to 342 fish/ha in 2017. Biomass of age-1+ bloater in 2017 (5.0 kg/ha) remained at levels similar to 2016 (5.2 kg/ha). Emerald shiner density decreased from 38.6 fish/ha in 2016 to 19.5 fish/ha in 2017. Emerald shiner biomass remained at 0.02 kg/ha between 2016-2017 which represented 19% of the long-term mean. Cisco lake-wide mean biomass was estimated at 2.2 kg/ha and mean density was estimated at 5.1 fish/ha in 2017. Bloater and rainbow smelt will likely continue to be the primary pelagic species available to offshore predators in coming years.

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[1] Presented at Great Lakes Fishery Commission, Lake Huron Committee Meeting, Sault Ste. Marie, ON on March 19, 2018.

[2] The data associated with this report are available at: U.S. Geological Survey, Great Lakes Science Center, 2018, Great Lakes Research Vessel Operations 1958-2017 (ver. 2.0, March 2018): U.S. Geological Survey Data Release, https://doi.org/10.5066/F75M63X0.

Introduction

Estimates of fish biomass derived from scientific trawl surveys are critical to understanding ecosystem dynamics and managing fishery resources (Koslow 2009; Cotter et al. 2009). In Lake Huron, the U.S. Geological Survey Great Lakes Science Center (GLSC) began conducting annual trawl surveys of the Lake Huron fish community in the 1970s. These surveys have tracked broad-scale changes in the benthic fish community and provided valuable information on prey fish dynamics to fishery managers tasked with balancing predatory demand by native and introduced salmonines. Integrated acoustic and mid-water trawl surveys were implemented because it was recognized that a substantial proportion of the prey fish biomass was distributed in pelagic zones, which could not be measured using bottom trawl gear (Fabrizio et al. 1997, Stockwell et al. 2007, Yule et al. 2008). Acoustic surveys were first conducted during the 1970s, but the first lake-wide acoustic survey that included all of Lake Huron's distinct basins was conducted in 1997. Annual surveys have been conducted since 2004; however, only the main basin was sampled during 2006. The purpose of this report is to present 2017 abundance and biomass estimates for major pelagic offshore prey fish species in Lake Huron and compare these estimates to previous years (1997, 2004-2016). Furthermore, our purpose is to highlight spatial patterns in distribution and abundance of these species throughout Lake Huron. We also summarize cisco *Coregonus artedi* catch data from acoustic surveys during 2010-2017 and present information on abundance and spatial patterns of this species in Lake Huron.

Survey and analytical methods

The pelagic prey fish survey in Lake Huron is based on a stratified-random design with acoustic transects in five geographic strata: eastern main basin (ME), western main basin (MW), southern main basin (SB), Georgian Bay (GB), and the North Channel (NC) (Figure 1). Within each stratum, the first transect is selected randomly each year based on latitude and longitude; subsequent transects are spaced relatively uniformly around the first. Effort (transects per stratum) is reallocated each year based on stratum area and variability of total biomass in each stratum from previous surveys (sampling design described in Adams et al. 2006). For analyses, each transect was divided into 10 m bottom contour intervals and 5-10 m depth layers (1997), 1,000 m distance intervals and 10 m depth layers (2004-2011), or 3,000 m distance units and 10 m depth layers (2012-2017). These comprise the elementary sampling units (ESUs) within which fish density is summarized along transects.

The 2017 pelagic fisheries survey was completed from 6-29 September. Sampling was conducted by both the GLSC (R/V *Sturgeon*) and U.S. Fish and Wildlife Service (USFWS; M/V *Spencer F. Baird*). Twenty-six acoustic transects were sampled, resulting in approximately 480 km of acoustic data. Fifty-six mid-water trawl tows were conducted in conjunction with acoustic data collection.

Fish were collected using a 16.5-m headrope mid-water trawl with 76, 38, 25, and 6.35 mm stretch meshes (USGS) and a 19.8-m headrope mid-water trawl with 200, 150, 100, 75, 50, and 38 mm stretch mesh with a cod-end liner having 3.175 mm stretch mesh (USFWS). Mid-water trawl locations and depths were chosen to target fish aggregations, but multiple tows per transect were conducted when fish were present so that trawl data within a stratum were available from each scattering layer formed by fish. At a minimum, a single mid-water trawl was conducted on each transect except in rare instances when very few fish targets were detected. Trawl fishing depth was monitored using Netmind™ (2004-2015) and Marport M3 (2016-2017) systems (USGS) and a Simrad PI44 catch monitoring system (USFWS). In 2017, trawling depths ranged from 7 to 76 m (mean = 28.7 m, mode = 20 m). Most mid-water trawl tows were of 20 minutes duration, with tow times extended up to 25 or 30 minutes when few fish were present. All fishes captured in the mid-water trawl tows were identified, counted, and weighed in aggregate (g) by species. Total length in millimeters was measured on a random subsample (100-200 fish) per species per tow. Individual fishes were assigned to age categories (age-0 or age 1+) based on the following length cutoffs: alewife *Alosa pseudoharengus* =100 mm; rainbow smelt *Osmerus mordax* = 90 mm; bloater *Coregonus hoyi* = 120 mm. These lengths approximate the lengths of the smallest age-1 fish of these species (USGS 2018).

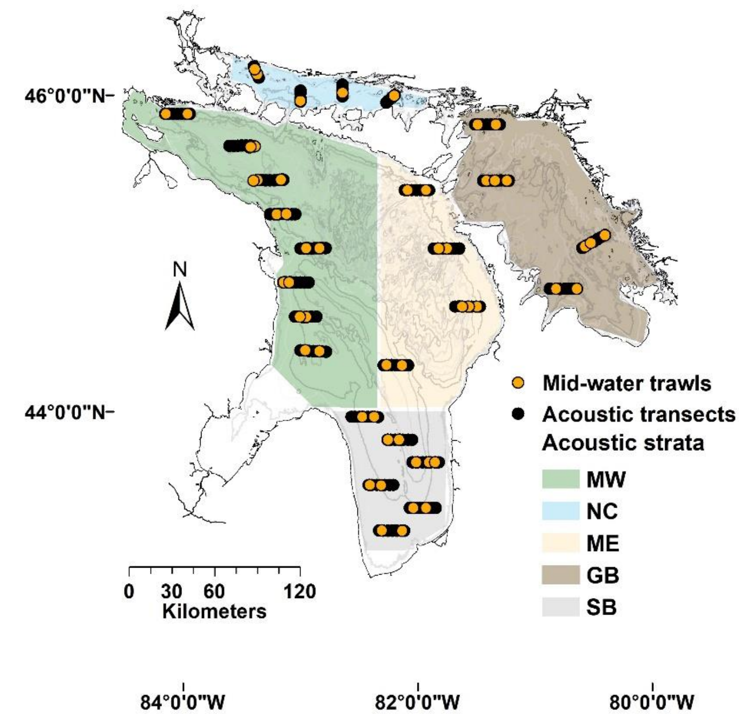

Figure 1. Location of acoustic transects and mid-water trawls within sampling strata in Lake Huron during 2017. Sampling strata correspond to geographic regions: eastern main basin (ME), western main basin (MW), southern main basin (SB), Georgian Bay (GB), and the North Channel (NC).

Density (fish/ha) of individual species was estimated for each transect as the product of acoustic fish density and the proportion of each species (by number) in the mid-water trawl catches at that location. Total density per species was subdivided into age-0 and age-1+ age-classes by multiplying total density by the numeric proportions of each age group. Biomass (kg/ha) of each species was estimated for each transect as the product of density and size-specific mean mass estimated from fish lengths in trawls, and length-weight relationships. The arithmetic mean and standard error are presented for total and species-specific density and biomass estimates for the survey area.

Mean, standard error, and confidence limits for density and biomass for the entire survey area (all three basins pooled) were estimated using stratified cluster analysis methods in SAS (SAS Institute Inc. 2007). Cluster sampling techniques are appropriate for acoustic data, which represent a continuous stream of autocorrelated data (Williamson 1982, Connors and Schwager 2002). Density and biomass values for each ESU in each stratum were weighted by dividing the stratum area by the number of ESUs in the stratum. Numeric density and biomass density of cisco were estimated using the R package EchoNet2Fish (R Core Team 2017). Acoustic equipment specifications, software versions, single target detection parameters, noise levels, and detection limits can be found in appendices 1 and 2. Supplemental methods on acoustic analysis methods and acoustic equipment can be found in appendix 3.

Results and Discussion

Density and biomass by species

Alewife – Alewife continue to be scarce in mid-water trawl surveys of Lake Huron, including during 2017 when only three specimens were captured. Alewife densities estimated in 1997, 2005-2006, 2008, and 2013 were considerably higher than other years in the time series. However, we note that these increases in density did not mean that age-0 alewives were especially abundant in any survey year (Figure 2). During 1997, the year of their highest abundance, age-0 alewives were only 2% of total fish density.

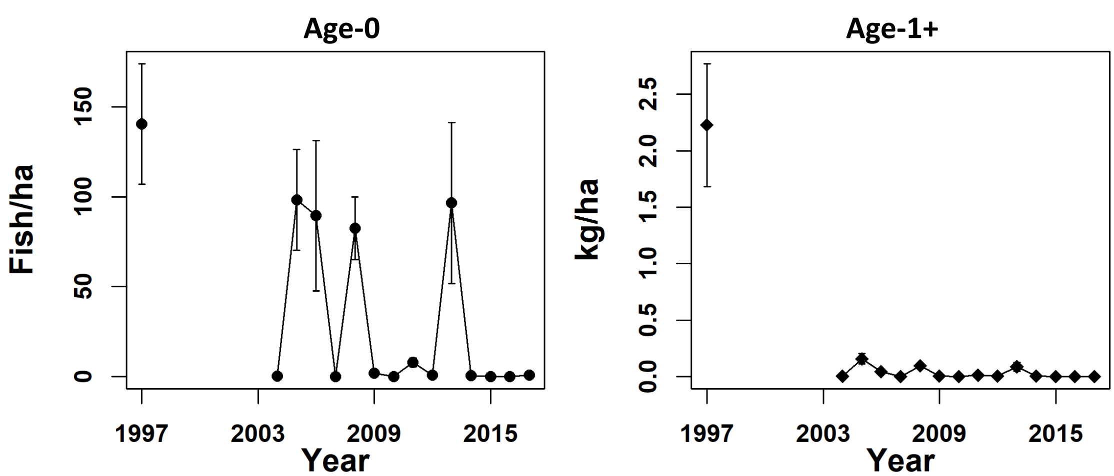

Figure 2. Acoustic and mid-water trawl estimates of alewife numeric density (fish/ha; left panel) and biomass (kg/ha; right panel) in Lake Huron, 1997-2017. Error bars represent ±1 standard error.

Acoustic estimates of age-1+ alewife biomass have remained low for the last decade despite fluctuations in age-0 densities during 2004-2013 (Figure 2). Temporal biomass differences were largely due to differences in size and age structure between 1997 and other years. Higher biomass in 1997 was due to higher abundance of age 1+ alewife and low biomass during 2004-2014 was the result of trawl catches dominated by age-0 fish (Figure 2). Since 2004, alewives have never comprised more than 2% of pelagic fish biomass. Although sporadic catches of alewife have continued, recruitment to older age classes appears to be limited based on evidence from both mid-water and bottom trawl surveys conducted by the GLSC.

Rainbow smelt – During 2017, age-0 rainbow smelt density increased from 2016 estimates by nearly a factor of 4 to 86% of the long-term mean (Figure 3). Age-0 rainbow smelt production still remains lower than 1997. There has been no clear trend in abundance since 2004. Age 1+ rainbow smelt biomass also increased in 2017 from 2.5 kg/ha in 2016 to 4.1 kg/ha in 2017. This is roughly 95% of the long-term mean of 4.3 kg/ha, but only 24% of the biomass estimated in 1997 (Figure 3). Rainbow smelt biomass was spatially variable during 2017 and primarily distributed in the SB, NC, and northern MW strata (Figure 4).

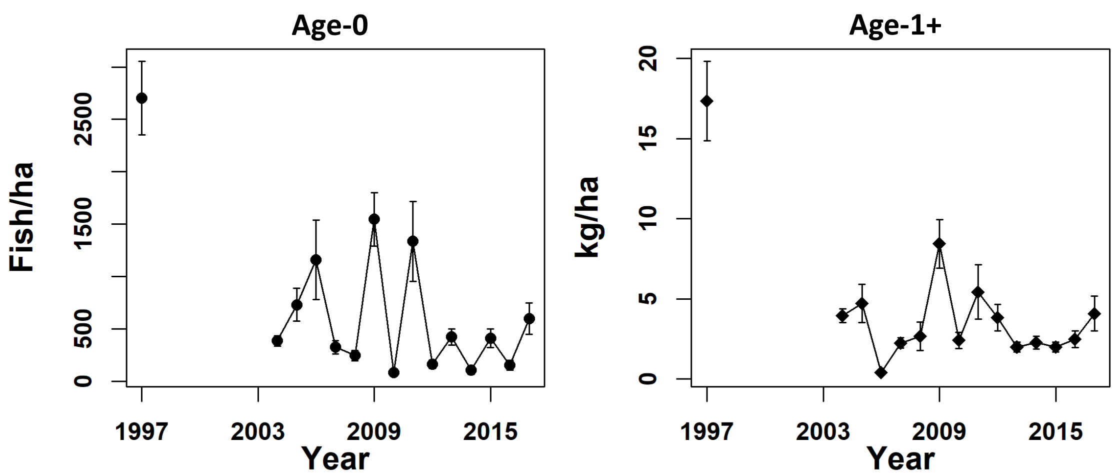

Figure 3. Acoustic and mid-water trawl estimates of rainbow smelt age-0 numeric density (fish/ha; left panel) and age-1+ biomass (kg/ha; right panel) in Lake Huron, 1997-2017. Error bars represent ±1 standard error.

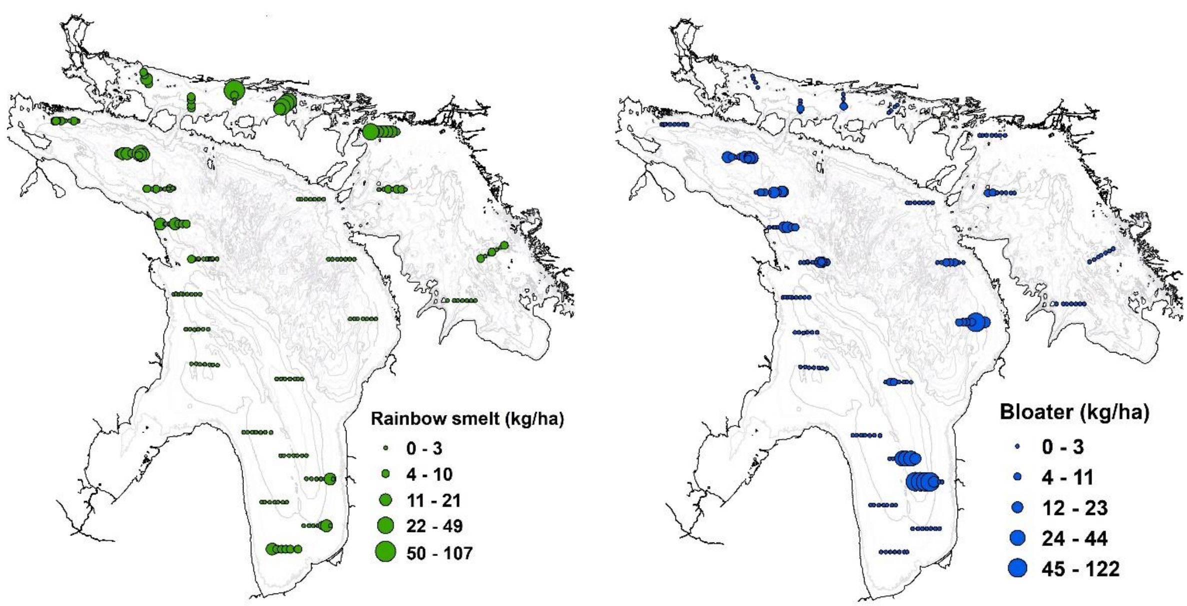

Figure 4. Geographic distribution of rainbow smelt (left) and bloater (right) biomass summarized within elementary sampling units (dots) during 2017. Gray lines are 20 m depth intervals.

Bloater – Lake-wide mean age-0 bloater density in 2017 was 3.5-times that estimated in 2016 and was the second highest estimate for the time series (Figure 5). Mean biomass of age-1+ bloater decreased from 5.2 kg/ha in 2016 to 5.0 kg/ha in 2017 (Figure 5). Since 2014, age-1+ bloater biomass has remained at or above 5 kg/ha, but standard error around these estimates have been fairly large indicating lower precision. Similar to results from bottom trawl surveys, age-0 bloater density was variable, but increased during 2004-2015 (average density > 160 fish/ha). Biomass of age-1+ bloater indicated an increasing trend during 2004-2008, followed by a decrease from 2009-2010. Although we have estimated somewhat higher bloater biomass during the past four years, variable spatial distribution across the survey area has resulted in greater uncertainty in the precision of these estimates. As in the past several years, bloater biomass in Lake Huron tends to be concentrated in the SB and ME strata and in the northern MW stratum
(Figure 4).

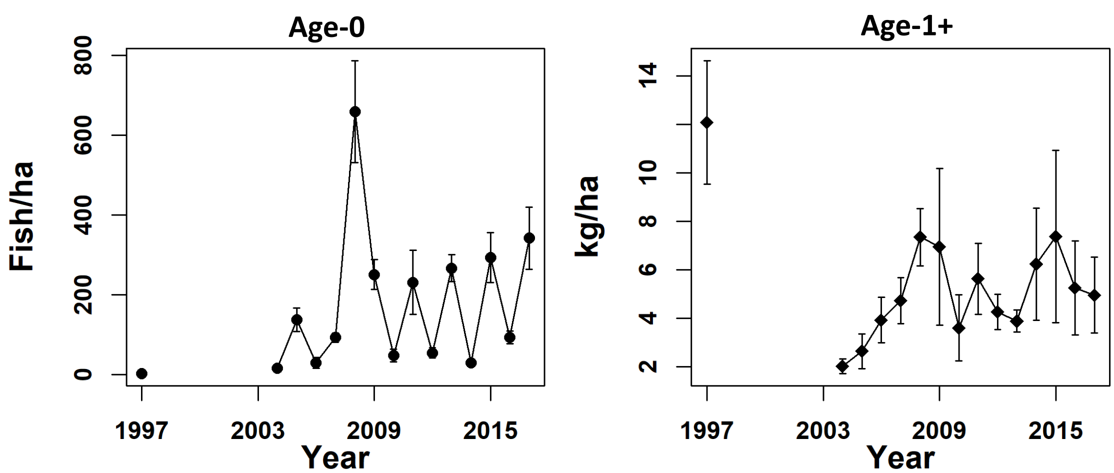

Figure 5. Acoustic and mid-water trawl estimates of bloater age-0 numeric density (fish/ha; left panel) and age-1+ biomass (kg/ha; right panel) in Lake Huron, 1997-2017. Error bars represent ±1 standard error.

Cisco – Cisco catches were sporadic during acoustic surveys in 2010-2013, with few (<10) specimens caught in most years. During 2014-2017, cisco catches increased (Figure 6). Biomass increased during 2016 and 2017 due to the increased number of larger fish (>300 mm) in trawl catches. Cisco caught in trawls during 2010-2017 were mostly > 100 mm (mean 280 mm, median 295 mm) and ranged from 80-471 mm.

Cisco are almost exclusively caught in GB, NC, and northern MW strata during September and early October (Figure 7). The highest densities of cisco have been observed in NC and GB but densities have also increased in northern ME and MW strata the last two years.

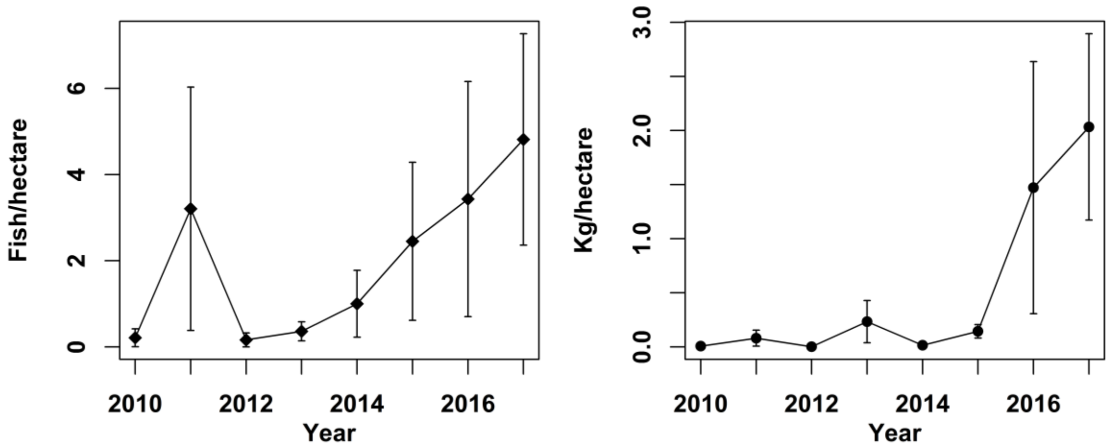

Figure 6. Acoustic and mid-water trawl estimates of cisco numeric density (fish/ha; left panel) and biomass (kg/ha; right panel) in Lake Huron, 2010-2017. Error bars represent ±1 standard error.

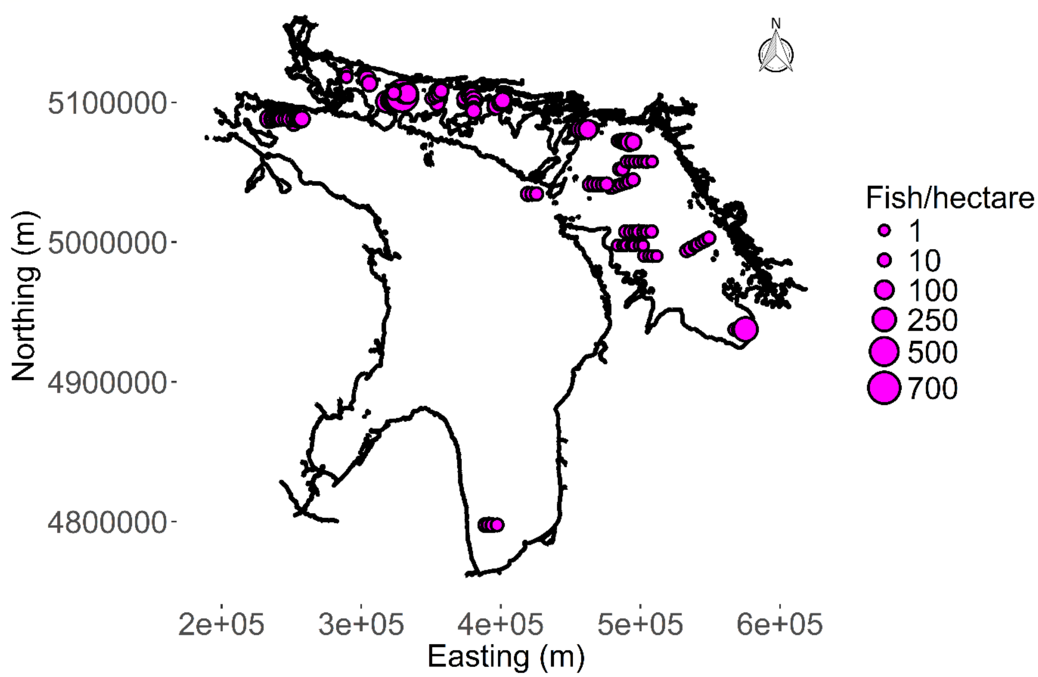

Figure 7. Geographic distribution of cisco numeric density (mean) estimated from acoustic surveys during 2010-2017. Points are elementary sampling units.

Emerald shiner – Mean density of emerald shiner declined moderately in 2017 and was approximately 24% of the long-term mean. Emerald shiner biomass in 2017 was 0.02 kg/ha and remained unchanged relative to 2016 (Figure 8). The 2017 biomass estimate was 20% of the long-term mean of 0.10 kg/ha. Emerald shiner biomass averaged 1.6% of total fish biomass during 2004-2014, but with the exception of 2006, rarely exceeded 1% of total fish biomass in a given year.

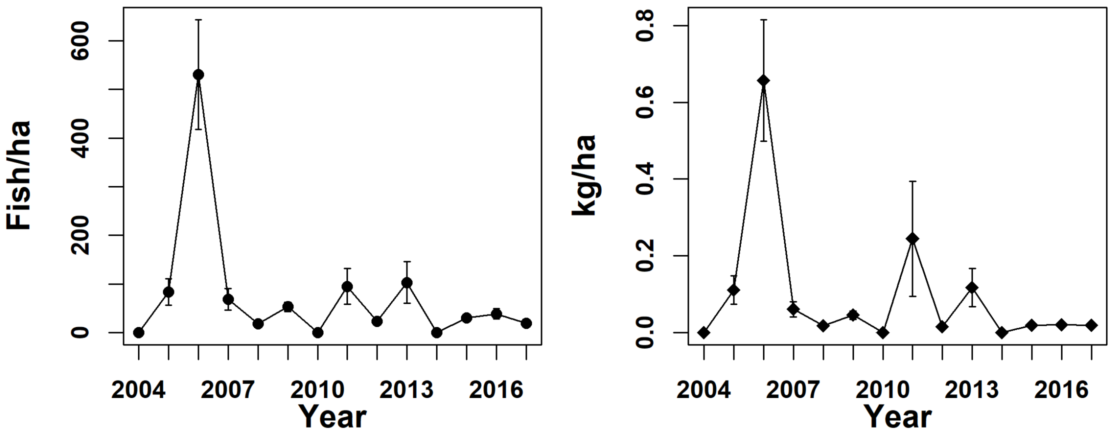

Figure 8. Acoustic and mid-water trawl estimates of emerald shiner numeric density (fish/ha; left panel) and biomass (kg/ha; right panel) in Lake Huron, 2004-2017. Error bars represent ±1 standard error.

Other species - Other species captured during acoustic and mid-water trawl surveys included threespine stickleback *Gasterosteus aculeatus*, ninespine stickleback *Pungitius pungitius*, chinook salmon *Oncorhynchus tshawytscha*, lake whitefish *Coregonus clupeaformis*, and lake trout *Salvelinus namaycush*. These species typically compose a small proportion of the mid-water trawl catch.

Among-basin comparisons of fish biomass

Biomass in the North Channel (22.9 kg/ha) in September of 2017 was roughly double that estimated in 2016 and was driven solely by increased biomass of rainbow smelt (Figure 9). Biomass in the main basin (MW, SB, ME strata combined, 11.6 kg/ha) increased marginally from 2016 estimates, and was due to small increases in rainbow smelt biomass. Biomass in Georgian Bay (7.7 kg/ha) changed little between 2016 and 2017, with increases in rainbow smelt biomass but decreases in bloater biomass (Figure 9). Over the long-term, total pelagic fish biomass in both Georgian Bay and the main basin remains lower than in 1997. There is no clear evidence of a declining trend in the North Channel (Figure 9).

Biomass in Georgian Bay has been primarily composed of rainbow smelt (58% average), while biomass in the main basin has consisted of varying proportions of rainbow smelt and bloater. Since 2012, bloater has been the dominant contributor in the main basin, averaging 75% of pelagic fish biomass annually. In the North Channel, rainbow smelt have averaged 75% of annual biomass since 1997.

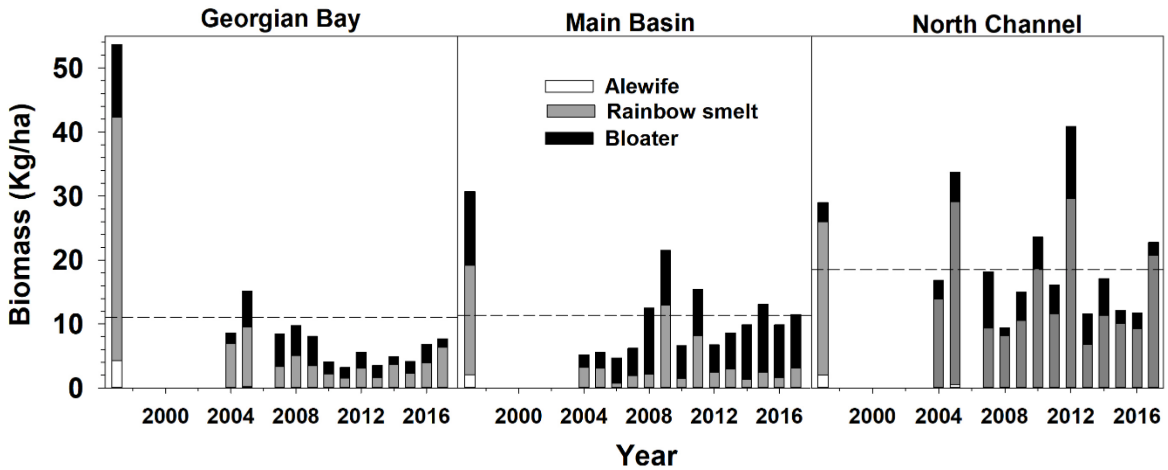

Figure 9. Biomass (kg/ha) of major pelagic fish species in Georgian Bay, main basin, and North Channel during 1997-2017. Horizontal lines denote 1997-2016 mean density.

Lake-wide fish density and biomass

Lake-wide mean pelagic fish density increased from 775 fish/ha in 2016 to 1582 fish/ha in 2017, representing roughly 60% of the long-term mean (Figure 10). The 2017 pelagic fish density estimate represented roughly 30% of the 1997 estimate. The 2017 lake-wide mean pelagic fish biomass estimate was 10.4 kg/ha, a 23% increase from 2016. Total standing stock biomass in 2017 was estimated at 49 kt (SE 10.4 kt) (Figure 10). The increase in standing stock biomass in 2017 was driven primarily by increased rainbow smelt biomass. In general, acoustic estimates of pelagic fish biomass in Lake Huron have been relatively stable between 2004 and 2017.

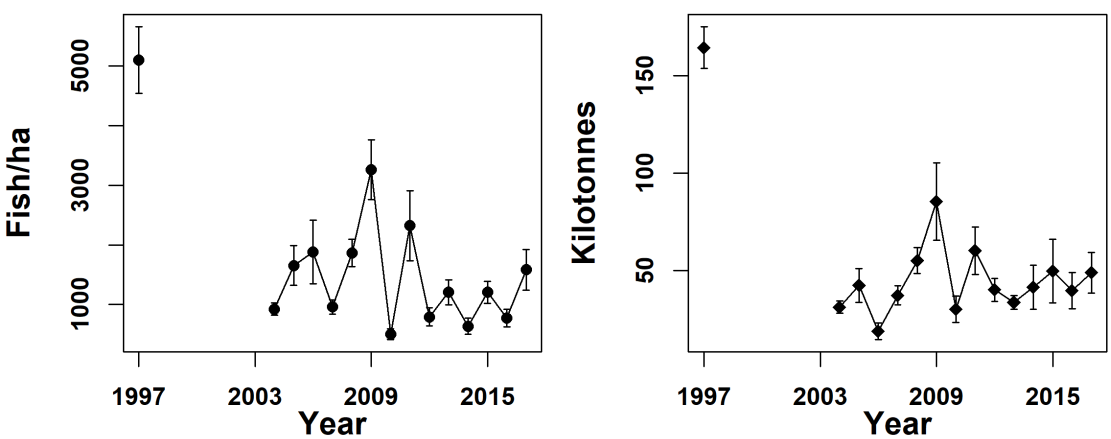

Figure 10. Acoustic and mid-water trawl estimates of lake-wide numeric density (fish/ha; left panel) and standing stock biomass (kilotonnes; right panel) in Lake Huron, 1997-2017. Error bars represent ±1 standard error.

Fish population estimates derived from the lake-wide acoustic survey, as with any other type of fishery survey, include assumptions about the sampling and data analysis techniques. For example, we assumed that the areas sampled were representative of the respective basins. This survey sampled areas of Lake Huron from 10 to 250 m in depth. These depths encompass 85% of the range of depths in Lake Huron, although sampling is limited in shallower (<20 m) areas of the lake. For example, nearshore zones and large shallow embayments, especially Thunder Bay, Saginaw Bay, and Parry Sound, are not sampled. These areas could be responsible for high rates of pelagic fish production (Fielder and Thomas 2014, Höök et al. 2001, Klumb et al. 2003), but could not be sampled safely due to the draft of our research vessel (3 m). Given the small surface areas of these shallow-water embayments relative to the total surface area, densities would need to be considerable to influence the lake-wide mean. We conducted sufficient mid-water trawls to achieve an acceptable degree of confidence in fish community composition, according to guidelines in Warner et al. (2012). An additional assumption was that fish size was a reasonable proxy for age-0 or age-1+ groupings. We used size to assign age and assumed no overlap in age among size classes. This assumption was likely violated, especially for rainbow smelt. While this might have slight effects on our estimates of age-0 versus age-1+ density and biomass, it would have no impact on our estimates of total density or biomass for a species.

Conclusions

Lake-wide biomass of common pelagic species in Lake Huron continues to consist of primarily bloater and rainbow smelt, with bloater making up more of the biomass in recent years. Distribution of preyfish biomass also continues to be patchy, with high areas of biomass in the North Channel (rainbow smelt) and the southern main basin (bloater). Since 2012, acoustic-derived estimates of lake-wide prey fish biomass in Lake Huron have remained relatively stable, with biomass fluctuating by 1-2 kg/ha per year. At the basin level, annual biomass continues to show some variation, but this is mostly for the North Channel.

Better delineation of cisco stocks and estimates of their abundance continue to be a focus of the acoustic program on Lake Huron. Based on catches in mid-water trawls during 2010-2017, cisco in offshore areas appear to be mostly confined to northern Lake Huron, Georgian Bay, and the North Channel. Extant cisco stocks in Lake Huron are not well understood but acoustic surveys have served to help better define offshore habitat use by this species. Most information on cisco spatial distribution and abundance in Lake Huron has resulted from collections made during the late fall when fish are aggregated for spawning purposes. We anticipate acoustic surveys to continue providing important information on ecology and habitat use of cisco during other seasons.

To provide accurate estimates of available prey fish resources in Lake Huron, the continuation of acoustic surveys will be instrumental in assessing the pelagic component of the prey fish community, while complementing bottom trawl surveys that better estimate benthic prey resources. The information gathered from acoustic surveys that sample areas where bottom trawling is not feasible will increase our understanding of variation in prey fish biomass across large temporal and spatial scales (i.e., all of Lake Huron's basins). As no single gear is best for assessing all species, life stages, or habitats, estimates of fish biomass from multiple gear types will lead to a better understanding of fish population dynamics.

Acknowledgements

We thank the vessel crews and biologists of the R/V *Sturgeon*, R/V *Grayling*, and M/V *Spencer Baird* for their assistance with field surveys. We thank Capt. Joe Bergan, Lyle Grivicich, and Brad Briggs for vessel support during 2017 field operations. Scott Nelson, Dan Benes, and Limei Zhang provided computer and database support. The Ontario Ministry of Natural Resources and Forestry provided support for field operations. Mark Vinson and Arunas Liskauskas provided helpful reviews of this report. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government. All GLSC sampling and handling of fish during research are carried out in accordance with guidelines for the care and use of fishes by the American Fisheries Society (http://fisheries.org/docs/wp/Guidelines-for-Use-of-Fishes.pdf).

Literature cited

Adams J.V., R. L. Argyle, G. W. Fleischer, G. L. Curtis, and R. G. Stickel. 2006. Improving the design and efficiency of acoustic and midwater trawl surveys through stratification, with an application to Lake Michigan prey fishes. North American Journal of Fisheries Management 26: 612-621.

Argyle, R.L., G.W. Fleischer, G.L. Curtis, J.V. Adams, and R.G. Stickel. 1998. An integrated acoustic and trawl based prey fish assessment strategy for Lake Michigan. A report to the Illinois Department of Natural Resources, Indiana Department of Natural Resources, Michigan Department of Natural Resources, and Wisconsin Department of Natural Resources. U.S. Geological Survey, Biological Resource Division, Great Lakes Science Center, 1451 Green Road, Ann Arbor, MI USA.

Connors, M.E., and S.J. Schwager. 2002. The use of adaptive cluster sampling for hydroacoustic surveys. ICES Journal of Marine Science 59:1314-1325.

Cotter, J., P. Petitgas, A. Abella, P. Apostolaki, B. Mesnil, C. Politou, J. Rivoirard, M. Rochet, M. T. Spedicato, V.M. Trenkel, and M. Woillez. 2009. Towards and ecosystem approach to fisheries management (EAFM) when trawl surveys provide the main source of information. Aquatic Living Resources 22: 243-254.

Fabrizio, M. C., J. V. Adams, and G. L. Curtis. 1997. Assessing prey fish populations in Lake Michigan: comparison of simultaneous acoustic-midwater trawling with bottom trawling. Fisheries Research 33: 37-54.

Fielder, D. G., and M. V. Thomas, 2014. Status and Trends of the Fish Community of Saginaw Bay, Lake Huron 2005–2011. Michigan Department of Natural Resources, Fisheries Report 03. Lansing.

Fleischer, G. W., R. L. Argyle, and G. L. Curtis. 1997. *In situ* relations of target strength to fish size for Great Lakes pelagic planktivores. Transactions of the American Fisheries Society 126: 784-796.

Höök, T.O., N.M. Eagan, and P.W. Webb. 2001. Habitat and human influences on larval fish assemblages in northern Lake Huron coastal marsh bays. Wetlands 21:281–291.

Klumb, R.A., Rudstam, L.G., Mills, E.L., Schneider, C.P., and Sawko, P.M. 2003. Importance of Lake Ontario embayments and nearshore habitats as nurseries for larval fish with emphasis on alewife (*Alosa pseudoharengus*). Journal of Great Lakes Research 29:181-198.

Koslow, J. A. 2009. The role of acoustics in ecosystem-based fishery management. ICES Journal of Marine Science 66:966-973.

Parker-Stetter, S.L., Rudstam, L.G., Sullivan, P.J., and Warner, D.M. 2009. Standard operating procedures for fisheries acoustic surveys in the Great Lakes. Great Lakes Fishery Commission Special Publication 09-01.

R Core Team. 2017. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Riley, S.C., E.F. Roseman, D. Hondorp, M. Chriscinske, E. Glassini, and M. Smith. 2017. Status and trends of the Lake Huron offshore demersal fish community, 1976-2016. A report to the Great Lakes Fishery Commission, Lake Huron Committee, Ypsilanti, MI, March 21, 2017.

Rudstam, L. G., S. L. Parker, D. W. Einhouse, L. Witzel, D. M. Warner, J. Stritzel, D. L. Parrish, and P. Sullivan. 2003. Application of *in-situ* target strength to abundance estimations in lakes- examples from rainbow smelt surveys in Lakes Erie and Champlain. ICES Journal of Marine Science 60: 500-507.

Rudstam, L. G., Parker-Stetter, S. L., Sullivan, P. J., and Warner, D. M. 2009. Towards a standard operating procedure for fishery acoustic surveys in the Laurentian Great Lakes, North America. ICES Journal of Marine Science, 66: 1391–1397.

SAS Institute,, Inc. 2007. Online Doc 9.1.2. Cary, NC, SAS Institute, Inc.

Sawada, K., Furusawa, M., and Williamson, N. J. 1993. Conditions for the precise measurement of fish target strength in situ. Journal of the Marine Acoustical Society of Japan, 20: 73–79.

Stockwell, J. D., D. L. Yule, T. R. Hrabik, J. V. Adams, O. T. Gorman, and B. V. Holbrook. 2007. Vertical distribution of fish biomass in Lake Superior; implications for day bottom trawl surveys. North American Journal of Fisheries Management 27: 735-749.

TeWinkel, L. M., and G. W. Fleischer. 1999. Vertical Migration and Nighttime Distribution of Adult Bloaters in Lake Michigan. Transactions of the American Fisheries Society 128: 459-474.

U.S. Geological Survey, Great Lakes Science Center. 2018. Great Lakes Research Vessel Operations 1958-2017 (ver. 2.0, March 2018): U.S. Geological Survey Data Release, https://doi.org/10.5066/F75M63X0.

Warner, D.M., L. G. Rudstam, and R. A. Klumb. 2002. In-situ target strength of alewives in freshwater. Transactions of the American Fisheries Society 131: 212-223.

Warner, D.M., J.S. Schaeffer, and T.P. O’Brien. 2009. The Lake Huron pelagic fish community: persistent spatial pattern along biomass and species composition gradients. Canadian Journal of Fisheries and Aquatic Sciences 66:1199 - 1215.

Warner, D.M., R.M. Claramunt, J.S. Schaeffer, D.L. Yule, T.R. Hrabik, B. Pientka, L.G. Rudstam, J.D. Holuszko, and T.P. O’Brien. 2012. Relationship between mid-water trawling effort and catch composition uncertainty in two large lakes (Huron and Michigan) dominated by alosines, osmerids, and coregonines. Fisheries Research 123/124:62-69.

Williamson, N.J. 1982. Cluster sampling estimation of the variance of abundance estimates derived from quantitative echo sounder surveys. Canadian Journal of Fisheries and Aquatic Sciences 39:228-231.

Yule, D.L., J.V. Adams, T.R. Hrabik, M.R. Vinson, Z. Woiak, and T.D. Ahrenstorff. 2013. Use of Classification Trees to Apportion Single Echo Detections to Species: Application to the Pelagic Fish Community of Lake Superior. Fisheries Research 140:123-132.

Yule, D.L., J. V. Adams, J. D. Stockwell, and O.T. Gorman. 2008. Factors affecting bottom trawl catches; implications for monitoring the fishes in Lake Superior. North American Journal of Fisheries Management 28: 109-122.

Appendix 1. Single target detection parameters used in acoustic data analyses in 2017

Parameter	Value
TS threshold (dB)	-77[1]
Pulse length determination level (dB)	6
Minimum normalized pulse length	0.7
Maximum normalized pulse length	1.5
Maximum beam compensation (dB)	6
Maximum standard deviation of minor-axis angles	0.6
Maximum standard deviation of major-axis angles	0.6

[1] Only targets ≥-60 dB were included in analysis

Appendix 2. Noise levels, detection limits, and acoustic equipment specifications in Lake Huron, 2017

Vessel	R/V Sturgeon	M/V Spencer Baird
Collection software	Visual Acquisition 6.0	ER60 2.2
Transducer beam angle (3dB)	8.28º split beam	6.53º split beam
Frequency (kHz)	120	120
Pulse length (ms)	0.4	0.256
Sv noise at 1 m (dB)	-125	-125
2 way equivalent beam angle	-19.78	-21
Detection limit (m) for -60 dB target[2]	>100	>100

[2] Assuming 3 dB signal-to-noise ratio.

Appendix 3. Supplement to methods

Acoustic data collected in 1997 were analyzed using custom software (Argyle et al. 1998). Data collected in 2004 and later years were analyzed using Echoview™ software, which provided fish density estimates for each sampling unit. Fish density was calculated as:

$$Density\ (fish/ha) = 10^4 \bullet \frac{ABC}{\sigma}$$

where *ABC* was the area backscattering coefficient (m^2 / m^2) of each 10 m high by 1000-3,000 m long cell, and σ was the mean backscattering cross section (m^2) of all targets between -60 and -30 dB in each cell. The lower threshold should have included any age-0 alewives present (Warner et al. 2002), but may have underestimated age-0 rainbow smelt density (Rudstam et al. 2003). The upper threshold excluded fish larger than our species of interest.

In 1997, a BioSonics model 102 dual-beam echosounder was used to collect acoustic data during pelagic fish surveys. During 2004-2005 and 2007-2008 acoustic data were collected during September through early October with a BioSonics split-beam 120 kHz echosounder deployed from the Research Vessel (R/V) *Sturgeon*. During 2006, acoustic data were collected during August with a 70 kHz echosounder and a transducer deployed via towfish from the R/V *Grayling*. During 2009, the survey was performed with a 38 kHz echosounder because the 120 kHz transducer failed field calibration tests. In 2010-2015, we used both a 38 and 120 kHz echosounder to facilitate frequency comparisons, but with the exception of 2009, only 120 kHz data are presented in this report. Comparison of paired 120 kHz and 38 kHz data revealed that a) density estimates from 38 kHz are higher than from 120 kHz, b) this difference does not vary among fish species, and c) fish density estimates from the two frequencies are highly correlated (r^2 =0.77). In order to provide estimates for 2009 that would have been equivalent to 120 kHz, we predicted the 2009 fish density estimates using the 38 kHz estimates and a regression model relating the two from data collected in subsequent years. Additionally, studentized residual plots indicated that the model was acceptable. During 2011-2012 and 2014-2017, the survey was carried out jointly between GLSC and the United States Fish and Wildlife Service (USFWS). USFWS used 70 kHz and 120 kHz split-beam echosounders (Simrad EK60) to sample transects located in the MW stratum. In all years, sampling was initiated one hour after sunset and ended no later than one hour before sunrise. A threshold equivalent to uncompensated target strength (TS) of -70 decibels (dB) was applied to S_v data.

In order to assign fish species and size composition to acoustic data, we used a technique described by Warner et al. (2009), with different approaches depending on the vertical position in the water column. For cells with depth < 40 m, mid-water trawl and acoustic data were matched according to transect, depth layer (0-10, 10-20 m, etc., depending on headrope depth and upper depth of the acoustic cell), and by bottom depth. For acoustic cells without matching trawl data, we assigned the mean of each depth layer and bottom depth combination from the same transect. If acoustic data still had no matching trawl data, we assigned the mean of each depth layer and bottom depth combination within the same geographic stratum. Finally, if acoustic data still had no matching trawl data, we used a lake-wide mean for each depth layer. Mean mass of species/size groups at depths < 40 m were estimated using weight-length equations from mid-water trawl data. For depths 40 m, we assumed that acoustic targets were large bloater if mean TS was > -45 dB (TeWinkel and Fleischer 1999). Mean mass of bloater in these cells was estimated using the mass-TS equation of Fleischer et al. (1997). If mean TS was ≤ -45 dB, we assumed the fish were large rainbow smelt and estimated mean mass from mean length, predicted using a TS-length equation (Rudstam et al. 2003).

As recommended by the Great Lakes Acoustic Standard Operating Procedures (Parker-Stetter et al. 2009, Rudstam et al. 2009), we used a number of techniques to assess or improve acoustic data quality. We used the N_v index of Sawada et al. (1993) to determine if conditions in each acoustic analysis cell were suitable for estimation of *in situ* TS. We defined suitability as an N_v value < 0.1 and assumed mean TS in cells at or above 0.1 were biased. We replaced mean TS in these cells with mean TS from cells that were in the same depth layer and transect having N_v < 0.1. To help reduce the influence of noise, we estimated Sv noise at 1 m on each transect using either passive data collection or echo integration of data below the bottom echoes. We then used noise at 1 m to estimate noise at all depths, which we subtracted from the echo integration data. Additionally, we estimated the detection limit (depth) for the smallest targets we include in our analyses.

Lake Trout Rehabilitation in Lake Ontario, 2017[1,2,3]

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Abstract
Each year we report on the progress toward rehabilitation of the Lake Ontario lake trout (Salvelinus namaycush) population, including the results of stocking, annual assessment surveys, creel surveys, and evidence of natural reproduction observed from all standard surveys performed by USGS and NYSDEC. The first-year survival index for the 2015 year-class of stocked lake trout (age 2 in 2017) was below the average for the 1993-2015 year-classes. The catch per unit effort of adult lake trout in gill nets increased each year from 2008-2014, recovering from historic lows recorded during 2005-2007. Adult abundances declined each year from 2015 to 2017; and in 2017 were about 35% below the 2014 peak and 17% below the 1999-2004 mean. The 2017 rate of wounding by sea lamprey (Petromyzon marinus) on lake trout caught in gill nets (0.50 A1 wounds per 100 lake trout) was below target (2 wounds per 100 lake trout). Estimates from the NYSDEC fishing boat survey indicated 2017 angler catch rate was nearly 3.5 times higher than the lows observed in 2007. Condition values for an adult lake trout, indexed in September from the predicted weight for a 700mm lake trout from annual length-weight regressions and Fulton's K for age-6 males, were among the highest levels observed for the 1983-2017 time series. July-August condition of juvenile lake trout indexed from the predicted weight of a 400 mm individual and Fulton's K for age-2 fish increased sharply from low values observed during 2015-2016. Reproductive potential for the adult stock, determined from the annual egg deposition index, rebounded from the 2007-2008 values that were the lowest observed since 1985 and stabilized during 2009-2017. Twenty three cohorts of naturally produced lake trout have been collected since 1994 with the largest catches occurring during 2014-2017.

Introduction
Restoration of a naturally reproducing population of lake trout (*Salvelinus namaycush*) is the focus of a major international effort in Lake Ontario. Coordinated through the Lake Ontario Committee of the Great Lakes Fishery Commission, representatives from cooperating agencies (New York State Department of Environmental Conservation [NYSDEC], U.S. Geological Survey [USGS], U.S. Fish and Wildlife Service [USFWS], and Ontario Ministry of Natural Resources and Forestry [OMNRF]) developed the Joint Plan for Rehabilitation of Lake Trout in Lake Ontario (Schneider et al. 1983, 1997) which guided restoration efforts and evaluation through 2014. A revised document, A Management Strategy for the Restoration of Lake Trout in Lake Ontario, 2014 Update (Lantry et al. 2014), will guide future efforts. The present report documents progress towards restoration by reporting on management plan targets and measures through 2017.

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[1]Presented at Great Lakes Fishery Commission, Lake Ontario Committee Meeting, Markham, ON on March 27, 2018.

[2] The data associated with this report are available at: U.S. Geological Survey, Great Lakes Science Center, 2018, Great Lakes Research Vessel Operations 1958-2017 (ver. 2.0, March 2018): U.S. Geological Survey Data Release, https://doi.org/10.5066/F75M63X0.

[3] All GLSC sampling and handling of fish during research are carried out in accordance with guidelines for the care and use of fishes by the American Fisheries Society (http://fisheries.org/docs/wp/Guidelines-for-Use-of-Fishes.pdf). Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Methods

Adult Gill Net Survey

During September 1983-2017, adult lake trout were collected with gill nets at random transects within each of 14 to 17 geographic areas distributed uniformly within U.S. waters of Lake Ontario. Survey design (size of geographic areas) and gill net construction (multi- vs. mono-filament netting) has changed through the years. For a description of survey history including gear changes and corrections see Elrod et al. (1995).

During September 2017, USGS R/V *Kaho* and NYSDEC R/V *Seth Green* fished standard monofilament gill nets for adult lake trout at 14 geographic locations encompassing the entire U.S. shore in Lake Ontario. Survey gill nets consisted of nine, 15.2- x 2.4-m (50 x 8 ft) panels of 51- to 151-mm (2- to 6-in stretched measure) mesh in 12.5-mm (0.5 in) increments. At the 12 sites in the lake's main basin, four survey nets were fished along randomly chosen transects, parallel to depth contours beginning at the 10ºC (50ºF) isotherm and proceeding deeper in 10-m (32.8-ft) increments. At two sites in the eastern basin, less than the standard four nets per site were fished due to thermocline depth. In the Black River Channel two nets were fished between 40 m and 44 m (131.2 – 144.4 ft); and in the St. Lawrence Channel three nets were fished between 34 to 52 m (111.5 – 170.6 ft).

For all lake trout captured, total lengths and weights were measured, body cavities were opened and prey items were removed from stomachs and enumerated. Presence and types of fin clips were recorded, and when present, coded wire tags (CWTs) were removed. Sex and maturity of lake trout were determined by visual inspection of gonads. Sea lamprey (*Petromyzon marinus*) wounds on lake trout were counted and graded according to King and Edsall (1979) and Ebener et al. (2006).

A stratified catch per unit effort (CPUE) was calculated using four depth based strata, representing net position from shallowest to deepest. The unit of effort was one overnight set of one net. Depth stratification was used because effort was not equal among years and catch per net decreased uniformly with increasing depth below the thermocline (Elrod et al. 1995). To examine variability in CPUE between years, the relative standard error was calculated (RSE = 100 * {standard error / mean}).

Survival of various year-classes and strains was estimated by taking the antilog of the slope of the regression of ln(CPUE) on age for fish ages 7 to 11 that received coded wire tags. Catches of age-12 and older lake trout were not used in calculations because survival often seemed to greatly increase after age 11 and catch rates were too low to have confidence in estimates using those ages (Lantry and Prindle 2006).

Adult condition was indexed from both the predicted weights of a 700-mm (27.6 in) fish calculated from annual length-weight regressions based on all lake trout caught that were not deformed, and from Fulton's *K* (Ricker 1975, Nash et al. 2006) for age-6 males:

$K = (WT/ TL^3)*100{,}000;$

where WT is weight (g) and TL is total length (mm). We grouped data across strains because Elrod et al. (1996) found no difference between strains in the slopes or intercepts of annual length-weight regressions in 172 of 176 comparisons for the 1978 through 1993 surveys. Lake trout in those comparisons were of the lean morphotype, the only morphotype stocked into Lake Ontario until 2009. Since 2009, five year-classes of the Klondike (SKW) strain lake trout (2008, 2013-2016) were stocked into Lake Ontario. The SKW strain originated from a native, deep spawning "humper" morphotype of Lake Superior lake trout that are intermediate in fat content to lean and fat (siscowet) morphotypes with the potential to have a higher condition factor than the leans. When the first year-class (2008) of SKWs reached maturity in 2014, however, their age-6 Fulton's K value (1.07) was almost identical to Seneca Lake strain (SEN's; 1.08), one of the most prominent strains in the population.

Lake trout fecundity changes with age and length (O'Gorman et al. 1998), and both mean age and mean length increased after effective control of sea lamprey (achieved during the mid-1980s) reduced size-selective mortality on lake trout ≥433 mm (17 in). Also, sea lampreys kill mature lake trout each fall, mostly between our September assessment and November spawning (Bergstedt and Schneider 1988, Elrod et al. 1995). The numbers of lake trout killed have varied through time, and not all strains of lake trout are equally vulnerable to attack by sea lampreys or are as likely to succumb to an attack (Schneider et al. 1996). Thus, change in age and strain composition of mature females has to be considered when judging reproductive potential from September gill net catches.

Population reproductive potential was estimated by calculating annual egg deposition indices (O'Gorman et al. 1998) from catches of mature females in September gill nets, length-fecundity relationships, and observed differences in mortality rates among strains. Length-fecundity relationships were determined from the fecundity of individual lake trout collected with gill nets in September and early October each year during 1977-1981 and in September 1994 (O'Gorman et al. 1998). Results from the two examinations indicated that at some point between the early 1980s and the mid-1990s, age-related factors began to influence fecundity. During 1977-1981, fecundity-length relationships were not different among fish of various ages, but in 1994, age-5 and age-6 fish had fewer eggs per unit length (P<0.003) than age-7 fish, and age-7 fish had fewer eggs per unit length (p<0.003) than fish of ages 8, 9, or 10. The lake trout population in the earlier period was small with few mature fish whereas the population in the 1990s was relatively large with many mature fish (Elrod et al. 1995).

Elrod et al. (1996) demonstrated that the weight of a 700-mm mature female lake trout was much greater during 1978-1981 than during 1982-1993. They attributed the better condition during 1978-1981 to a lack of competition for food or space at low population levels. Therefore, we used the fecundity-length regression for 1977-1981 to calculate indices of egg deposition during 1980-1981 and the fecundity-length regressions for 1994 to calculate indices of age and size related egg deposition during 1982-2017. To account for sea lamprey-induced mortality that occurred between September gill net sampling and November spawning, we reduced catches of mature females by factors representing strain related differences in susceptibility to sea lamprey predation developed in O'Gorman et al. (1998). Where susceptibility factors were lacking for some strains we substituted factors from other strains that were similar in geographic and genetic origin (i.e., we grouped Lake Champlain strains with SEN strain, and all Lake Superior lean strains with Superior Marquette Domestics (SUP)). The addition of the SKW strains to the stocking mix for Lake Ontario will necessitate reexamining fecundity relationships as the 2013-2016 year-classes begin to reach maturity in 2018.

<u>Creel Survey</u>

Catch and harvest by anglers fishing from boats is measured by a direct-contact creel survey, which covers the open-lake fishery from the Niagara River in the western end of the lake to Association Island near Henderson in the eastern basin (Lantry and Eckert 2018). The survey uses boat trips as the primary unit of effort. Boat counts are made at boat access locations and interviews are based on trips completed during April 15 - September 30, 1985-2017.

<u>Juvenile Trawl Survey</u>

From mid-July to early-August, 1980-2017, crews from USGS and NYSDEC used the R/V *Kaho* and the R/V *Seth Green* to capture juvenile lake trout (targeting age-2 fish) with bottom trawls. Trawling was generally conducted at 14 locations in U.S. waters distributed evenly along the southern shore and within the eastern basin, and at one location in Canadian waters off the mouth of the Niagara River. In 2013, effort was reduced because no lake trout from the 2011 year-class were stocked in U.S. waters during 2012 (Lantry and Lantry 2013) and thus no U.S. stocked age-2 lake trout were present in 2013. Effort returned to routine levels in 2014. In 2017, trawling was conducted at 14 locations during July 6 - 14. A standard tow was 10 min long. From 1980 to 1996, trawling was conducted with a 12-m (39.4-ft, headrope) trawl at 5-m (16.4-ft) depth intervals, beginning at the metalimnion (15°C, 59°F isotherm) and progressing into deeper water until few or no lake trout were captured. Because of an abrupt shift in the depth distribution of juvenile lake trout to deeper waters in 1993 (O'Gorman et al. 2000) and fouling of the gear by dreissenid mussels in 1996, the sampling scheme and gear were changed. In 1997 the 12-m (39.4-ft) trawl was replaced with a 3-in-1 trawl (18-m or 59-ft headrope, 7.6-m or 24.9-ft spread) equipped with roller gear along the footrope. In addition, effort was decreased at depths < 55 m (180.4 ft) and increased at depths > 70 m (229.6 ft). For years after 1997, the sampling protocol was modified by alternating between odd and even depths (5-m or 16.4-ft increments) between adjacent sites and adjacent years. At four sites where depth did not exceed 75 m (246.1 ft), all 5-m (16.4-ft) contours at and below the 15°C (59°F) isotherm were fished.

Data collection from trawl-captured lake trout was the same as that described above for fish captured with gill nets. Survival indices were calculated from catches of age-2 lake trout that were stocked in U.S. waters. Survival was assessed at age-2 because the trends in index were similar for age-2 lake trout caught in this survey and age-3 lake trout from the same year-class caught in the gill net survey. This indicated that recruitment of hatchery fish to the population was governed by survival during their first year in Lake Ontario. For 1981 to 1996 (1979-1994 year-classes), survival indices were calculated by adjusting total catch for strain, stocking location, and to reflect a total of 500,000 spring yearlings stocked (total catch * 500,000 / the number stocked). Data obtained on the 1995 year-class were not adjusted for strain or stocking location because of poor retention rates of CWTs. Among the age-2 lake trout caught in trawls in 1997, 36% of adipose-fin clipped individuals did not have tags. Data for year-classes stocked since 1997 were not adjusted for strain or stocking location because from 36% to 84% of fish stocked during 1997-2003 did not receive CWTs and stockings thereafter did not include the CWL strain or the Niagara River stocking location which were the factors that necessitated catch adjustment. Catches of the 1995 through 2015 year-classes were, however, adjusted for numbers stocked. Most untagged fish stocked since 1997 received paired fin clips that facilitated year-class identification through at least age 4. The ages of unmarked fish and fish with poor clips were estimated with age-length plots developed from CWT tagged fish.

To assess the condition of juvenile lake trout, we used the predicted weight of a 400-mm (15.8 in) fish. A 400-mm fish would be age 2 or 3. Weights were estimated each year from length-weight regressions calculated from annual trawl catches of lake trout ranging in total length from 250 mm to 500 mm (9.8 in to 19.7 in); and from Fulton's *K* (Ricker 1975, Nash et al. 2006) for age-2 lake trout of both sexes.

Results and Discussion

<u>Stocking</u>

From 1973 to 1977 lake trout stocked in Lake Ontario were raised at several NYSDEC and USFWS (Michigan and Pennsylvania) hatcheries with annual releases ranging from 0.07 million for the 1973 year-class to 0.28 million for the 1975 year-class (Figure 1). By 1978 (1977 year-class) the USFWS Alleghany National Fish Hatchery (ANFH; Pennsylvania) was raising all lake trout stocked in U.S. waters of Lake Ontario and annual releases exceeded 0.60 million fish. In 1983, the first official Lake Ontario lake trout rehabilitation plan (Schneider et al. 1983) was formalized and it called for an annual U.S. target of 1.25 million yearlings. The stockings of the 1979-1986 year-classes approached that level, averaging about 1.07 million annually. The number of yearling equivalents released declined by about 22% between the stockings of the 1981 and 1988 year-classes. Stocking declined by 47% in 1992 (1991 year-class) due to problems encountered at the hatchery.

In 1993, fishery managers reduced the lake trout stocking target to 500,000 yearlings because of a predator-prey imbalance in Lake Ontario, and following recommendations from an international panel of scientists and extensive public review. Annual stockings were near the revised 1993 target level in 18 of 25 years during 1993-2017 (Figure 1). ANFH was closed in 2005 due to an outbreak of infectious pancreatic necrosis and remained closed for fish production through summer 2011. Completion of disinfection, renovation and disease trials

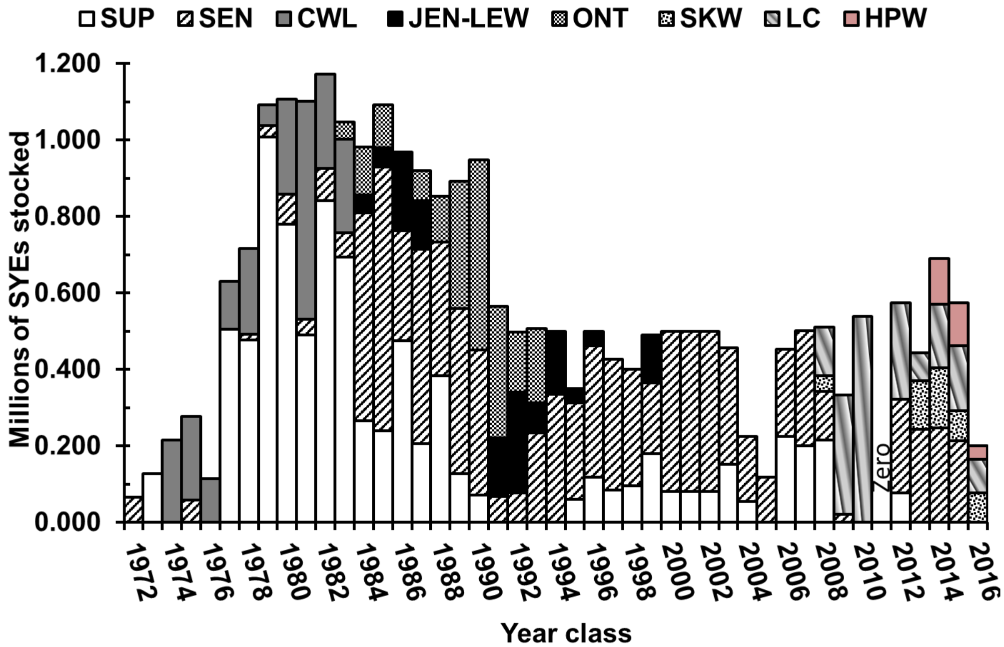

Figure 1. Total spring yearling equivalents (SYE) for lake trout strains (strain descriptions for ONT, JEN-LEW, CWL, SEN, LC, SUP, SKW, HPW appear in Appendix 1) stocked in U.S. waters of Lake Ontario for the 1972 – 2016 year-classes. For year-classes beginning in 2006, SUP refers to Lake Superior lean strains (SAW and STW) other than the Superior Marquette Domestics stocked prior to that time. SYE = 1 spring yearling or 2.4 fall fingerlings (Elrod et al. 1988). No lake trout from the 2011 year-class were stocked in 2012.

permitted fish production to resume at ANFH in fall 2011. Lake trout stocked in 2006 were raised at the NYSDEC Bath Fish Hatchery. Lake trout for 2007 and 2008 stockings were raised at the USFWS Pittsford (the name was changed in 2009 to Eisenhower (ENFH)) and White River National Fish Hatcheries (WRNFH) in Vermont. In 2010, 94% of the stocked lake trout were raised at WRNFH and 6% were raised at NYSDEC Bath Fish Hatchery. All lake trout from stockings in 2009 and 2011 were raised at the USFWS WRNFH. In late August 2011, flooding of WRNFH from the adjacent White River during tropical storm Irene led to the USFWS decision to depopulate the hatchery over serious concerns of raceway contamination with didymo (*Didymosphenia geminate*) from the adjacent White River. As a result, no lake trout from the 2011 year-class were stocked into Lake Ontario in May 2012. Combined production of the 2012 year-class at ANFH and ENFH resulted in stocking of nearly 123,000 fall fingerlings and over 520,000 spring yearlings. During 2014, combined production of the 2013 year-class at ANFH and ENFH resulted in stockings of approximately 442,000 spring yearlings. That same year, fish managers increased the lake trout stocking target to 800,000 spring yearling equivalents (Lantry et al. 2014). Combined production of the 2014 year-class at ANFH and ENFH resulted in stocking of nearly 528,000 fall fingerlings and 521,000 spring yearlings (Connerton 2016). Combined ANFH and ENFH production of the 2015 year-class fish resulted in stocking of nearly 454,000 fall fingerlings and 384,000 spring yearlings (Connerton 2017). In fall 2016, fish managers reduced lake trout and Chinook salmon stocking targets to reduce predatory demand on alewife. The planned target stocking number of the 2016 year-class was 400,000 spring yearlings. No fall fingerling lake trout from the 2016 year-class were stocked. A mortality event at ANFH beginning in late fall 2016 further reduced the number of fish available for stocking, resulting in a combined ANFH and ENFH May 2017 stocking of 200,843 spring yearlings (Connerton 2018). The need to refresh broodstock at the Berkshire National Fish Hatchery also resulted in the release of 304 Klondike strain (SKW) adults from the 2012 year-class into the lake in December 2017.

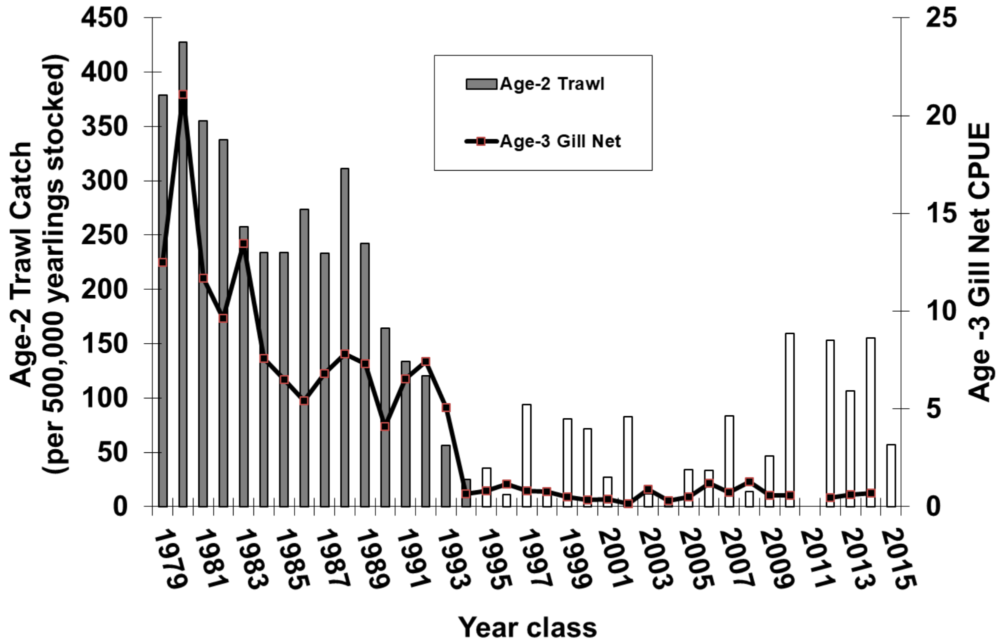

Figure 2. Survival indices for lake trout stocked in U.S. waters of Lake Ontario (no 2011 year-class lake trout were stocked into U. S. waters in 2012). Survival was indexed at age 2 as the total catch from bottom trawls (BTR) fished in July-August per 500,000 fish stocked (Note: White bars represent data collected with a new trawl configuration which employed roller gear on the footrope and did not fish as hard on the lake bottom as the old trawl).

<u>Survival of Stocked Fish to Age-2</u>

The first-year survival index was relatively high for the 1979-1982 year-classes but declined by about 32% and fluctuated without trend for the 1983-1989 year-classes (Figure 2). The index declined further for the 1990 year-class and continued to decline for the 1991-1996 year-classes. The average index value for the 1994-1996 year-classes at age 2 was only 6% of the average for the 1979-1982 year-classes and only 9% of the average for the 1983-1989 year-classes. The survival index was quite variable for the 1993-2009 year-classes, fluctuating by greater than 40-fold with no general trend apparent. The survival indices for the 2010, 2012, 2013 and 2014 year-classes were high compared to the 1995-2009 year-classes. No lake trout from the 2011 year-class were stocked in U.S. waters during 2012, thus no U.S. stocked age-2 lake trout were present/captured in 2014. The survival indices for the 2010, 2012 and 2014 year-class were the highest observed since the 1989 year-class and higher than any other year-class since the early 1990's reductions in stocking. Survival for the 2015 year-class declined by 63%.

<u>Abundance of Age-3 and Older Lake Trout</u>

A total of 641 lake trout were captured in 53 nets during the September 2017 gill net survey, resulting in a total CPUE of mature adults of 9.16 (Figure 3). Catches of lake trout among sample locations were similar within years with the RSE for the CPUE of adult males and females (generally ≥ age 5) averaging only about 9.1% and 10.7% respectively, for the entire data series (Figure 4). The CPUE of mature lake trout had remained relatively stable from 1986 to 1998, but then declined by 31% between 1998 and 1999 due to the poor recruitment of the 1993 year-class. Declines in adult numbers after 1998 were likely due to poor survival of hatchery fish in their first year post-stocking and lower numbers of fish stocked since the early 1990s. After the 1998-1999 decline, the CPUE for mature lake trout remained relatively stable during 1999-2004 (mean = 11.1) appearing to reflect a new stable equilibrium established subsequent to the stocking reductions in 1993, but then abundance declined further (by 54%) in 2005. The 2005-2007 CPUEs of mature lake trout were similar to the 1983-1984 values which pre-dated effective

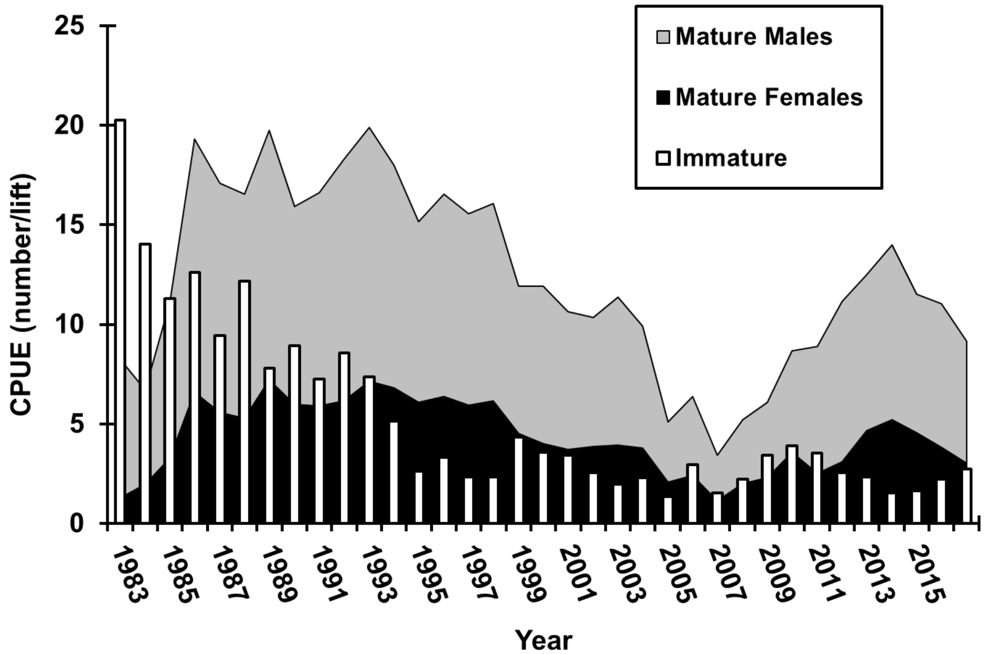

Figure 3. Abundance of mature (generally males ≥ age 5 and females ≥ age 6) and immature (sexes combined) lake trout calculated from catches made with gill nets set in U.S. waters of Lake Ontario, during September 1983-2017. CPUE (number/lift) was calculated based on four strata representing net position in relation to depth of the sets.

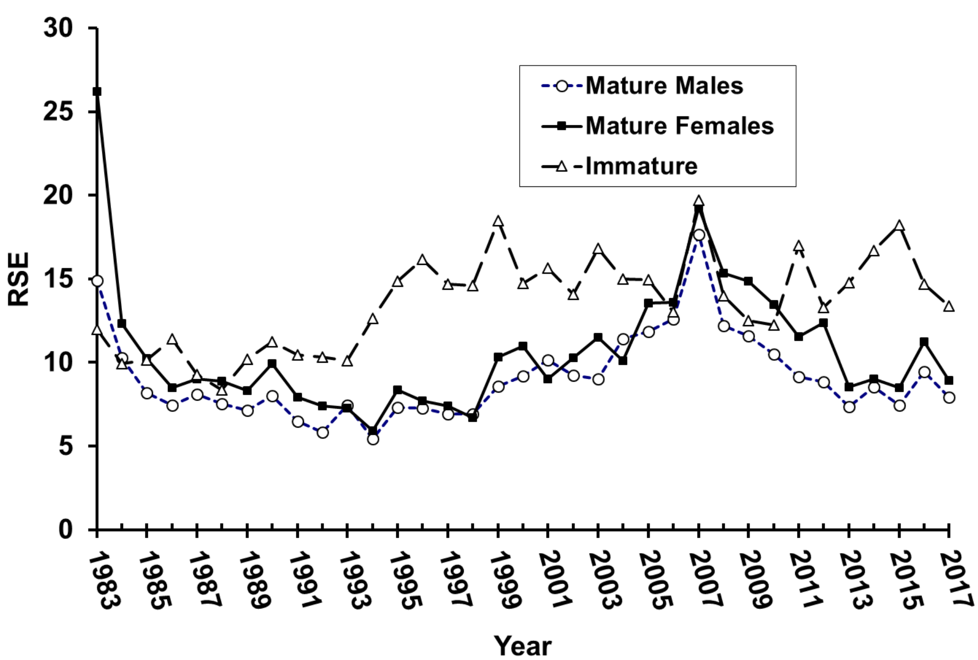

*Figure 4. Relative standard error (RSE = {SE / Mean}*100) of the annual CPUE for mature and immature (sexes combined) lake trout caught with gill nets set in U.S. waters of Lake Ontario, during September 1983-2017.*

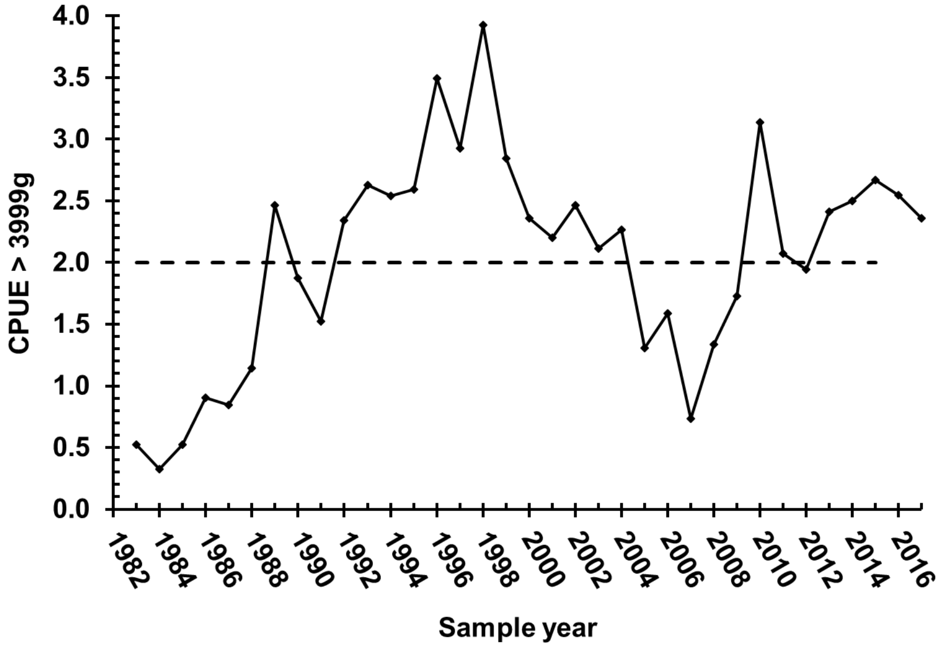

Figure 5. Abundance of mature female lake trout ≥4000g calculated from catches made with gill nets set in U.S. waters of Lake Ontario, during September 1983-2017. The dashed line represents the target CPUE from Schneider et al. (1997) and Lantry et al. (2014).

sea lamprey control. The CPUE of mature lake trout, however, increased each year during 2008-2014, but then declined each year during 2015-2017. Adult abundance in 2017 was 35% below the 2014 peak and 17% below 1999-2004 average. Similar to the catch of age-2 lake trout from bottom trawls, the CPUE for immature lake trout captured in gill nets (generally ages 2 to 5) declined by 64% between 1989-1993 (CPUE: 8.0) and 1995 (CPUE: 2.6) and remained at the lower level thereafter with a mean of 2.6 for 1995-2017.

Schneider et al. (1997) established a target gillnet CPUE of 2.0 for sexually mature female trout ≥ 4,000 g reflecting the level of abundance at which successful reproduction became detectable in the early 1990s. The CPUE for mature females reached the target value in 1989 and fluctuated about that value until 1992 (Figure 5). From 1992 until 2004, the CPUE exceeded the target, but fell below target during 2005 to 2009, coincident with the decline of the entire adult population. As the adult population abundance increased during 2008-2014, the CPUE of mature females ≥ 4,000 g also increased. During 2010-2017, CPUEs of mature females remained near or above target.

<u>Angler Catch and Harvest</u>

Fishing regulations, lake trout population size, and availability of other trout and salmon species influenced angler harvest through time. Since 1988, a slot size limit was instituted by managers to decrease harvest of mature fish and increase the number and ages of spawning adults. In 1992, the regulation permitted a limit of three lake trout harvested outside of the protected length interval of 635 to 762 mm (25 to 30 in). Effective October 1, 2006, the lake trout creel limit was reduced to two fish per day per angler, only one of which could be within the 635 to 762 mm slot.

Annual catch and harvest of lake trout from U.S. waters of Lake Ontario (Figure 6) declined over 84% from 1991 to the early-2000s (Lantry and Eckert 2018). Catch and harvest declined further from the early to the mid-2000s, coinciding with the lake trout population decline (Figure 3) and good fishing quality for other salmonids (i.e., anglers targeted other salmonids more frequently reached the lowest levels in the NYSDEC Fishing Boat Survey data series (Lantry and Eckert 2018). Harvest at that time was more than 97% below the 1991 estimate. After 2007, however, catch because of their relatively high catch rates;

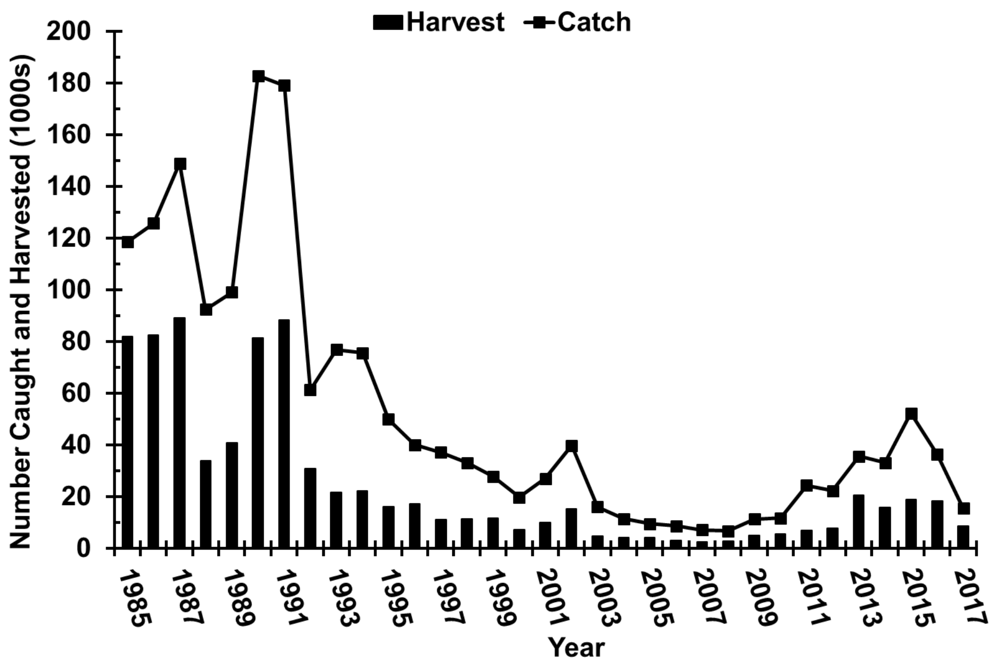

Figure 6. Estimated numbers of lake trout caught and harvested by boat anglers from U.S. waters of Lake Ontario, during April 15 – September 30, 1985-2017 (Lantry and Eckert 2018). Beginning with the 2012 report, all values have been reported reflecting a 5.5-month sampling interval. Prior reports were based on a 6-month sampling interval (April 1 – September 30).

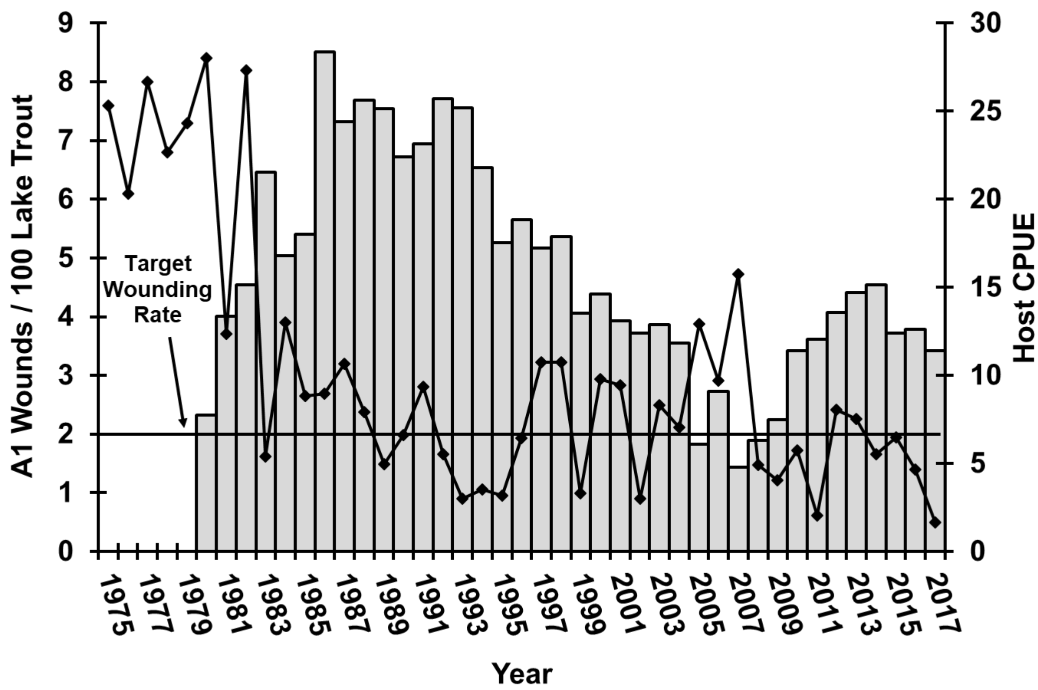

Figure 7. Wounding rates (A1 wounds per 100 lake trout, line) inflicted by sea lamprey on lake trout ≥ 433 mm (17.1 in) TL and the gill net CPUE of lake trout hosts (≥ 433 mm TL, bars) collected from Lake Ontario in fall, 1975-2017.

Lantry and Eckert 2018). In 2007, catch and harvest rates (0.12 and 0.05 lake trout per boat trip, respectively) and total harvest (2,570 fish) and harvest increased for six consecutive years, were relatively stable 2013-2016, then declined in 2017 (15,444 fish caught, 8,592 fish harvested). Increases from 2007 through 2016 follow the October 2006 regulation change, and coincide with an increase in lake trout abundance and anecdotal reports of anglers targeting lake trout more frequently (2013-2016).

While catch and harvest totals for the time trend have been low recently relative to the late 1980s, catch and harvest rates increased to near record high levels in 2015 and 2016 (e.g., catch rates were over 7.5 times higher than the 2007 record low). The 2017 catch rate declined 58.3% from 2015-2016, but was nearly 3.5 times higher than the lows observed in 2007. The 2017 harvest rate was more than 5.4 times higher than in 2007 (Lantry and Eckert 2018). The 2017 declines in catch, harvest, and catch and harvest rates coincide with good to excellent fishing quality for other trout and salmon species which may have reduced fishing effort directed at lake trout as compared to recent years.

Sea Lamprey Predation

Percentage of fresh (A1) sea lamprey marks on lake trout has remained low since the mid-1980s, however, wounding rates (Figure 7) in 9 out of 11 years between 1997 and 2007 were above the target level of 2 wounds per 100 fish ≥433 mm (17.1 in). Wounding rate rose well above target in 2005, reaching a maximum of 4.7 wounds in 2007 which was 2.35 times the target level. Wounding rates fell below target again in 2008 (1.47) and remained there through 2011 (0.62). While the rate was slightly above target again in 2012 (2.41) and 2013 (2.26), it fell below target in 2014 (1.65), 2015 (1.94) and 2016 (1.40). The 2017 wounding rate (0.50) was the lowest for the data series.

Adult Survival

Survival of SEN strain lake trout (ages 7 to 11) was consistently greater (20-51%) than that of the SUP strain for the 1980-1995 year-classes (Table 1). Lower survival of SUP strain lake trout was likely due to higher mortality from sea lamprey (Schneider et al. 1996). Survival of both Jenny (JEN) and Lewis (LEW) strains were similar to the SUP strain, suggesting that those strains may also be highly vulnerable to sea lamprey. Ontario strain (ONT) lake trout were progeny of SEN and SUP strains (Appendix 1) and their survival was intermediate to that of their parent strains.

Survival for all strains combined (hereafter referred to as population survival) was based on all fish captured for the 1983-1995 and 2003-2008 cohorts as all fish stocked during that period received coded wire tags. Population survival was not calculated for the 1978-1982 and 1996-2002 cohorts because only a portion of those stockings received coded wire tags. Population survival generally increased with successive cohorts through the 1985 year-class, exceeded the restoration plan target value of 0.60 beginning with the 1984 year-class, and remained above the target for most year-classes thereafter. The population survival of the most recent completely tagged year-classes (2003-2008) were all above target. The SEN strain survival and the population survival for the 2004 and 2005 year-classes are above target and are identical because the stockings for both year-classes were predominantly SEN. Stockings for both of those year-classes were also far below the 500K target with all 224K of the 2004 year-class being stocked at one site in the eastern basin and all 118K of the 2005 year-class released at one site in the western part of the lake. The SUP strain was no longer available in 2006 and while stockings for the 2006 to 2008 year-classes were back near the 500K target and more evenly distributed between SEN and SUP-like strains those strains from Lake Superior were now Traverse Island strain (STW) and Apostle Island strain (SAW). Strains from Seneca Lake origins now included SENs and feral (LCW) and domestic Lake Champlain strains (LCD). Survival for SENs (2006-2008 year-classes) continued to be high (≥74%) and survival for 2008 year-class of LCDs (72%, ages 7 to 9) resembled their mostly SEN origins. Only one year-class of LCWs was stocked (2009) and those disappeared from survey catches after age 8 preventing calculation of their survival values. Survival rates could also not be calculated for the first large stocking of STWs (225K of the 2006 year-class) which disappeared from survey catches after age 8. They were, however, represented in in population calculations for the 2006 cohort. Recent survival rates for STW

Table 1. Annual survival of various strains (strain descriptions appear in Appendix 1) of lake trout, sampled from U.S. waters of Lake Ontario, 1985-2017. Dashes represent missing values due to no or low numbers of tagged lake trout stocked for the strain, or when the strain was not in the US federal hatchery system. ALL is population survival of all strains combined using only coded wire tagged fish.

YEAR		STRAIN									
CLASS	AGES	JEN	LEW	ONT	SUP	SAW	STW	SEN	LCD	SKW	ALL
1978	7-10	-	-	-	0.40	-	-	-	-	-	-
1979	7-11	-	-	-	0.52	-	-	-	-	-	-
1980	7-11	-	-	-	0.54	-	-	0.85	-	-	-
1981	7-11	-	-	-	0.45	-	-	0.92	-	-	-
1982	7-11	-	-	-	0.44	-	-	0.82	-	-	-
1983	7-11	-	-	0.61	0.54	-	-	0.90	-	-	0.57
1984	7-11	0.39	-	0.61	0.48	-	-	0.70	-	-	0.65
1985	7-11	-	-	0.80	0.47	-	-	0.77	-	-	0.73
1986	7-11	0.57	-	-	0.43	-	-	0.81	-	-	0.62
1987	7-11	0.50	-	-	0.50	-	-	0.80	-	-	0.73
1988	7-11	-	-	0.77	0.61	-	-	0.73	-	-	0.68
1989	7-11	-	-	0.78	0.59	-	-	0.86	-	-	0.81
1990	7-11	-	-	0.64	0.60	-	-	0.75	-	-	0.68
1991	7-11	-	0.56	0.62	-	-	-	0.70	-	-	0.70
1992	7-11	-	0.51	-	-	-	-	0.81	-	-	0.60
1993	7-11	-	0.64	-	-	-	-	0.72	-	-	0.71
1994	7-11	-	0.73	-	-	-	-	0.45	-	-	0.56
1995	7-11	-	0.50	-	-	-	-	0.76	-	-	0.72
1996	7-10	-	-	-	0.43	-	-	-	-	-	-
1999	7-11	-	-	-	-	-	-	0.84	-	-	-
2000	7-11	-	-	-	-	-	-	0.90	-	-	-
2001	7-11	-	-	-	-	-	-	0.73	-	-	-
2003	7-11	-	-	-	0.53	-	-	0.72	-	-	0.68
2004	7-11	-	-	-	-	-	-	0.78	-	-	0.78
2005	7-11	-	-	-	-	-	-	0.85	-	-	0.85
2006	7-11	-	-	-	-	-	-	0.74	-	-	0.72
2007	7-10	-	-	-	-	-	0.36	0.81	-	-	0.74
2008	7-9	-	-	-	-	0.53	0.42	0.76	0.72	0.064	0.65

(36%-42%, 2007 and 2008 year-classes) and SAW (53%, 2008 year-class) strains are low, and similar the original SUP strain, but based on small catches and only 3-4 years of data.

<u>Growth and Condition</u>

The predicted weight of a 700-mm lake trout (from length-weight regressions) decreased during 1983 to 1986, but increased irregularly from 1986 to 1996 and remained relatively constant through 1999 (Figure 8). Predicted mean weight declined by 158.8 g (5.6 oz) between 1999 and 2006, but increased again in 2007 and remained high through 2015. Predicted mean weight rose sharply after 2015 so that 2016-2017 mean (3803.1 g, 8.4 lb) was the highest level for the data series. The trend of improving condition through 1996 and from 2007 to 2017 corresponded to periods when the abundance of older lake trout in the population was increasing. Our data suggested that for lake trout of similar length, older fish were heavier.

To examine condition while removing the effects of age and sex, we calculated annual means for Fulton's *K* for age-6 mature male lake trout (Figure 8). Values of *K* for age-6 males followed a similar trend as predicted weights, which were calculated using data from all fish captured and indicated that age alone was not the determinant of condition for this population. While both predicted weight and condition generally remained at a high level during 2007-2015, a declining trend from 2011 to 2015 was apparent. That trend reversed in 2016 with the second highest Fulton's K value recorded since the time series began in 1983. No value was calculated in 2017 as no fish were stocked from the 2011 year-class. Predicted weights of 400-mm lake trout, based on bottom trawl catches of 250-500 mm

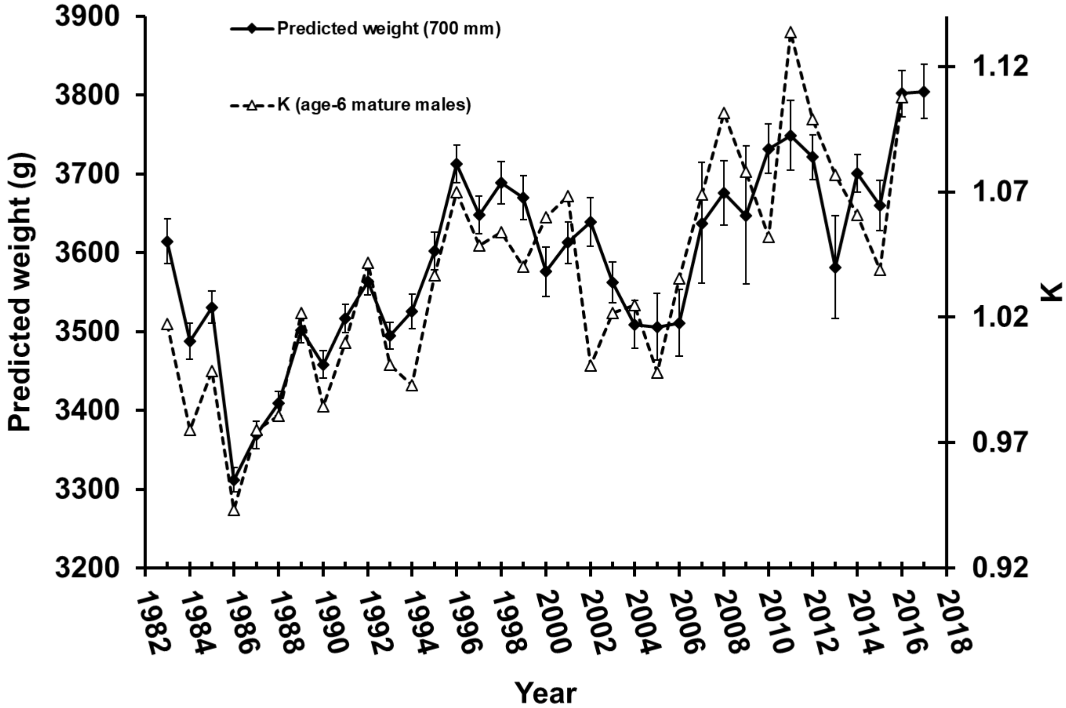

Figure 8. Lake Ontario lake trout condition (K) for age-6 mature males and predicted weight at 700-mm (27.6 in) TL from weight-length regressions calculated from all fish collected during each annual gill net survey, September 1983 – 2017. There were no fish stocked from the 2011 year-class in 2012 so age-6 K is not available in 2017. Error bars represent the regression confidence limits for each annual value.

fish, and Fulton's K for an age-2 lake trout changed between the late 1990s and early 2000s (Figure 9). The mean predicted weight during 1999-2016 declined by 15.4g below the 1979-1998 mean, paralleling declines in native benthic prey resources (Weidel et al. 2014). Predicted weight increased for a brief period during 2006-2008 paralleling increases in round goby (*Neogobius melanostomus)* abundance (Weidel et al. 2014) which are now common in lake trout diets. Condition of immature fish fell again in 2009 (591.3 g, 1.3 lb.) and in most years during 2010-2016, remained at values that were among the lowest for the time series, however condition was high in 2014 (620.0 g, 1.4 lb) and 2017 (617.5 g, 1.4 lb).

<u>Reproductive Potential</u>

Temporal patterns in the egg deposition index (Figure 10) differed considerably from temporal abundance patterns in the CPUE of all mature females (Figure 3). The CPUE of all mature females suggested that reproductive potential quadrupled from 1983 to 1986 and then fluctuated around a high level through 1998. In contrast, the egg index suggested that reproductive potential quadrupled from 1985 to 1993 and then remained high through 1999. The CPUE of mature females declined by 31% between 1998 and 1999, yet a change in reproductive potential was delayed by one year, dropping by 27% between 1999 and 2000. Trends more closely agreed between the egg deposition index and the CPUE of mature females ≥ 4,000 g (Figure 10) than between the index and the CPUE of all females, reflecting the effects of population age structure on fecundity. Strain composition of the eggs was mostly SUP during 1983-1990 and mostly SEN during 1991-2002. After 2002, it became increasingly difficult to assess strain-specific contribution to the egg deposition index because many fish stocked between 1997 and 2003 were not marked with coded wire tags. The first predominantly untagged cohort since 1983 was stocked as spring yearlings in 1997 and was first captured in substantial numbers as mature females at age 5 in 2001. For 2001 and later indices, we calculated size and age-specific fecundities for untagged fish with paired fin clips that facilitated age

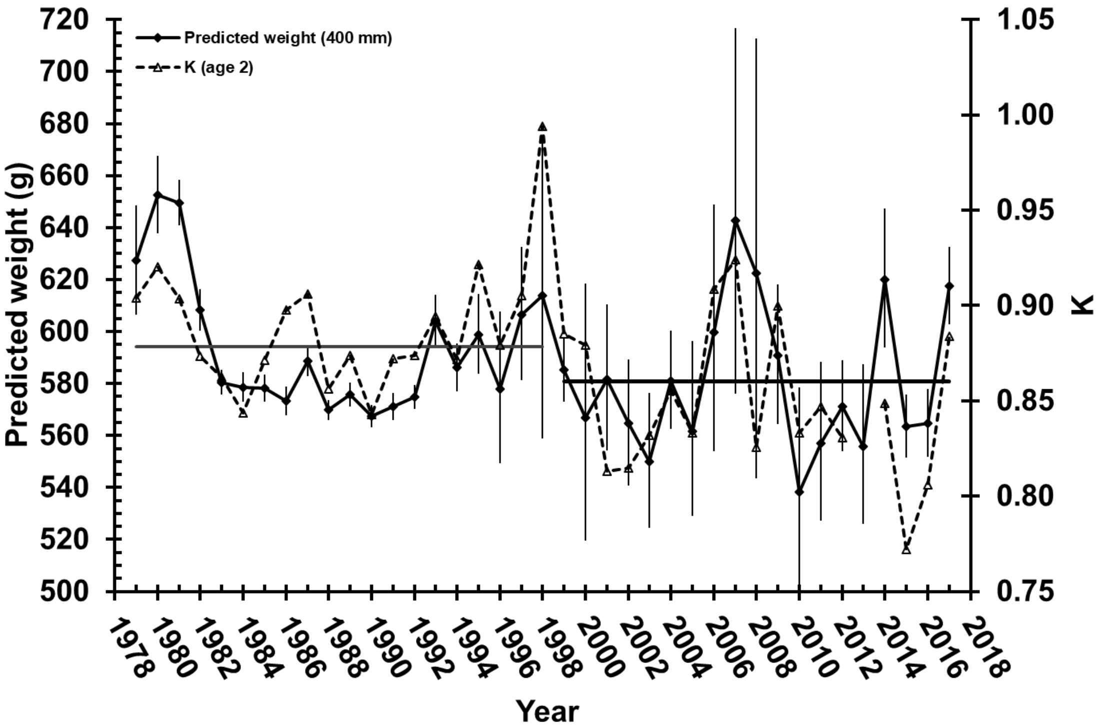

Figure 9. Lake Ontario lake trout condition (K) for age-2 coded wire tagged fish and predicted weight at 400-mm (15.8 in) TL from annual weight-length regressions calculated from fish 250 mm-500 mm (9.8 to 19.7 in). All lake trout were sampled from bottom trawls, July-August 1978-2017. The horizontal lines represent the mean predicted weights during 1979-1998 and during 1999-2017. Sample sizes for regressions were ≥ 39 except for 1997, 2000, 2005, 2006, 2007, 2008 and 2013 (n = 13, 15, 19, 11, 14, 20 and 12, respectively). There were no fish stocked from the 2011 year-class in 2012 so age-2 K is not available in 2013. Error bars represent the regression confidence limits for each annual value.

estimation. We then applied strain-specific mortality correction factors to fecundity estimates of untagged fish and weighted them based on strain composition for specific cohorts at stocking.

The egg deposition index changed little between 2001 and 2004 and the average for those years was 42% lower than the average for 1993 to 1999. In 2005, the index dropped by 40% below the 2001-2004 mean and during 2007-2008 values dropped to the lowest observed since 1985. The index value increased in 2009 and remained relatively constant through 2012. The 2009-2012 mean was 25% below the mean for 2001-2004. In 2013-2017 egg deposition indices were similar to 2001-2004 values and, for the first time, included contributions from SKW lake trout from the 2008 year-class (see Appendix 1 for strain descriptions).

<u>Natural Reproduction</u>

Evidence of survival of naturally produced lake trout past the summer/fall fingerling stage occurred in each year during 1993-2017 (Figure 11) except 2008, representing production of 23 year-classes. Numbers caught represent the entire annual bottom trawl catch from four surveys occurring during April-October 1979-2017 (for a description of the surveys see O'Gorman et al. 2000 and Owens et al. 2003). In 2015, the June bottom trawl survey was discontinued, so total trawl effort decreased. Catch was not corrected for effort due to the low catch in most years and a relatively constant level of effort expended within the depth range (20m - 100m) where age-0 to age-2 naturally reproduced lake trout are most often encountered in Lake Ontario for most years. Low numbers of small (<100 mm, 3.9 in), wild fish captured during1997-2017 may have been due in part to a change in our trawl gear that was necessary to avoid.

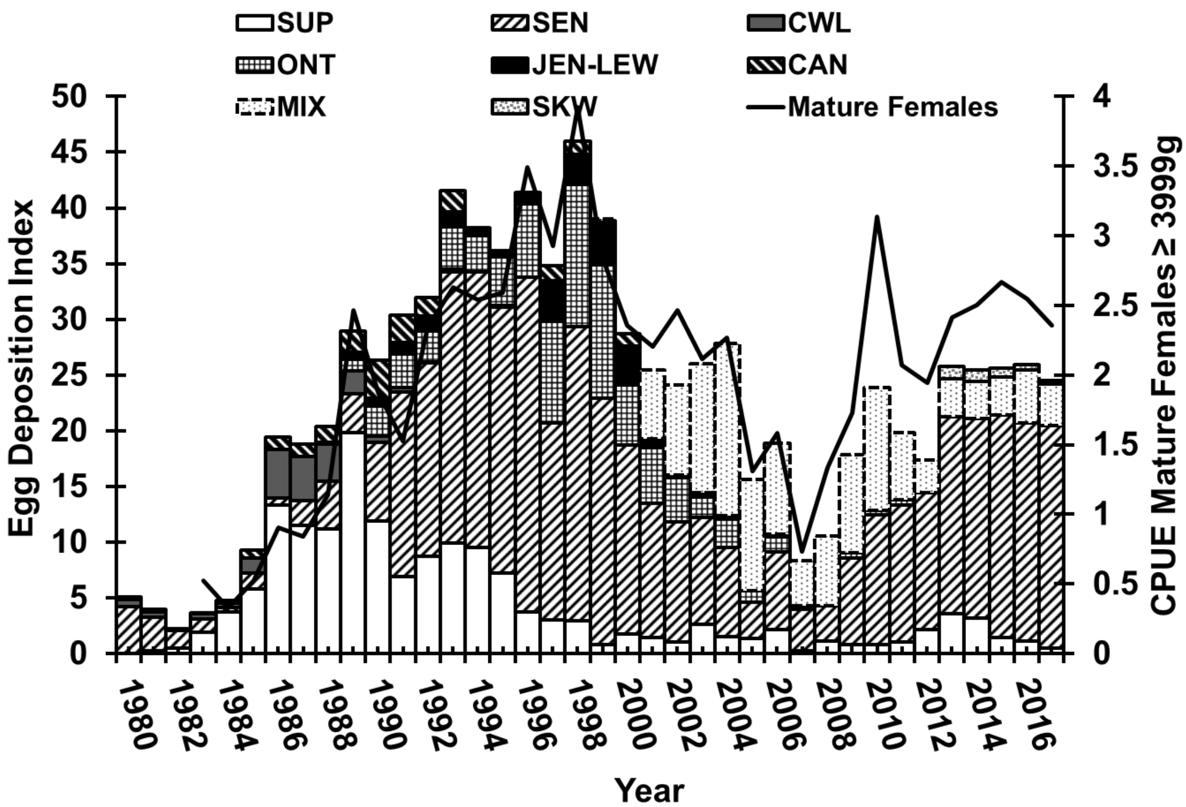

Figure 10. Egg deposition indices by strain (strain descriptions for ONT, JEN-LEW, CWL, SEN, SUP and SKW appear in Appendix 1) for lake trout in U.S. waters of Lake Ontario during 1980-2017. CAN represents a mix of the strains stocked by OMNRF and MIX represents values for untagged females stocked since 1997 for which strain could not be determined. The solid line is the CPUE of mature females ≥4000g.

abundant dreissenid mussels. The wild yearlings captured in 2010-2017 were the first wild yearlings caught since 2005. The four largest catches of the 24-year time-series occurred during 2014-2017 with 47 age-1 (93-186 mm, 3.7-7.3 in) and 70 age-2 wild lake trout (176-291 mm, 6.9-11.5 in) caught in 2014; 24 age-1 (94-147 mm, 3.7-5.8 in) and 48 age-2 (167-262 mm, 6.6-10.3 in) caught in 2015; 21 age-1 (87-169 mm, 3.5-6.6 in) and 30 age-2 (178-245 mm, 7.0-9.6 in) caught in 2016; and 8 age-1 (90-133 mm, 3.5-5.2 in) and 62 age-2 (148-265 mm, 5.8-10.4 in) caught in 2017.

The distribution of catches of wild fish suggests that lake trout are reproducing throughout New York waters of Lake Ontario with the greatest concentration coming off the Niagara Bar area at the mouth of the Niagara River (Figure 12). Catches from at least 23 cohorts of wild lake trout since 1994 and survival of those year-classes to older ages demonstrates the feasibility of lake trout rehabilitation in Lake Ontario (Schneider et al. 1997). Although recent large catches of wild lake trout are encouraging, achieving the goal of a self-sustaining population requires consistent production of relatively large wild year-classes and survival of those fish to reproductive ages.

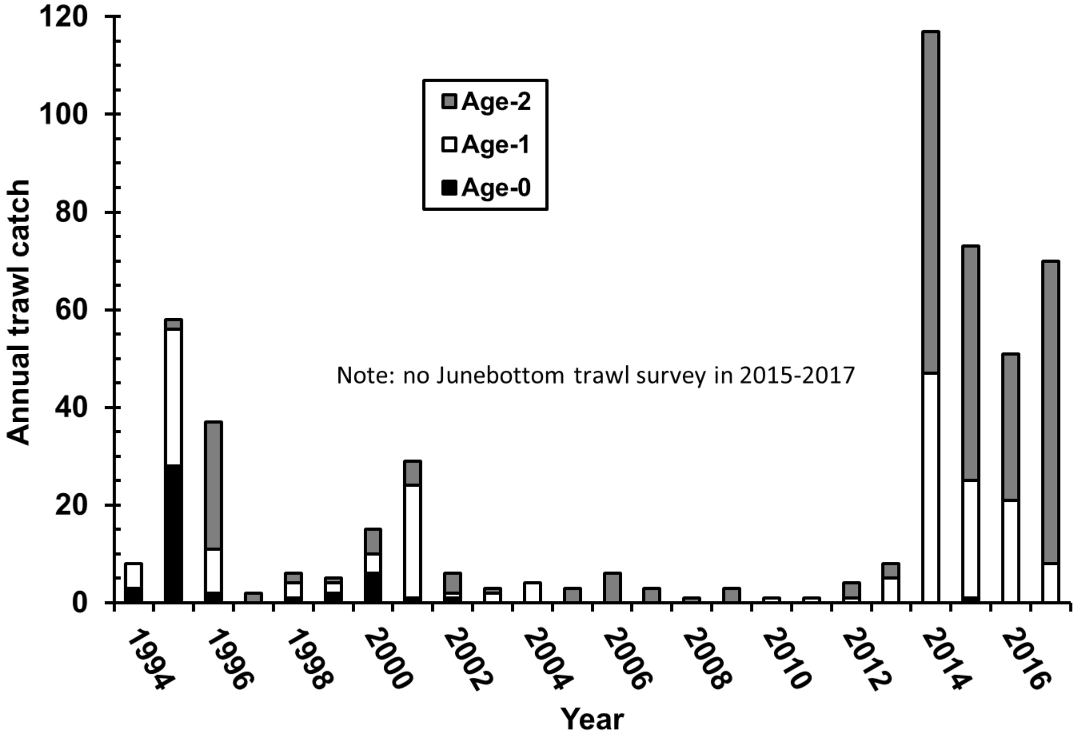

Figure 11. Numbers and ages of naturally produced (wild) lake trout captured with bottom trawls in Lake Ontario by NYSDEC and USGS, 1994-2017. During 1980-1993, only one naturally produced lake trout was captured with bottom trawls.

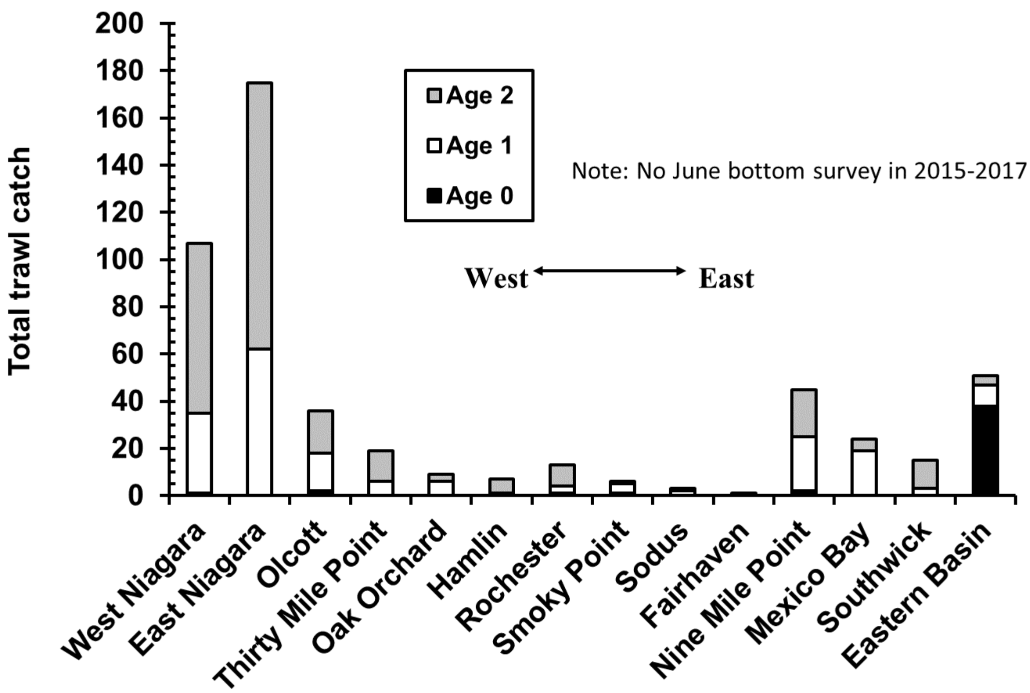

Figure 12. Numbers of wild lake trout (age 0 to 2) captured with bottom trawls at various locations in Lake Ontario by NYSDEC and USGS, 1994-2017. (Note: east and west Niagara are only sampled once per year whereas the other locations are usually sampled four times per year.

References

Bergstedt, R. A. and C. P. Schneider. 1988. Assessment of sea lamprey (*Petromyzon marinus*) predation by recovery of dead lake trout (*Salvelinus namaycush*) from Lake Ontario, 1982-85. Can. J. Fish. Aquat. Sci. 45:1406-1410.

Connerton, M. J. 2016. New York Lake Ontario and Upper St. Lawrence River Stocking Program 2015. Section 1 *In* 2015 NYSDEC Annual Report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to the Great Lakes Fishery Commission's Lake Ontario Committee.

Connerton, M. J. 2017. New York Lake Ontario and Upper St. Lawrence River Stocking Program 2016. Section 1 *In* 2016 NYSDEC Annual Report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to the Great Lakes Fishery Commission's Lake Ontario Committee.

Connerton, M. J. 2018. New York Lake Ontario and Upper St. Lawrence River Stocking Program 2017. Section 1 *In* 2017 NYSDEC Annual Report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to the Great Lakes Fishery Commission's Lake Ontario Committee.

Ebener, M. P., E. L. King, Jr., and T. A. Edsall. 2006. Application of a dichotomous key to the classification of sea lamprey marks on Great Lakes Fish. Great Lakes Fishery Commission Miscellaneous Publication 2006-2.

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

Elrod, J. H., O'Gorman, R. and C. P. Schneider. 1996. Bathythermal distribution, maturity, and growth of lake trout strains stocked in U.S. waters of Lake Ontario, 1978-1993. J. Great Lakes Res. 22:722-743.

Elrod, J. H., Ostergaard, D. E. and C. P. Schneider. 1988. Comparison of hatchery-reared lake trout stocked as fall fingerlings and as spring yearlings in Lake Ontario. N. Amer. J. of Fish. Manage. 8:455-462.

King, E. L. Jr. and T. A. Edsall. 1979. Illustrated field guide for the classification of sea lamprey attack marks on Great Lakes lake trout. Great Lakes Fishery Commission Special Publication 70-1.

Krueger, C. C., Horrall, R. M., and Gruenthal, H. 1983. Strategy for use of lake trout strain in Lake Michigan. Report 17 of the Genetics Subcommittee to the Lake Trout Technical Committee for Lake Michigan, Great lakes Fish. Comm., Madison, WI.

Lantry, B. F. and Lantry, J. R. 2013. Lake trout rehabilitation in Lake Ontario, 2012. Section 5 *In* 2012 NYSDEC Annual Report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to the Great Lakes Fishery Commission Lake Ontario Committee.

Lantry, B. F. and Prindle, S. P. 2006. Lake trout rehabilitation in Lake Ontario, 2005. Section 5 *In* 2005 NYSDEC Annual Report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to the Great Lakes Fishery Commission Lake Ontario Committee.

Lantry, J. R. and Eckert, T. H. 2018. 2017 Lake Ontario fishing boat survey. Section 2 In 2017 NYSDEC Annual Report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to the Great Lakes Fishery Commission's Lake Ontario Committee.

Lantry, J., Schaner, T., and Copeland T. 2014. A management strategy for the restoration of lake trout in Lake Ontario, 2014 Update. Available from http://www.glfc.org/lakecom/loc/lochome.php [accessed 03 March 2015].

Nash, D. M., A. H. Valencia, and A. J. Geffen. 2006. The origin of Fulton's condition factor – setting the record straight. Fisheries 31:236-238.

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

O'Gorman, R., Elrod, J. H. and C. P. Schneider. 1998. Reproductive potential and fecundity of lake trout strains in southern and eastern Lake Ontario, 1977-94. J. Great Lakes Res. 24:131-144.

Owens, R. W., O'Gorman, R., Eckert, T. H., and Lantry, B. F. 2003. The offshore fish community in southern Lake Ontario. Pages 407-441, in Munawar, M. (ed.), State of Lake Ontario: Past, Present, and Future. Ecovision World Monograph Series. Backhuys Publishers, Leiden, The Netherlands.

Page, K. S., Scribner, K. T., Bennett, K. R., and Garzel, L. M. 2003. Genetic assessment of strain-specific sources of lake trout recruitment in the Great lakes. Trans. Am. Fish. Soc. 132:877-894.

Schneider, C. P., Kolenosky, D. P. and D. B. Goldthwaite. 1983. A joint plan for the rehabilitation of lake trout in Lake Ontario. Great Lakes Fishery Commission, Lake Ontario Committee. Spec. Publ. 50 p.

Schneider, C. P., Owens, R. W., Bergstedt, R. A. and R. O'Gorman. 1996. Predation by sea lamprey (*Petromyzon marinus*) on lake trout (*Salvelinus namaycush*) in southern Lake Ontario, 1982-1992. Can. J. Fish. Aquat. Sci. 53:1921-1932.

Schneider, C. P., Schaner, T., Orsatti, S., Lary, S. and D. Busch. 1997. A management strategy for Lake Ontario lake trout. Report to the Lake Ontario Committee.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Bulletin of the Fisheries Research Board of Canada 191:1-382.

Visscher, L. 1983. Lewis Lake lake trout. U. S. Fish Wild. Ser., Denver, CO.

Weidel, B. C., Walsh, M. G., and M.J. Connerton. 2014. Sculpins and round goby assessment in the U.S. waters of Lake Ontario, 2013. Section 12 *In* 2013 NYSDEC Annual Report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to the Great Lakes Fishery Commission Lake Ontario Committee.

Appendix 1

<u>Strain Descriptions</u>

SEN - Lake trout descended from a native population that coexisted with sea lamprey in Seneca Lake, NY. A captive brood stock was maintained at the USFWS Alleghany National Fish Hatchery (ANFH) which reared lake trout for stocking in Lakes Erie and Ontario beginning with the 1978 year-class. Through 1997, eggs were collected directly from fish in Seneca Lake and used to supplement SEN brood stocks at the USFWS Alleghany National Fish Hatchery (ANFH) and USFWS Sullivan Creek National Fish Hatchery (SCNFH). Beginning in 1998, SEN strain broodstocks at ANFH and SCNFH were supplemented using eggs collected from both Seneca and Cayuga Lakes. Since 2003 eggs to supplement broodstocks were collected exclusively from Cayuga Lake.

LC - Lake trout descended from a feral population in Lake Champlain. The brood stock (Lake Champlain Domestic; LCD) is maintained at the State of Vermont's Salisbury Fish Hatchery and is supplemented with eggs collected from feral Lake Champlain fish. Eggs taken directly from feral Lake Champlain fish (Lake Champlain Wild; LCW) were also reared and stocked.

SUP - Captive lake trout brood stocks derived from "lean" Lake Superior lake trout. Brood stock for the Lake Ontario stockings of the Marquette strain (initially developed at the USFWS Marquette Hatchery; stocked until 2005) was maintained at the USFWS Alleghany National Fish Hatchery until 2005. The Superior – Marquette strain is no longer available for Lake Ontario stockings. Lake Ontario stockings of "lean" strains of Lake Superior lake trout resumed in 2007 with Traverse Island strain fish (STW; 2006-2008 year-classes) and Apostle Island strain fish (SAW; 2008 and 2012 year-classes). Traverse Island strain originated from a restored "lean" Lake Superior stock. The STW brood stock was phased out of production at USFWS Iron River National Fish Hatchery (IRNFH) and is no longer be available as a source of eggs for future Great Lakes stockings. The Apostle Island strain was derived from a remnant “lean” Superior stock restored through stocking efforts, was phased out of production at USFWS Iron River National Fish Hatchery (IRNFH) and is no longer be available as a source of eggs for future Great Lakes stockings.

SKW - Originated from a native, deep spawning “humper” morphotype of Lake Superior lake trout that are intermediate in fat content to lean and fat (siscowet) morphotypes. Captive brood stocks have been held at the USFWS Sullivan Creek National Fish Hatchery and USFWS Iron River National Fish Hatchery. The USFWS Berkshire National Fish Hatchery developed a SKW brood stock to supply fertilized eggs to ANFH for rearing and stocking into Lake Ontario.

CWL - Eggs collected from lake trout in Clearwater Lake, Manitoba, Canada and raised to fall fingerling and spring yearling stage at the USFWS Alleghany National Fish Hatchery in Warren, Pennsylvania (see Elrod et al. 1995).

JEN-LEW - Northern Lake Michigan origin stocked as fall fingerlings into Lewis Lake, Wyoming in 1890. Jenny Lake is connected to Lewis Lake. The 1984-1987 year-classes were from brood stock at the Jackson (Wyoming) National Fish Hatchery and the 1991-1992 year-classes were from broodstock at the Saratoga (Wyoming) National Fish Hatchery

ONT - Mixed strains stocked into and surviving to maturity in Lake Ontario. The 1983-1987 year-classes were from eggs collected in the eastern basin of Lake Ontario. The 1988-1990 year-classes were from broodstock developed from the 1983 egg collections from Lake Ontario. Portions of the 1991-1992 year-classes were from ONT strain broodstock only and portions were developed from crosses of ONT strain broodstock females and SEN males (see Elrod et al. 1995).

HPW - “Lean” lake trout strain originated from a self-sustaining remnant population located in Parry Sound on the Canadian side of Lake Huron in Georgian Bay. A captive HPW broodstock is maintained at the USFWS Sullivan Creek National Fish Hatchery and is the source of eggs for HPW reared at USFWS Alleghany National Fish Hatchery in Warren, Pennsylvania for stocking into Lake Ontario. The first HPW lake trout stocking into Lake Ontario occurred in fall 2014.

For further discussion of the origin of strains used in Lake Ontario lake trout restoration see Krueger et al. (1983), Visscher, L. 1983, and Page et al. 2003.

Bottom trawl assessment of Lake Ontario prey fishes[1,2]

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Abstract
Managing Lake Ontario fisheries in an ecosystem-context requires prey fish community and population data. Since 1978, multiple annual bottom trawl surveys have quantified prey fish dynamics to inform management relative to published Fish Community Objectives. In 2017, two whole-lake surveys collected 341 bottom trawls (spring: 204, fall: 137), at depths from 8-225m, and captured 751,350 fish from 29 species. Alewife were 90% of the total fish catch while Deepwater Sculpin, Round Goby, and Rainbow Smelt comprised the majority of the remaining total catch (3.8, 3.1, and 1.1% respectively). The adult Alewife abundance index for U.S. waters increased in 2017 relative to 2016, however the index for Canadian waters declined. Adult Alewife condition, assessed by the predicted weight of a 165 mm fish (6.5 inches), declined in 2017 from record high values observed in spring 2016. Spring 2017 Alewife condition was slightly less than the 10-year average, but the fall value was well below the 10-year average, likely due to increased Age-1 Alewife abundance. The Age-1 Alewife abundance index was the highest observed in 40 years, and 8-times higher than the previous year. The Age-1 index estimates Alewife reproductive success the preceding year. The warm summer and winter of 2016 likely contributed to the large year class. In contrast the relatively cool 2017 spring and cold winter may result in a lower than average 2017 year class. Abundance indices for Rainbow Smelt, Cisco, and Emerald Shiner either declined or remained at low levels in 2017. Pelagic prey fish diversity continues to be low since a single species, Alewife, dominates the catch.

Deepwater Sculpin were the most abundant benthic prey fish in 2017 because Round Goby abundance declined sharply from 2016. Slimy Sculpin density continued to decline and the 2017 biomass index for U.S. waters was the lowest ever observed. Prior to Round Goby proliferation, juvenile Slimy Sculpin comprised ~10% of the Slimy Sculpin catch, but since 2004, the percent of juveniles within the total catch is less than 0.5%, suggesting Round Goby are limiting Slimy Sculpin reproduction. Despite Slimy Sculpin declines, benthic prey fish community diversity has increased as Deepwater Sculpin and Round Goby comprise more of the community.

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[1]Presented at Great Lakes Fishery Commission, Lake Ontario Committee Meeting, Markham, ON on March 27, 2018.

[2]The data associated with this report are available at: U.S. Geological Survey, Great Lakes Science Center, 2018, Great Lakes Research Vessel Operations 1958-2017 (ver. 2.0, March 2018): U.S. Geological Survey Data Release, https://doi.org/10.5066/F75M63X0.

Introduction

Managing Lake Ontario fisheries in an ecosystem-context requires reliable data on the status and trends of prey fishes that support predators and drive food web dynamics (Stewart et al., 2017). Alewife are the primary pelagic prey fish in Lake Ontario and support most of the lake's predators (Mills et al., 2003; Murry et al., 2010; Stewart and Sprules, 2011). Rainbow Smelt and Round Goby are also important diet items for various species and sizes of piscivores (Lantry, 2001; Rand and Stewart, 1998; Rush et al., 2012). The demersal, or benthic, prey fish community is primarily comprised of nonnative Round Goby, and native Deepwater and Slimy Sculpin.

The Lake Ontario pelagic prey fish community has undergone dramatic change. Historically, it is believed Cisco and Bloater were the primary prey fishes in Lake Ontario, and these species also supported commercial fisheries (Christie, 1972). In the early and mid-1900s, Cisco and Bloater populations declined due to overfishing, habitat alterations, and competition with introduced species (Christie, 1972). Alewife was first observed in Lake Ontario in 1873 and are believed to have gained entrance in the late 1800s after the opening of the Erie Canal system (Smith, 1985). Rainbow Smelt was first reported in Lake Ontario in 1929, and probably moved from the upstream Finger Lakes, where they were introduced (Greely 1939; Nellbring 1989; Rooney and Patterson 2009). Alewife, and to a lesser extent Rainbow Smelt, have dominated the Lake Ontario fish community during the modern period (1978-present) and they dominate piscivore diet consumption (Lantry, 2001; Murry et al., 2010; Stewart and Sprules, 2011).

The native Lake Ontario benthic fish community was believed to include Deepwater, Spoonhead, and Slimy Sculpin in deep habitats, while Spottail Shiner, Johnny Darter, and Trout-perch were abundant closer to shore (Christie, 1972, 1973). When trawl surveys began in 1978, Slimy Sculpin and the nearshore species comprised the benthic prey fish community. At that time, Spoonhead Sculpin and Deepwater Sculpin were rare or considered extirpated. Since the 1990s, Slimy Sculpin have fluctuated, but generally declined as dreissenid mussel and Round Goby introductions have changed the benthic fish and invertebrate community (Owens and Dittman, 2003; Weidel and Walsh, 2015).

Slimy Sculpin were historically important in juvenile Lake Trout diets (Elrod and O'Gorman, 1991), but more recently Round Goby abundance has increased and are now common benthic prey found in Lake Trout (Rush et al., 2012). Finally, Deepwater Sculpin, a native species listed as "endangered" in New York State, has undergone a dramatic population recovery since the mid-2000s (Weidel et al., 2017).

Two prey fish bottom trawl surveys are collaboratively conducted each year in April and October to inform fisheries management decisions by improving the collective understanding of the Lake Ontario prey fish community. This report describes the status of Lake Ontario prey fishes with emphasis on information addressing the bi-national Lake Ontario Committee's Fish Community Objectives (Stewart et al., 2017).

Methods

Spring survey

The Lake Ontario spring bottom trawl survey has been collaboratively conducted by NYSDEC and USGS during April and May since 1978. The survey collects many species but targets Alewife at a time when their winter, bottom-oriented behavior maximizes their susceptibility to bottom trawls (Wells, 1968). Trawling is conducted during the day at fixed transect locations. Although random sampling is preferable for abundance estimates, it is not practical because of varied substrates that can prohibitively damage trawls at randomly selected sites (MacNeill et al., 2005). A team of fish sampling experts reviewed the Lake Ontario prey fish trawl program and found the fixed-station sampling design generated a suitable estimate of relative abundance (ICES, 2004; MacNeill et al., 2005). The original survey design sampled from 8-150m (26-495 ft) in U.S. waters at 12 transects. Fish distribution changes and needs for lake-wide information have resulted in survey expansion. For instance, nutrient reductions and dreissenid mussel filtration resulted in increased water clarity and subsequently the early depth distributions of Alewife and other prey fish shifted deeper (O'Gorman et al., 2000). In 2004 trawling was expanded to 170m in U.S. waters. In 2016, the survey effort expanded to a whole-lake design and the Ontario Ministry of Natural Resources and Forestry (OMNRF) research vessel joined the survey. Since 2016, trawls have been *collected from 8-225m (26-743 ft), with sites organized in 23 transects or regions distributed around the lake (Figure 1).

The original survey used a nylon Yankee bottom trawl with an 11.8-m (39 ft) headrope and flat, rectangular, wooden trawl doors. Prohibitive catches of dreissenid mussels in the 1990s required changing to a “3N1” trawl, with an 18-m (59 ft) headrope and spread with slotted, metal, cambered V-doors. The survey adopted this new trawl design in 1997 and for consistency the time series statistics for the spring bottom trawl survey are illustrated from 1997 to present. Bottom trawl catches were separated to species, counted, and weighed in aggregate. Subsamples of all species were also measured for individual length and weight, and stomachs, muscle tissue, and various aging structures were removed for age interpretation and archives.

Abundance indices are based on the mean, lake area-weighted catch per 10-minute bottom trawl. Stratification is based on 20 meter (66 ft) stratification depth intervals and the proportional area of those depth intervals within the lake (Table 1). Separate indices are calculated for U.S. and Canadian trawl catches. Mean and standard error calculations were from Cochrane (1977). The survey expansion complicates analyses because the proportions of lake area within each 20m-strata change as more strata area included (Table 1). Statistics reported for trawl catches in Canadian waters followed a similar analysis, however the area within 20m strata in Canada differed from U.S. waters (Table 1). Condition indices are estimated using a linear model that predicts weight based on length and illustrated as the average weight a 165-mm (6.5 inch) Alewife in the spring and fall over time. Statistics for community diversity calculations were based on the most commonly captured pelagic species and those species identified in Fish Community Objectives (Table 2). The Shannon index was used to describe pelagic and benthic community diversity based on the overall trawl catch (Shannon and Weaver, 1949).

Fall survey

From 1978-2011, the fall bottom trawl survey sampled six transects along the southern shore of Lake Ontario from Olcott to Oswego, NY and targeted benthic or demersal prey fish. Daytime trawls were typically 10 minutes and sampled depths from 8–150 m (26-495 ft). The original survey gear was a Yankee bottom trawl described above. Abundant dreissenid mussel catches led to a variety of alternate polypropylene bottom trawls and metal trawl doors being used from 2004-2010. Comparison towing indicated alternate trawls had low and variable catchability for benthic fishes and the alternative trawl doors influenced net morphometry (Weidel and Walsh, 2013). Since 2011, the survey has used the historical standard Yankee trawl and reduced tow times to reduce mussel catches. Experimental sampling at new transects and/or deeper habitats began in 2012. More notably, in 2015 the survey effort was doubled to include Canadian waters and the NYS Department of Environmental Conservation and OMNRF research vessels joined the survey. Benthic prey fish time series are illustrated from 1978 to present and no adjustments are available for data when the alternative trawls were used. Trawl catch processing is as described for the spring survey. In contrast to the spring survey results that are expressed as the average number of fish caught (?) per 10-minute tow, benthic fish abundance is represented as average biomass (units: kg/ha). The lake bottom area swept by the trawl varies according to depth (Weidel and Walsh, 2013). Reporting in these units provides data in a more readily useable form to address ecosystem questions and to make species and community comparisons across lakes. Time series are still regarded as biomass indices since we lack estimates of trawl catchability (proportion of the true density captured by the trawl).

Results and Discussion

Alewife – The adult Alewife (Age-2 and older) abundance index for U.S. waters increased in 2017 (1672 Alewife per 10 minute tow) relative to 2016 (746) but was below the 10-year average (10-yr avg =1940, Figure 2). The increase is relevant since the 2016 U.S. adult Alewife abundance index value was likely the lowest observed since the current survey and trawl design began in 1997. A lower value was observed in 2010 (460 Alewife per 10 minute tow), but cohort analyses indicated that value was biased low. In contrast to the U.S. index, the adult Alewife index in Canadian waters declined from 2016 to 2017 (Figure 2). The Age-1 Alewife abundance index for U.S. waters increased in 2017 (3977 fish per 10 minute trawl) relative to 2016 (506) and was approximately 5 times higher than the 10-year average (2007:2016 average = 684; Figure 2).

The low Alewife abundance observed in 2016 is consistent with the two consecutive years of low Alewife reproductive success observed in 2013 and 2014. Alewife reproductive success for a given year is measured the following year, so those low year classes from 2013 and 2014 are illustrated in Figure 3 as low numbers of Age-1 Alewife captured in 2014 and 2015. The increased catch in adult Alewife, from 2016 to 2017 (U.S. index) was attributable to the moderate 2015 Alewife year class, which first counted towards the adult index when they reached age-2 in 2017.

Since the record high 2016 Alewife year class will be Age-2 in 2018, we expect the 2018 adult Alewife index value to increase relative to 2017. The relatively cool 2017 spring and cold winter may result in a lower than average 2017 year class since temperature has been shown to influence Alewife year class strength in Lake Ontario (O'Gorman et al., 2004).

The seasonal timing of trawl surveys, within a given year, has a strong influence on Lake Ontario Alewife catches. For example, in 2017, the average biomass of all Alewife captured in the spring trawls was 72 kilograms per hectare, while the average of the 137 fall trawls was 2 kilograms per hectare (Figure 4). In addition to the broad seasonal effects, survey timing within the spring survey period may also influence Alewife catches. An experimental effort in 2017 sampled the Oswego transect twice, 21 days apart, and the mean biomass value for that transect was 75% less during the second sampling. This may explain the relatively lower Alewife abundance index in Canadian waters in 2017, where trawling occurred slightly later than in U.S. waters. The direction and magnitude of the differences in U.S. and Canadian trawl indices in 2016 and 2017 accentuates the need for a lake wide survey. Seasonal effect on Alewife susceptibility to bottom trawls was also apparent in Lake Michigan in 1964 (Wells, 1968). Future research efforts should consider evaluating how Alewife behavior changes in the spring with respect to photoperiod and temperature and how those behavior changes influence abundance estimates.

Adult Alewife condition, assessed by the predicted weight of a 165 mm fish (6.5 inches) declined in 2017 from a record high spring value observed in 2016 (Figure 5). Condition in spring 2017 was slightly less than the 10-year average, but the fall value was well below the 10-year average, likely due to record high Age-1 Alewife abundance that would have increased competition for zooplankton resources (Figure 5).

Other Pelagic Fishes – Bottom trawl abundance indices for Rainbow Smelt, Cisco, and Emerald Shiner either declined or remained at low levels in 2017 (Figure 6). Alewife dominance relative to Rainbow Smelt in Lake Ontario trawl catches may be related to adult Alewife predation on Age-0 Rainbow Smelt and competition for zooplankton. The habitat distribution of Age-0 Rainbow Smelt overlaps with adult Alewife during the summer (Simonin et al., 2016). Increased Cisco catches observed in 2015 were not evident in 2017 (Figure 6), however bottom trawl surveys have been shown to underestimate Cisco abundance compared to acoustic and midwater sampling (Stockwell et al., 2006).

Demersal prey fishes - In 2017, Deepwater Sculpin were the most abundant benthic prey fish because Round Goby abundance declined sharply from 2016 (Figure 7). Deepwater Sculpin were once thought to be extirpated from Lake Ontario, but their abundance and weight indices have increased steadily since 2004 (Weidel et al., 2017). Slimy Sculpin density has continued to decline and the 2017 biomass index for U.S. waters was the lowest observed (Figure 7). Slimy Sculpin declines in the 1990s were attributed to the collapse of their preferred prey, the amphipod Diporeia (Owens and Dittman, 2003).

The declines that occurred in the mid-2000s appear to be related to Round Goby. Since Round Goby numbers have increased the proportion of juvenile Slimy Sculpin in the total catch of Slimy Sculpins dropped from ~10% to less than 0.5% (Figure 8). These data suggest Round Goby are limiting Slimy Sculpin reproduction or possibly recruitment of juvenile Slimy Sculpin to adult stages. Interestingly, Slimy Sculpin biomass is higher in Canadian waters but may also be declining although the time series only includes three years (Figure 7).

Prey fish diversity - Lake Ontario Fish Community Objectives call for increased prey fish diversity (Stewart et al., 2017). Bottom trawl data suggest that pelagic prey fish community diversity remains low since a single species, Alewife, dominates the catch (Figure 9). Actions to improve pelagic community diversity are currently underway in Lake Ontario, including Bloater restoration and Cisco rehabilitation. Despite Slimy Sculpin declines, benthic prey fish community diversity has generally increased over the time series. In the 1970s – 1990s a single species, Slimy Sculpin, dominated the catch, resulting in lower diversity values. More recently, increases in Deepwater Sculpin and the introduction of Round Goby, which make up more even portions of the catch, have caused the index value to increase (Figure 9).

Acknowledgements
Special thanks to all information, vessel, biological, and administrative support staff for their effort and flexibility conducting the 2017 Lake Ontario prey fish surveys. Funding for USGS sampling and analysis is from the Ecosystems area and the Fisheries and Status and Trends programs. Provincial funding to implement OMNRF sampling was from the Canada-Ontario Agreement on Great lakes Water Quality and Ecosystem Health and Ontario's Great Lakes Strategy. NYSDEC funding was from the Federal Aid in Sport Fish Restoration Program. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government. Data herein are available from U.S. Geological Survey, Great Lakes Science Center, 2018, Great Lakes Research Vessel Operations 1958-2017 (ver. 2.0, March 2018): U.S. Geological Survey Data Release, https://doi.org/10.5066/F75M63X0. All USGS sampling and handling of fish during research are carried out in accordance with guidelines for the care and use of fishes by the American Fisheries Society (http://fisheries.org/docs/wp/Guidelines-for-Use-of-Fishes.pdf).

Literature Cited

Christie, W.J., 1973. A review of the changes in the fish species composition of Lake Ontario (Technical Report No. 23). Great Lakes Fishery Commission.

Christie, W.J., 1972. Lake Ontario: effects of exploitation, introductions, and eutrophication on the salmonid community. J. Fish. Board Can. 29, 913–929.

Cochrane, W.G., 1977. Sampling Techniques, 3rd ed. Wiley.

Elrod, J.H., O'Gorman, R., 1991. Diet of juvenile lake trout in southern Lake Ontario in relation to abundance and size of prey fishes, 1979–1987. Trans. Am. Fish. Soc. 120, 290–302.

ICES, 2004. Report of the Workshop on Survey Design and Data Analysis (WKSAD). Lantry, J.R., 2001. Spatial and temporal dynamics of predation by Lake Ontario trout and salmon. SUNY-ESF.

MacNeill, D.B., Ault, J.S., Smith, S., S., M., 2005. A technical review of the Lake Ontario forage base assessment program (No. YSGI-T-05-001). NY Sea Grant.

Mills, E.L., Casselman, J.M., Dermott, R., Fitzsimons, J.D., Gal, G., Holeck, K.T., Hoyle, J.A., Johannsson, O.E., Lantry, B.F., Makarewicz, J.C., others, 2003. Lake Ontario: food web dynamics in a changing ecosystem (1970 2000). Can. J. Fish. Aquat. Sci. 60, 471–490.

Murry, B.A., Connerton, M.J., O'Gorman, R., Stewart, D.J., Ringler, N.H., 2010. Lakewide Estimates of Alewife Biomass and Chinook Salmon Abundance and Consumption in Lake Ontario, 1989–2005: Implications for Prey Fish Sustainability. Trans. Am. Fish. Soc. 139, 223–240. https://doi.org/10.1577/T08-216.1

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

O'Gorman, R., Lantry, B.F., Schneider, C.P., 2004. Effect of Stock Size, Climate, Predation, and Trophic Status on Recruitment of Alewives in Lake Ontario, 1978–2000. Trans. Am. Fish. Soc. 133, 855–867. https://doi.org/10.1577/T03-016.1

Owens, R.W., Dittman, D.E., 2003. Shifts in the Diets of Slimy Sculpin (Cottus cognatus) and Lake Whitefish (Coregonus clupeaformis) in Lake Ontario Following the Collapse of the Burrowing Amphipod Diporeia. Aquat. Ecosyst. Health Manag. 6, 311–323. https://doi.org/10.1080/14634980301487

Rand, P.S., Stewart, D.J., 1998. Dynamics of salmonine diets and foraging in Lake Ontario, 1983-1993: a test of a bioenergetic model prediction. Can. J. Fish. Aquat. Sci. 55, 307–317.

Rush, S.A., Paterson, G., Johnson, T.B., Drouillard, K.G., Haffner, G.D., Hebert, C.E., Arts, M.T., McGOLDRICK, D.J., Backus, S.M., Lantry, B.F., Lantry, J.R., Schaner, T., Fisk, A.T., 2012. Long-term impacts of invasive species on a native top predator in a large lake system. Freshw. Biol. 57, 2342–2355. https://doi.org/10.1111/fwb.12014

Shannon, C.E., Weaver, W., 1949. The mathematical theory of communication. The University of Illinois Press, Urbana, IL.

Simonin, P.W., Parrish, D.L., Rudstam, L.G., Pientka, B., Sullivan, P.J., 2016. Interactions between Hatch Dates, Growth Rates, and Mortality of Age-0 Native Rainbow Smelt and Nonnative Alewife in Lake Champlain. Trans. Am. Fish. Soc. 145, 649–656. https://doi.org/10.1080/00028487.2016.1143401

Smith, C.L., 1985. The inland fishes of New York state. New York State Department of Environmental Conservation.

Stewart, T.J., Sprules, W.G., 2011. Carbon-based balanced trophic structure and flows in the offshore Lake Ontario food web before (1987–1991) and after (2001–2005) invasion- induced ecosystem change. Ecol. Model. 222, 692–708. https://doi.org/10.1016/j.ecolmodel.2010.10.024

Stewart, T.J., Todd, A., Lapan, S., 2017. LOC Fish Community Objectives for Lake Ontario 2013.pdf.

Stockwell, J.D., Yule, D.L., Gorman, O.T., Isaac, E.J., Moore, S.A., 2006. Evaluation of Bottom Trawls as Compared to Acoustics to Assess Adult Lake Herring (Coregonus artedi) Abundance in Lake Superior. J. Gt. Lakes Res. 32, 280–292. https://doi.org/10.3394/0380-1330(2006)32[280:EOBTAC]2.0.CO;2

Weidel, B.C., Walsh, M.G., 2015. Lake Ontario benthic prey fish assessment, 2014 (2014 Annual Report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to the Great Lakes Fishery Commission's Lake Ontario Committee).

Weidel, B.C., Walsh, M.G., 2013. Estimating the area-swept by the 11.8 m Yankee bottom trawl in Lake Ontario (2012 Annual Report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to the Great Lakes Fishery Commission's Lake Ontario Committee).

Weidel, B.C., Walsh, M.G., Connerton, M.J., Lantry, B.F., Lantry, J.R., Holden, J.P., Yuille, M.J., Hoyle, J.A., 2017. Deepwater sculpin status and recovery in Lake Ontario. J. Gt. Lakes Res. https://doi.org/10.1016/j.jglr.2016.12.011

Wells, L., 1968. Seasonal depth distribution of fish in southeastern Lake Michigan. Fish. Bull. 67, 1–15.

Table 1. Lake Ontario area (square kilometers) within different depth strata in U.S. and Canadian waters. The proportional area columns illustrate how the area-weighting of stratified abundance mean indices changes as additional depths are included in the survey.

			proportional Area U.S.			proportional area CA
range (m)	area U.S.	area CA	0-160m	0-180m	0-240m	0-160m
0-19	1155	1749	0.19	0.15	0.13	0.18
20-39	905	1616	0.15	0.12	0.10	0.16
40-59	680	1248	0.11	0.09	0.08	0.13
60-79	514	1426	0.08	0.07	0.06	0.14
80-99	441	1198	0.07	0.06	0.05	0.12
100-119	527	1293	0.09	0.07	0.06	0.13
120-139	822	964	0.13	0.11	0.09	0.10
140-159	1112	353	0.18	0.14	0.12	0.04
160-179	1598	0		0.21	0.18	
180-199	737	0			0.08	
200-219	448	0			0.05	
220-239	79	0			0.01	
240-243	>1	0				

Table 2. Species and number of fish captured in the spring and fall Lake Ontario prey fish bottom trawl surveys. All numbers represent total numbers caught in each survey except for *Dreissena sp.* mussels, which represent a total weight in kilograms. The Classification column denotes which species are used in pelagic and benthic community diversity index calculations.

Species	Spring	Fall	Classification
Alewife	671868	6863	pelagic
Deepwater sculpin	13273	15081	benthic
Round goby	12757	10271	benthic
Rainbow smelt	6513	1913	pelagic
Yellow perch	792	566	benthic
Slimy sculpin	587	1182	benthic
Trout-perch	203	1505	benthic
Spottail shiner	189	76	benthic
Threespine stickleback	87	255	pelagic
Lake trout	62	34	
White perch	42	960	pelagic
Lake whitefish	10	0	
Pumpkinseed	10	7	
Crayfish	2	0	
Cisco (lake herring)	1	1	pelagic
Emerald shiner	1	12	pelagic
Gizzard shad	1	52	pelagic
Sea lamprey	1	0	
Unidentified redhorse	1	0	
Walleye	1	1	
Brown bullhead	0	58	
Brown trout	0	3	
Carp	0	12	
Channel catfish	0	2	
Freshwater drum	0	58	
Johnny darter	0	5	benthic
Logperch	0	5	
Smallmouth bass	0	1	
White sucker	0	157	
Dreissena mussel weight (kg)	1515	3820	

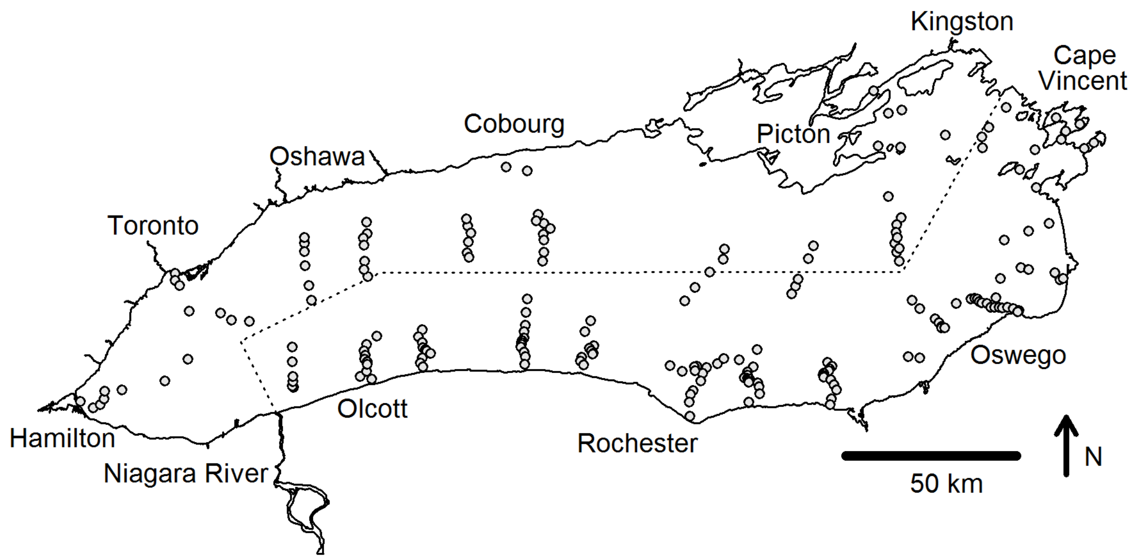

Figure 1. Lake Ontario sampling sites (N=204) from the 2017 spring bottom trawl survey collaboratively conducted by USGS, NYSDEC, and OMNRF. The fall survey that targets demersal or benthic prey fishes is sampled over a similar geographic area, but not all sites were trawled (N=137).

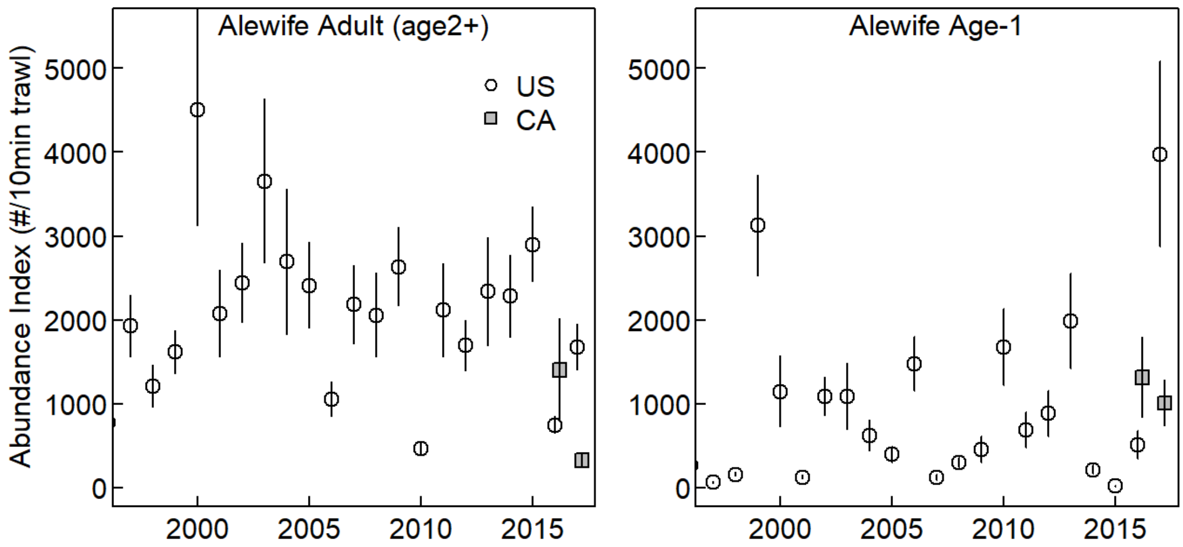

Figure 2. Lake Ontario spring bottom trawl-based abundance indices for adult Alewife (Age-2 and older, left panel) and Yearling or Age-1 Alewife (right panel). Values represent a stratified, area-weighted mean number of Alewife captured in a 10 minute trawl. Error bars represent one standard error of the mean. Trawling in Canadian waters began in 2016, but to maintain consistent comparisons through time, separate indices are illustrated for Canadian and U.S. waters. (lake area: Canada-52% U.S.-48%)

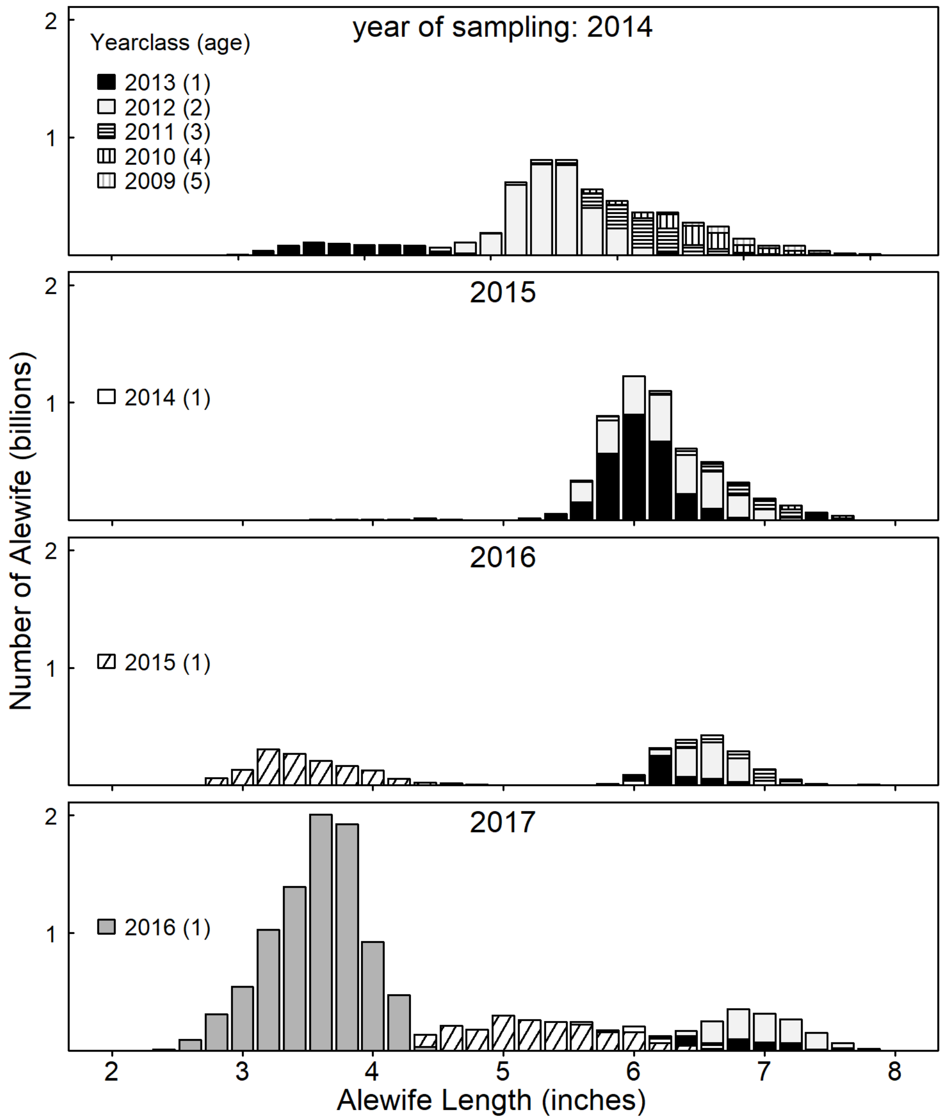

Figure 3. Alewife size and age distributions from spring bottom trawl surveys conducted in U.S. waters of Lake Ontario, 2014-2017. Each Alewife year class (all the fish born in a given year) are represented by a consistent color or pattern. The low catches of Age-1 fish in 2014 and 2015 (1st and 2nd panels) contributed to management concerns that resulted in salmonid stocking reductions in 2017 and 2018. The catch of Age-1 fish in 2017 (2016 year class, bottom panel) was the largest observed in the survey.

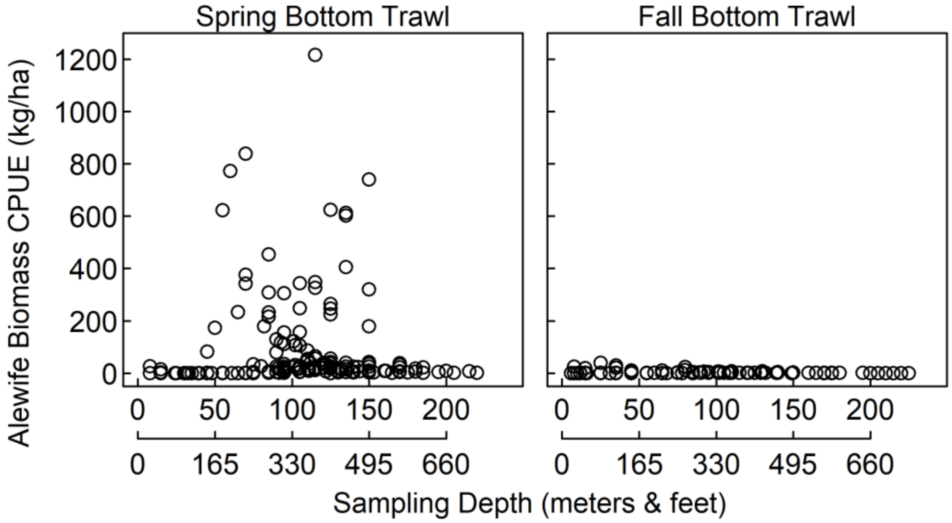

Figure 4. The biomass of all ages of Alewife caught in 2017 Lake Ontario bottom trawls varies across sampling depths and between the spring (left panel) and fall (right panel) surveys. Individual values represent Alewife weight according to the area of lake bottom swept by the bottom trawls. Note, different trawls are used on each survey and the abundance indices are calculated from the spring survey.

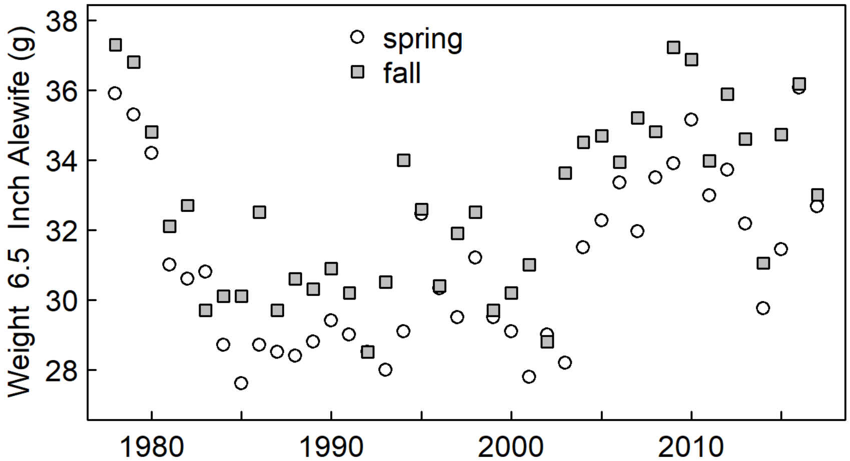

Figure 5. Alewife condition for spring and fall surveys illustrated as the predicted weight of a 165mm (6.5 inch) adult Alewife. The 2016 values for spring and fall were similar and the points are plotted over one another.

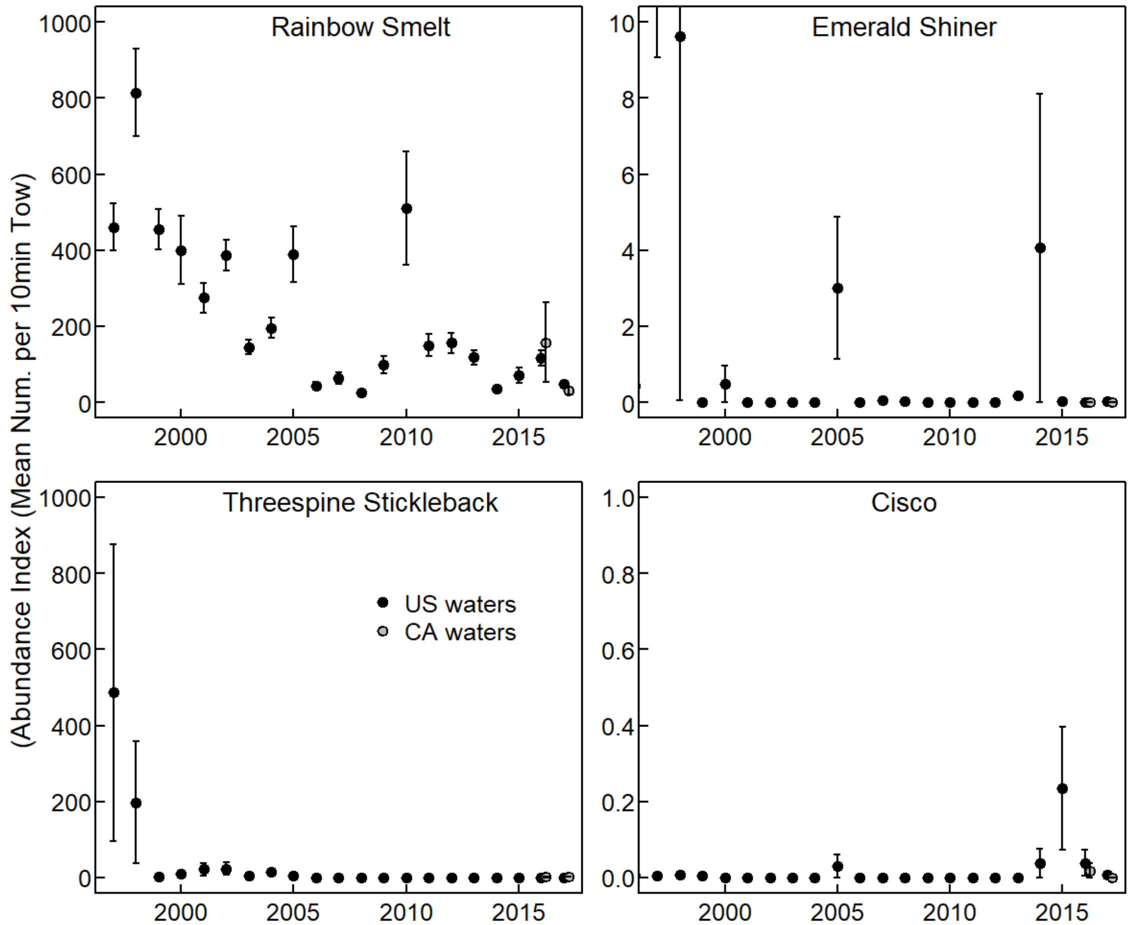

Figure 6. Abundance indices for other Lake Ontario pelagic prey fishes based on bottom trawls in U.S. and Canadian waters, 1997-2017. Error bars represent one standard error.

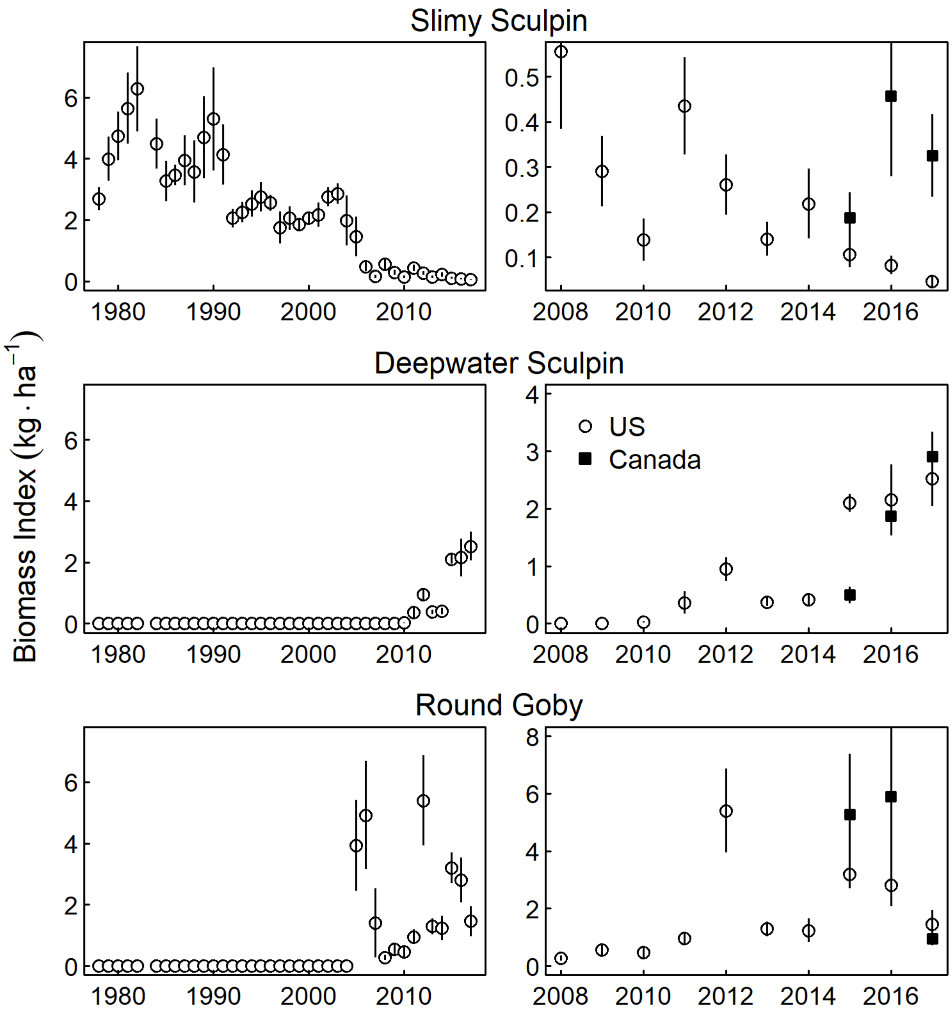

Figure 7. Lake Ontario prey fish trends for demersal or bottom-oriented species from 1978-2017 (left panels) and 2008-2017 (right panels). The survey is conducted in late-September and early-October and error bars represent one standard error. Sampling in Canadian waters began in 2015 and values from Canadian waters are shown in the left panels as filled squares. Separate 20m stratified, lake area-weighted means are calculated separately for tows in U.S. and Canadian waters to maintain comparability across the U.S. index time series.

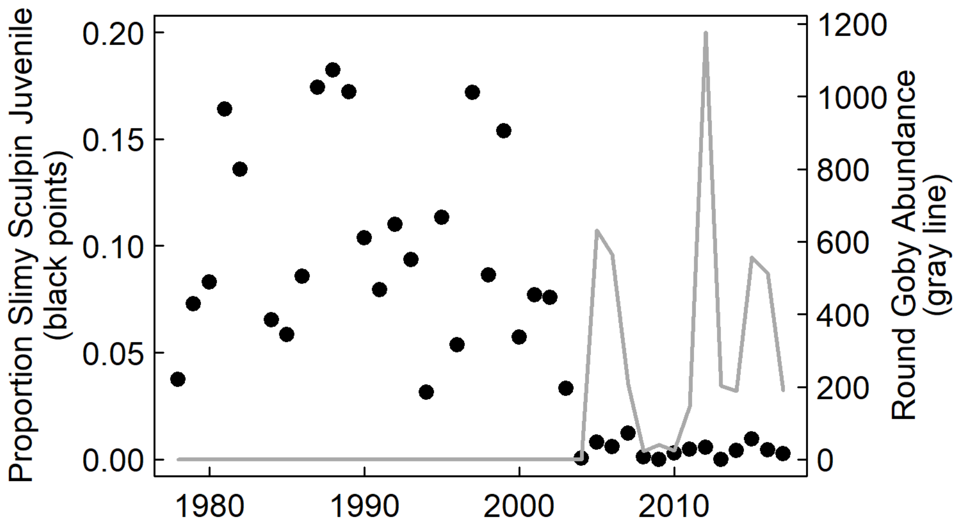

Figure 8. The proportion of Slimy Sculpin captured that were juveniles (<50mm or ~2 inches) continues to be low in Lake Ontario bottom trawl catches from the benthic prey fish survey. The proportion of the Slimy Sculpin catch that is juveniles (black filled circles) appears to drop once Round Goby catches increased (gray line). Round Goby were first collected in the spring trawl survey in 2002 and first collected in the fall survey in 2005.

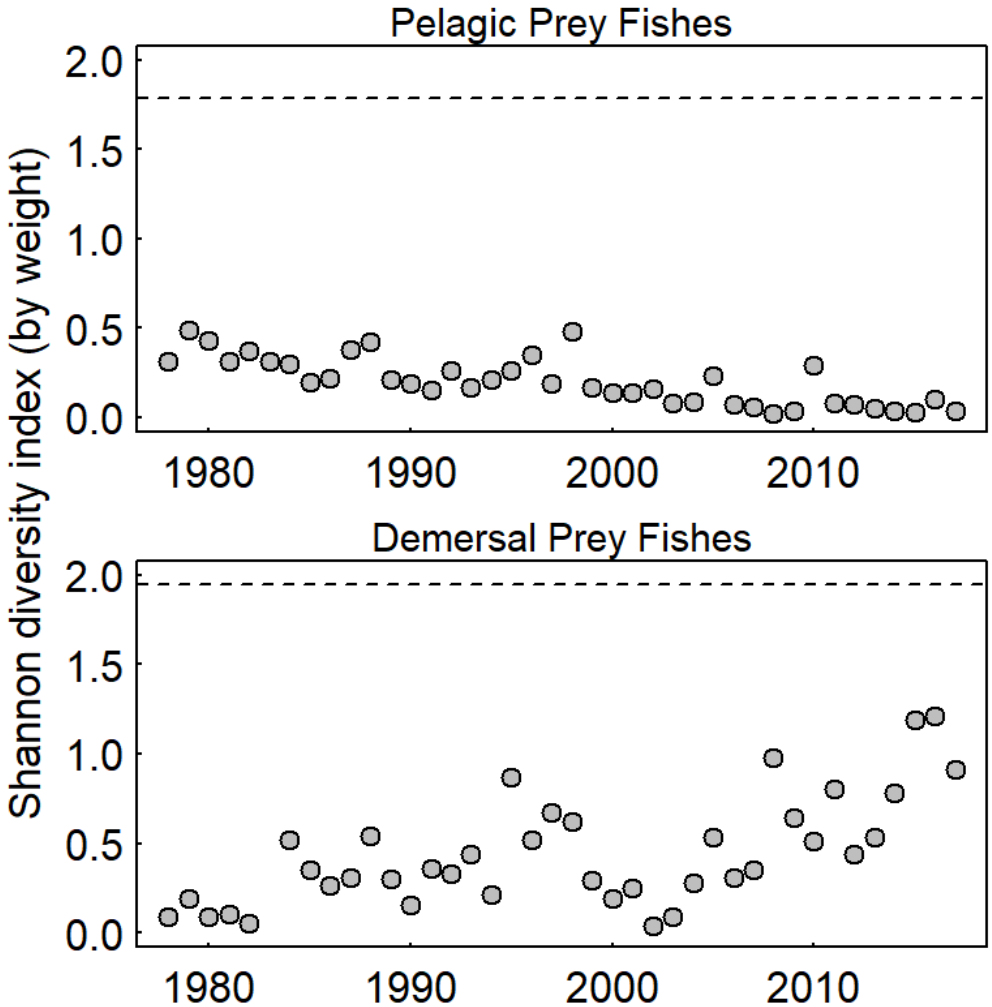

Figure 9. Lake Ontario prey fish diversity indices for pelagic and demersal prey fish communities based on bottom trawl catch weights 1978-2017. Species used for calculations are identified in Table 1. Diversity is represented with the Shannon index (Shannon and Weaver, 1949) using the seven most commonly encountered species in the spring (pelagic) and fall (benthic) surveys. The dashed lines represent the maximum diversity index value if all species considered made up equal proportions of the catch by weight. Lake Ontario Fish Community Objectives include improving pelagic and demersal prey fish diversity (Stewart et al., 2017).

Hydroacoustic Assessment of Pelagic Planktivores, 2017[1,2]

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Abstract

Alewife (*Alosa pseudoharengus*) and rainbow smelt (*Osmerus mordax*) are the most abundant pelagic planktivores in Lake Ontario (Weidel et al. 2018), and the most important prey for salmon and trout which support a multimillion dollar sportfishery. Alewife make up greater than 90% of the diet of the top predator, Chinook salmon (Lantry 2001, Brandt 1986), and are also important prey for warm water predators, notably Walleye (Sander vitreus) (Hoyle et al. 2017). The abundance of alewife and rainbow smelt has declined since the 1980s, likely due to reduced nutrient loading, proliferation of invasive dreissenid mussels, and predation by stocked salmon and trout. Cisco (*Coregonus artedi*) and Bloater (*C. hoyi*), both native planktivores, historically dominated the offshore pelagic prey fish community of Lake Ontario, but their populations were severely reduced in the mid-20th century due to overfishing and competition with Alewife and Smelt (Christie 1973). Remnant cisco populations still exist, mostly in the Eastern Basin, producing strong year classes only once or twice per decade (Owens et al 2003), most recently in 2012 and 2014 (OMNRF 2017). Bloater was extirpated from Lake Ontario during the mid-20th century; however, from 2012-2017, this species has been stocked by Canadian and U.S. agencies in order to reestablish this species in the lake.

Hydroacoustic assessments of Lake Ontario prey fish have been conducted since 1991, with a standardized mid-summer survey initiated in 1997. The survey is conducted jointly by the Ontario Ministry of Natural Resources and Forestry (OMNRF) and the New York State Department of Environmental Conservation (NYSDEC). Results from the hydroacoustic survey complement information obtained in spring bottom trawling surveys (Weidel et al. 2018) and provide whole-lake abundance indices for alewife and rainbow smelt. In addition, the results provide insights into the midsummer distribution of these species. We present results from the 2017 survey in this report.

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[1]Presented at Great Lakes Fishery Commission, Lake Ontario Committee Meeting, Markham, ON on March 27, 2018.

[2]The data associated with this report are available at: U.S. Geological Survey, Great Lakes Science Center, 2018, Great Lakes Research Vessel Operations 1958-2017 (ver. 2.0, March 2018): U.S. Geological Survey Data Release, https://doi.org/10.5066/F75M63X0.

Introduction

Cisco was previously a minor component in midwater trawling conducted during the hydroacoustic survey from 1991-2005. Recent evidence of strong cisco year classes in OMNRF trawling surveys of juveniles in 2012 and 2014 (OMNRF 2017) and increasing cisco catches during bottom trawling by USGS and NYSDEC) suggest that Cisco populations are increasing. Cisco are still relatively rare in existing surveys, although these surveys do not target this generally pelagic fish. In 2016 and 2017, the NYSDEC, OMNRF and USGS conducted midwater trawling along with hydroacoustics in eastern and central portions of Lake Ontario as a pilot effort to evaluate methods for assessment of native Coregonine species (Cisco and Bloater). The preliminary results of those efforts are also reported here.

The hydroacoustic survey indexes pelagic preyfish abundance, and like other assessments, this survey employs a consistent approach. Increasingly, however, there is strong interest by Great Lakes scientists in knowing the total abundance and biomass of prey fish (and predators) for understanding and modeling predator-prey balance. This information is important for fisheries managers when making decisions regarding predator stocking levels (Murry et al. 2010). As with other assessment gears (e.g. bottom trawls), making the transition from relative to absolute abundance with acoustics requires rigorous testing of assumptions of gear catchability. Bottom trawling has its own assumptions and unknowns regarding gear catchability and we are currently addressing these (e.g., Weidel and Walsh 2013).

We have also been exploring the "catchability" of hydroacoustic gear. Experimental sampling with vertical gillnets and upward looking hydroacoustics conducted during 2008-2014 identified some limitations to using the traditional down-looking hydroacoustic approach for achieving accurate, whole-lake estimates of alewife abundance. Increasing evidence indicates that alewife can be oriented near the surface at night and potentially undetectable with traditional down-looking acoustics because vessel draft, transducer depth, and acoustic "cone" area create a near-field acoustic "blind-spot" in the first 4 m (13.1 ft) of surface water (Connerton and Holden 2015). In addition, the sound and/or vibration of the research vessel may cause surface-oriented alewife to scatter or dive which affects fish target strength (TS), detectability and ultimately abundance estimates (Thorne 1983). NYSDEC and OMNRF have been experimentally towing submersible acoustic equipment suspended away from the boat hull in deep water with the transducer aimed upward to detect fish near the surface. Results of upward looking acoustics conducted from 2010-2014 suggested that an average of 50% of the alewife are near the surface during the survey and undetected by downlooking acoustic methods (Connerton and Holden 2015). The values for alewife reported herein do not include a conversion factor to account for this unmeasured biomass and thus should be treated as an index of abundance between years and not as a whole lake population estimate.

We also continue to explore other potential biases of this survey. For example, the hydroacoustic survey samples most depths in proportion to the lake area except for shallow habitats (<40 m or 131 ft). This may potentially bias the alewife estimate low if significant numbers of alewife occupy these habitats and the measured densities are highly variable. Although the survey has certain limitations for sampling inside of 10 m (32.8 ft) due to vessel draft, additional sampling is possible from 10-40 m (32.8-131 ft). In 2016, we sampled additional areas over 10-40 m bottom depths to test whether increased sampling in shallow water would significantly change the survey estimate, and found that the alewife acoustic estimate was about 15% higher compared with normal transects although this difference was not statistically significantly (Holden et al 2017). In 2017, we repeated this experiment and compared the results.

Methods

Before 2005, surveys followed established transects with only minor yearly modifications due mostly to logistics. This was a practical approach dictated by harbor locations, running time, and limited periods of darkness in the summer. In 2005, we modified the fixed transect design to include a statistically preferable random element. Five fixed, cross-lake corridors approximately 15 km (9.3 mi) wide were established (Figure 1) based on logistical constraints, but within these corridors, transects were selected at random. A single east-west offset was randomly chosen each year determining the relative position of all transects within their respective corridors, and thus, the survey is systematic with a random start. The randomly chosen offset in 2017 was 0, meaning that transects were at the eastern most boundary of the corridor. In addition to the 5 cross-lake transects, a U-shaped transect is surveyed each year in the Eastern

Basin (Figure 1); however, no offset is applied to this transect.

The 2017 hydroacoustic survey was conducted from July 18-29 using two research vessels (R/V), OMNRF's *R/V Ontario Explorer* and NYSDEC's *R/V Seth Green*. Acoustic data were collected using a BioSonics 120 kHz split-beam echosounder set at a rate of 1 ping per second and a pulse width of 0.4 milliseconds. Each night, sampling began approximately one hour after sunset at the 10 m (32.8 ft) depth contour on one end of the transect and continued across the lake to the 10 m depth contour on the opposite end or one hour before sunrise. A temperature profile was measured hourly at points along each transect.

Hydroacoustic data were stratified by thermal layer (2 layers, upper: ≥10 °C (50 °F) to surface, and lower: <10°C to 100 m (328 ft) and geographic zone (six zones: NW, SW, N-Central, S-Central, SE, NE), and whole-lake abundance estimates were calculated as the area-weighted average of these zones. The data were processed with Echoview software (Myriax Inc. version 8.0) using -64 decibels (dB) volume backscattering strength and TS thresholds. Targets in the lower layer were assumed to be smelt or cisco, and targets in the upper layer were assumed to be alewife or cisco depending on target strength. Thermal separation of alewife and rainbow smelt was confirmed by historical midwater trawling data collected from 2000 to 2004 which showed a thermal separation between these species (also see Schaner and LaPan 2003). Midwater tows in depths where water temperatures were 9°C or warmer were dominated by catches of Alewife (95% total catch weight of prey fish species) whereas tows in depths at temperatures below 9°C captured mostly Rainbow Smelt (84%).

In 2014 and 2015, Connerton and Holden (2016) explored alternative methods for analyzing hydroacoustic survey data to refine estimates of whole-lake abundance. Three analytical approaches were compared for each species and data were reanalyzed for the entire time series. In general, results produced by the three methods for Rainbow Smelt were well correlated with each other, were reasonably correlated with spring bottom trawls (r^2=0.68), and most of the differences between the methods' results were attributed to varying TS thresholds employed by each method (Connerton and Holden 2016). The favored method from this analysis included targets ranging from -52 to -39 dB which, according to TS vs length relationships (Love 1977), represent the

Rainbow Smelt size distribution (60-250 mm or 2.4-9.8 in total length [TL]) typically observed in Lake Ontario (Weidel et al. 2015). The preferred approach also used a bootstrapping procedure to iteratively estimate average density based on 500 m transect intervals, and to estimate more robust confidence intervals compared with the traditional area weighted approach (AW) for Smelt which produced a standard deviation based on seven lake areas (Connerton and Holden 2016).

For Alewife, the traditional analysis method split the scaled, integrated voltage estimates of total target abundance in the upper layer into 1 dB TS bins according to results of single target analysis. This produced a histogram typically with three modes (e.g., Figure 2) assumed to be: 1. Zooplankton, *Mysis* and larval fish; 2. A mix of larval Alewife, Smelt and other fish, and possibly larger, diving fish exhibiting lower target strengths; and 3. Yearling and older Alewife (YAO) (Schaner and LaPan 2003). The abundances of YAO Alewife were apportioned from the resulting target strength histograms by fitting normal curves to the three modes using a solver routine (SR) and then by calculating the proportions of each curve relative to the total TS frequency distribution (Schaner and LaPan 2003). Histograms were processed to identify the proportions of targets in the mode at or around -40 dB, and typically included the proportion of the targets from

-45 dB to -28 dB which were assumed to be YAO Alewife (Warner et al. 2002, Love 1977). The solver routine, however, was sensitive to the approximation of initial starting conditions and the distribution of non-fish targets, and the results could be affected by user judgment which made it difficult to apply a standard method annually. Connerton and Holden (2016) instead favored using a new TS range (i.e., -50 to -35 dB) which better corresponded to Alewife sizes encountered in Lake Ontario (54mm-240 mm [2.1-9.4 in TL) when compared with the traditional method (-45 to -28 dB), and because research has shown that in-situ Alewife target strength (Brookings and Rudstam 2009) can vary depending on fish orientation (e.g. if Alewife dive to avoid the vessel). Two new methods were evaluated in 2015: 1) The bootstrapping method (as with Rainbow Smelt above) using TS thresholds -50 to -35 dB; and 2) using the area weighted approach but eliminating the SR step, and using the new TS thresholds. The SR method index showed the best correlation (r^2=0.57) with the spring bottom trawling index using results from 1997-2015 (Connerton and Holden 2016), but in 2016, the bottom trawling survey's analytical methods and resulting time series indices underwent significant changes (Weidel et al 2017). New discoveries regarding the catch efficiency of age-1 and age-2 Alewife by the bottom trawl, and the distribution of Alewife in New York vs Ontario waters raised new questions about potential biases of that survey (Weidel et al. 2017).

For this report, we applied the area weighted method to estimate the Alewife abundance index and the bootstrapping method for Rainbow Smelt abundance index for the entire time series. We used TS thresholds of -52 to -39 dB for Rainbow Smelt for targets in the lower temperature layer (<10ºC). Trawling results in 2016 (Holden et al. 2017) suggested that the previous upper TS level for Alewife (i.e., -35 dB) was generally too high, therefore we used TS of -50 to -39 dB for Alewife for targets in the upper temperature layer (≥10ºC). Also in 2016, we began considering targets from -39 to -35 dB as Cisco, since this species has recently become a more abundant component of the Lake Ontario pelagic fish community based on midwater trawling done by this survey in 2016, and recent catch increases observed in gillnetting and commercial fisheries in Ontario (OMNRF 2017).

To assess the distribution and abundance of Coregonines in 2016 and 2017, midwater trawling and additional hydroacoustic sampling was conducted by USGS *RV Kaho*, OMNRF *Ontario Explorer* and NYSDEC *RV Seth Green* (Holden et al. 2017). Trawling was conducted using a French midwater trawl (57m^2 [613.5 ft^2] net opening). Tows were 5 or 10 minutes duration and tows generally occurred above, within or below the metalimnion as determined by nightly temperature profiles and temperature loggers on the net's headrope, footrope or both. In 2017, mid-water trawling (58 total tows) was conducted at six locations. Five of the sites (i.e, Rochester, Fairhaven, Mexico Bay, Southwicks, and in the Eastern Basin) were similar to trawling sites visited in 2016 (Figure 1). A sixth area was added in 2017 and included three nights of sampling near Cobourg, ON (Figure 1). Mid-water trawl catches were primarily used to inform apportionment of generalized abundance estimates obtained from hydroacoustics to estimate species abundance. All fish were sorted, counted and weighed by species, and subsamples for length frequency were taken on all species. All Cisco were frozen and later processed for length, weight, gonadosomatic index, diet, and samples of tissue were archived for future genetic, isotope and fatty acid analysis. Only acoustic data where both hydroacoustics and midwater trawls were conducted were used to estimate Cisco abundance (Figure 1). Acoustic densities of Cisco were estimated by calculating the average density of upper and lower layers per 500 m section (with TS of -39 to -35 dB), then averaging densities per area, and then calculating a grand mean of all six Cisco areas.

Results and Discussion

The survey transects included acoustic data collected over 311 km (193 mi), plus an additional 247 km (154 mi) collected and paired with mid-water trawl tows (Figure 1). There were 58 mid-water tows conducted which captured seven species of fish. Alewife, Rainbow Smelt and Cisco were the most frequently caught and most abundant species (Table 1). Tows in the surface layer (≥ 10 ˚C) were 99% Alewife. Tows in the deep layer (< 10 ˚C) were also 95% Alewife; however, we hypothesize that catch contamination from the upper layer significantly impacted these results. Headrope and footrope temperatures were not recorded on all tows and thus a fishing temperature of 9˚C at the footrope and a net with a vertical opening of 5-7 m (16.4-23 ft) is likely fishing some portion of the net in temperatures greater than 9˚C. In the future we expect to have temperature loggers on both the footrope and headrope to better quantify this potential bias. There is also potential for catch contamination in midwater trawls since the net must pass through the upper laysers of the water column to reach the target fishing depth. For instance, a tow conducted in 2016 with no fishing time (i.e. trawl let out to 34 m fishing depth then immediately returned) captured Alewife, Cisco and Rainbow Smelt which indicates that the net fishes during either or both the let-out or haul-in periods of the tow. Rainbow Smelt and Cisco were predominantly (88% for each) caught in tows conducted in water less than 9˚C.

Summary size data for all species are presented in Table 1. The length distribution shows a clear size separation between Cisco and both Alewife and Rainbow Smelt (Figure 2). The thermal separation between Alewife and Rainbow Smelt and the size difference between these species and Cisco supports the current approach of species apportionment of acoustic density estimates (Table 1).

Cisco

Catches of Cisco were confined geographically within the eastern region of Lake Ontario in 2016 (Holden et al. 2017). The majority of Cisco were also caught at eastern sites in 2017, although one Cisco was caught near Cobourg, ON suggesting a broader distribution across the north shore than inferred by 2016 trawling (Figure 3). Cisco catches in 2017 (N = 15, mean CUE = 0.15 fish/5 min tow) were well below catches observed in 2016 (N = 361, mean CUE = 3.83 fish/5 min tow). Cisco occupied both upper and lower thermal layers in 2017 (Table 1) with trawl catches in water temperatures of 7-15 ˚C compared to 2016 when they were concentrated in the 10-15 ˚C layer (Holden et al. 2017). Length of captured Cisco ranged from 260-380 mm (10.2-15 in).

Hydroacoustic data, using only transects where Cisco were captured, estimated a mean density of 45 Cisco per hectare, markedly higher than 2016 (25 Cisco per hectare). Using the average Cisco weight captured in midwater trawls (210g and 271 g in 2016 and 2017, respectively), Cisco biomass density was ~5.25 kg/ha and 11.9 kg/ha in 2016 and 2017, respectively. If we conservatively assume the limited area where Cisco were observed represented 1/10th of the total lake area, and Cisco were absent elsewhere, whole-lake biomass densities were 0.5 kg/ha in 2016 and 1.2 kg/ha in 2017. Biomass values are still well below comparable Lake Superior hydroacoustic estimates (5.5 kg/ha, Yule et al 2013).

Rainbow Smelt

Rainbow Smelt abundance (15.1 million) in 2017 decreased relative to 2016 (Figure 4). However, inclusion of the additional near-shore transects in 2016 and 2017 resulted in a significantly larger population estimate (32 million and 50.3 million, respectively) than the traditional cross-lake transects would have estimated. The largest midwater trawl catches of Rainbow Smelt occurred in the eastern portion of the Lake (Mexico Bay), similar to previous analyses (Connerton and Holden 2014). Only one Rainbow Smelt was caught in OMNRF tows conducted near Cobourg.

Alewife

The YAO Alewife abundance index in 2017 (1.183 billion) based on the area weighted method increased 140% relative to 2016 (Figure 5). This increase is likely explained by the moderate to strong alewife year classes produced in 2015 and 2016. Spring bottom trawls in 2017 caught record numbers of age-1 Alewife in U.S. waters, moderate numbers of age-1 fish in 2016, and very low catches of age-1 fish in 2014 and 2015. Differences between acoustic target strength distributions throughout these years supports these observations (Figure 6), i.e. there was a noticeable lack of small targets in 2014 and 2015, followed by noticeable increases in small targets observed in 2016 and 2017, corresponding to weak year classes in 2013 and 2014, and then moderate and strong year classes in 2015 and 2016. While total Alewife abundance may be higher than recent years, most of the population consists of either young Alewife or fish age-5 and older (Figure 2 and Weidel et al. 2018), prompting concerns by fisheries managers about the future status of the population.

Alewife were spatially distributed throughout the lake but showed a bimodal distribution with bottom depth in 2017 (Figure 7). Distribution of Alewife during the survey, however, varies from year to year. Previous analyses found no discernable consistent geographic patterns in Alewife distribution in 2013-2014 (Connerton et al. 2014), nor any consistent regional trends from 2006-2014 (Holden et al. 2014). Distribution of Alewife may be more related to recent physical (e.g. weekly prevailing winds) and biological factors (e.g. zooplankton blooms) but more research is needed in this area and we are currently exploring other factors potentially affecting distribution.

The inclusion of the additional nearshore transects in 2017 resulted in a marginally lower whole-lake estimate (1.102 billion) compared with the estimate using the traditional cross-lake transects. In 2016, additional nearshore sampling resulted in a 15% higher lakewide estimate than using cross-lake transects alone, although these estimates were not significantly different (Holden et al. 2017).
Midwater trawl catches in 2017 expanded to a whole-lake population abundance (1.743 billion) estimated a higher abundance than the acoustic estimate, but was likely biased high because trawling effort generally targeted concentrations of fish in areas where acoustics showed fish to be more abundant over depths from 30-70 m (98.4-229.6 ft, Figure 7).

The acoustic abundance of Alewife is presented as an index as it produces a significantly lower abundance than spring bottom trawl estimates (e.g., ~4 kg/ha with acoustics [Connerton and Schaner 2012] vs 69 kg/ha with bottom trawls 2004-2006 [Murry et al 2009]). Vertical gillnets and towed up-looking acoustics show that a large proportion (on average 50%) of Alewife occupy the near-surface portion of the water column (<4 m depth) and are not detectable with the down-looking transducer used in the survey. While a significant proportion of the Alewife biomass is detected in this portion of the water column, the conversion still does not reconcile the difference between bottom trawl and acoustics population estimates. Stationary up-looking data is being analyzed to investigate the role that boat avoidance may contribute to explaining the differences.

Hydroacoustics remains an important method for indexing midsummer pelagic preyfish abundance. Midwater trawling has shown to be a useful method for informing species apportionment of this survey's acoustic data and for assessing Coregonines. Although the Lake Ontario offshore pelagic fish community is still dominated by Alewife and Rainbow Smelt, Cisco is a present and perhaps growing species of importance. While hydroacoustics has its challenges, this research has identified new opportunities, including estimating the abundance of other important animals in the Lake Ontario foodweb like Mysis (Watkins et al. 2015), zooplankton (Holbrook et al. 2006), and now Cisco. Our results support previous conclusions of Owens et al. (2003) who proposed that Cisco are mainly restricted to eastern portions of the Lake. Hydroacoustic surveys may also prove useful in assessing success of ongoing efforts to re-establish bloater in Lake Ontario.

Acknowledgements

Provincial funding to implement OMNRF sampling was from the Canada-Ontario Agreement on Great lakes Water Quality and Ecosystem Health and Ontario's Great Lakes Strategy. The USGS data associated with this report have not received final approval by the U.S. Geological Survey and are currently under review. The Great Lakes Science Center (GLSC) is committed to complying with the Office of Management and Budget data release requirements and providing the public with high quality scientific data. We plan to make all USGS research vessel data collected between 1958 and 2017 publicly available from the GLSC website later in 2018. The anticipated citation will be http://doi.org/10.5066/F75M63X0. Please direct any immediate questions to our Information Technology Specialist, Scott Nelson, at snelson@usgs.gov. All USGS sampling and handling of fish during research are carried out in accordance with guidelines for the care and use of fishes by the American Fisheries Society (http://fisheries.org/docs/wp/Guidelines-for-Use-of-Fishes.pdf). Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

References

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

Brookings, T.E. and L.G. Rudstam. 2009. Hydroacoustic Target Strength Distributions of Alewives in a Net-Cage Compared with Field Surveys: Deciphering Target Strength Distributions and Effect on Density Estimates. Transactions of the American Fisheries Society 138:471–486.

Christie, W.J. 1973. A review of the changes in the fish species composition of Lake Ontario. Great Lakes Fishery Commission Technical Report. 23:1–57.

Connerton, M.J., J. Holden. and T. Schaner. 2012. Acoustic assessment of pelagic planktivores 2011. Section 28, *in* 2011 NYSDEC Annual Report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to Great Lakes Fishery Commission's Lake Ontario Committee. NYSDEC, Albany, NY

Connerton, M.J., J. Holden. and T. Schaner. 2014. Acoustic assessment of pelagic planktivores 2013. Section 24, *in* 2013 NYSDEC Annual Report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to Great Lakes Fishery Commission's Lake Ontario Committee. NYSDEC, Albany, NY

Connerton, M.J. and J. Holden. 2015 Acoustic assessment of pelagic planktivores 2014. Section 24, *in* 2014 NYSDEC Annual Report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to Great Lakes Fishery Commission's Lake Ontario Committee. NYSDEC, Albany, NY

Connerton, M.J. and J. Holden. 2016 Acoustic assessment of pelagic planktivores 2015. Section 24, *in* 2015 NYSDEC Annual Report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to Great Lakes Fishery Commission's Lake Ontario Committee. NYSDEC, Albany, NY

Holden, J.P., M.J. Connerton and T.Schaner. 2014. Changes in mid-summer distributions of Rainbow Smelt and Alewife in Lake Ontario. International Association of Great Lakes Research 57th Annual Conference on Great Lakes Research at McMaster University. May 26-30, 2014.

Holden, J.P., M.J. Connerton, and B.C. Weidel. 2017. Acoustic assessment of pelagic planktivores 2016. Section 15, in 2016 NYSDEC Annual Report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to Great Lakes Fishery Commission's Lake Ontario Committee. NYSDEC, Albany, NY

Hoyle, J.A, J.P.Holden, and M.J. Yuille. 2017. Diet and relative weight in migratory walleye (*Sander vitreus*) of the Bay of Quinte and eastern Lake Ontario, 1992-2015. Journal of Great Lakes Research. 43 (5): 779-978

Holbrook, B.V, T.R. Hrabik, D.K. Branstrator, D.L. Yule, and J.D. Stockwell. 2006. Hydroacoustic Estimation of Zooplankton Biomass at Two Shoal Complexes in the Apostle Islands Region of Lake Superior Journal of Great Lakes Research 32: 680-696

Lantry, J. R. 2001. Spatial and temporal dynamics of predation by Lake Ontario trout and salmon. M. S. thesis. State University of New York. Syracuse, NY. Love, R. H. 1977. Target strength of an individual fish at any aspect. Journal of the Acoustical Society of America 62:1397–1403.

Murry BA, Connerton MJ, O'Gorman R, Stewart DS, Ringler NH. 2010. Lake-wide estimates of alewife biomass and chinook salmon abundance and consumption in Lake Ontario, 1989–2005: implications to prey fish sustainability. Transactions of the American Fisheries Society. 139:223–240

Ontario Ministry of Natural Resources and Forestry. 2017. Lake Ontario Fish Communities and Fisheries: 2016 Annual Report of the Lake Ontario Management Unit. Ontario Ministry of Natural Resources and Forestry, Picton, Ontario, Canada.

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

Schaner T. and S.R. LaPan. 2003. Lake Ontario Pelagic Fish: Preyfish. Section 1 in Lake Ontario Fish Communities and Fisheries. 2002 Annual Report of the Lake Ontario Management Unit Prepared for the Lake Ontario Committee Meeting Great Lakes Fishery Commission. March 27-28, 2003. Queen's Printer for Ontario.

Thorne, R.E. 1983. Assessment of Population Abundance by Hydroacoustics, Biological Oceanography 2:2-4, 253-262

Warner, D. M., Rudstam, L. G. and Klumb, R. A. 2002. In situ target strength of alewives in freshwater. Transactions of the American Fisheries Society, 131: 212–223.

Weidel, B and M. Walsh. 2013. Estimating the area-swept by the 11.8 m Yankee bottom trawl in Lake Ontario. Section 12, pages 25-32, In 2012 NYSDEC Annual Report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to Great Lakes Fishery Commission's Lake Ontario Committee. NYSDEC, Albany, NY

Weidel, B.C., M.G. Walsh, M.J. Connerton and J. Holden. 2015. Status of Rainbow Smelt in the U.S. waters of Lake Ontario, 2014. Section 12, pages 11-15, *in* 2013 NYSDEC Annual Report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to Great Lakes Fishery Commission's Lake Ontario Committee. NYSDEC, Albany, NY

Weidel, B.C., M.G. Walsh, M.J. Connerton and J. Holden. 2017. Trawl-based assessment of Lake Ontario pelagic prey fishes including Alewife and Rainbow Smelt. Section 12a i*n* 2016 NYSDEC Annual Report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to Great Lakes Fishery Commission's Lake Ontario Committee. NYSDEC, Albany, NY

Weidel, B.C., J.P. Holden, and M.J. Connerton 2018. Bottom trawl assessment of Lake Ontario prey fishes. Section 12 i*n* 2017 NYSDEC Annual Report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to Great Lakes Fishery Commission's Lake Ontario Committee. NYSDEC, Albany, NY

Weidel B.C., J. A. Hoyle, M.J. Connerton, J.P. Holden, M. Vinson. (In review), Lake Ontario Cisco dynamics based on long-term surveys. Advances in Limnology.

Yule, D.L., Evrard, L.M., Cachera, S., Colon, M., Guillard, J., 2013. Comparing two fish sampling standards over time: largely congruent results but with caveats. Freshw. Biol. 58, 2074–2088. https://doi.org/10.1111/fwb.12192

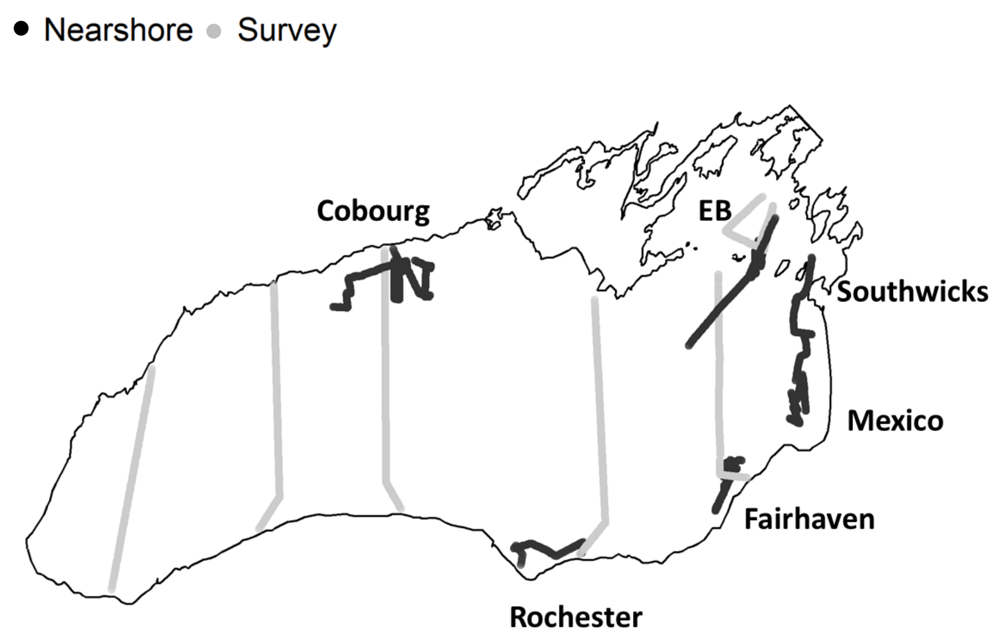

Figure 1. The Lake Ontario lake-wide prey fish survey uses cross-lake hydroacoustic transects (2017 transects shown in grey). In 2017, additional hydroacoustic sampling and midwater trawling was conducted in six areas (black lines). Notes: EB=Eastern Basin. USGS conducted midwater trawling west of Rochester but returned to port early due to a vessel mechanical problem. OMNRF collected hydroacoustic data near Rochester but conducted no midwater trawling.

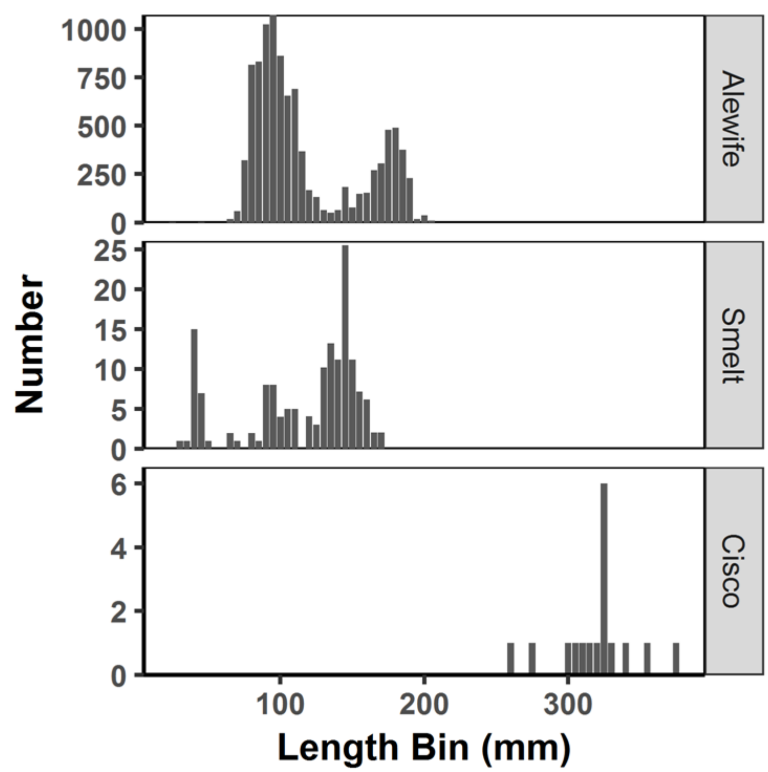

Figure 2. Length frequencies of Alewife, Rainbow Smelt and Cisco caught in midwater trawling in 2017.

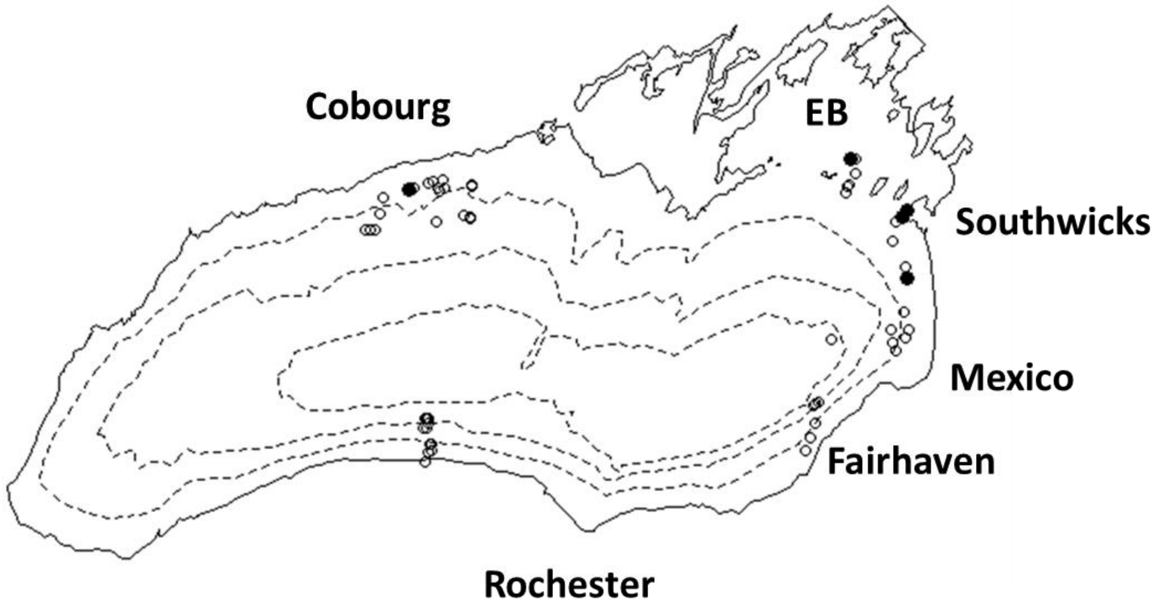

Figure 3. Distribution of Cisco caught during midwater trawling in July, 2017. Acoustics and trawling were conducted at Rochester, Fairhaven, Mexico, Southwicks, Cobourg and Eastern Basin sites (EB). Open circles are trawl locations where no Cisco were caught and closed circles are locations where Cisco were caught. Note: USGS conducted midwater trawling west of Rochester but returned to Port early due to vessel mechanical failure. OMNRF collected hydroacoustic data near Rochester but conducted no midwater trawling.

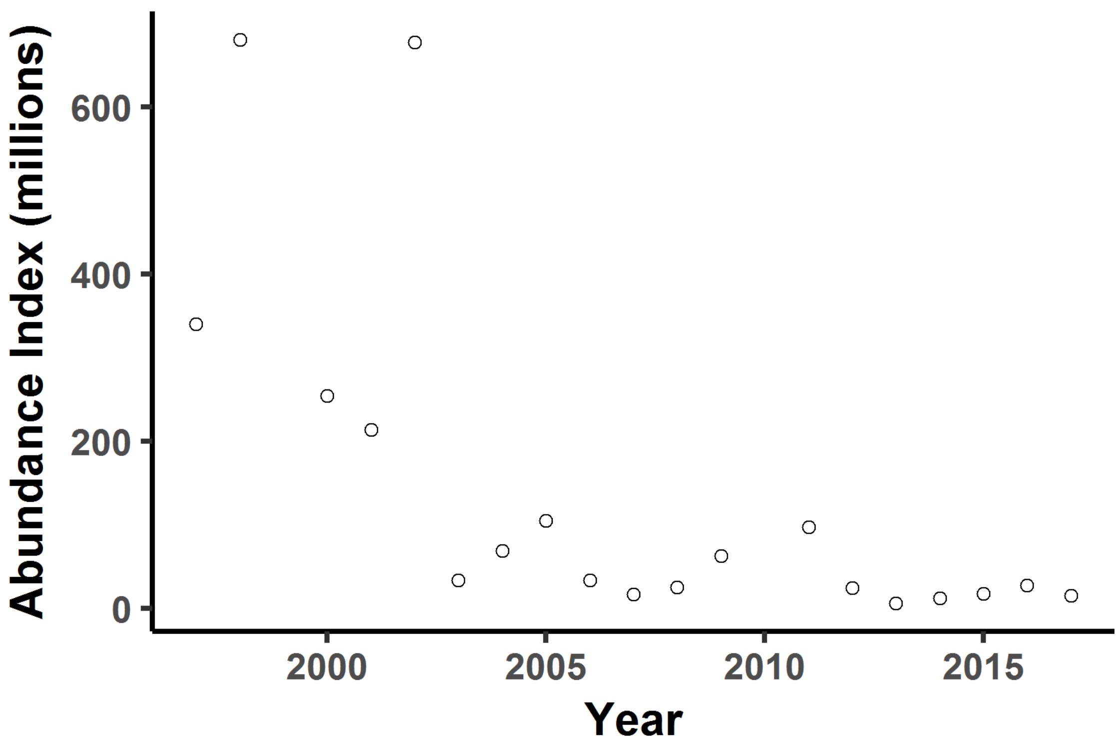

Figure 4. Abundance (in millions of fish) of yearling-and-older Rainbow Smelt in Lake Ontario from 1997-2017 as determined by the bootstrapping method. No acoustic survey was conducted in 1999 and 2010.

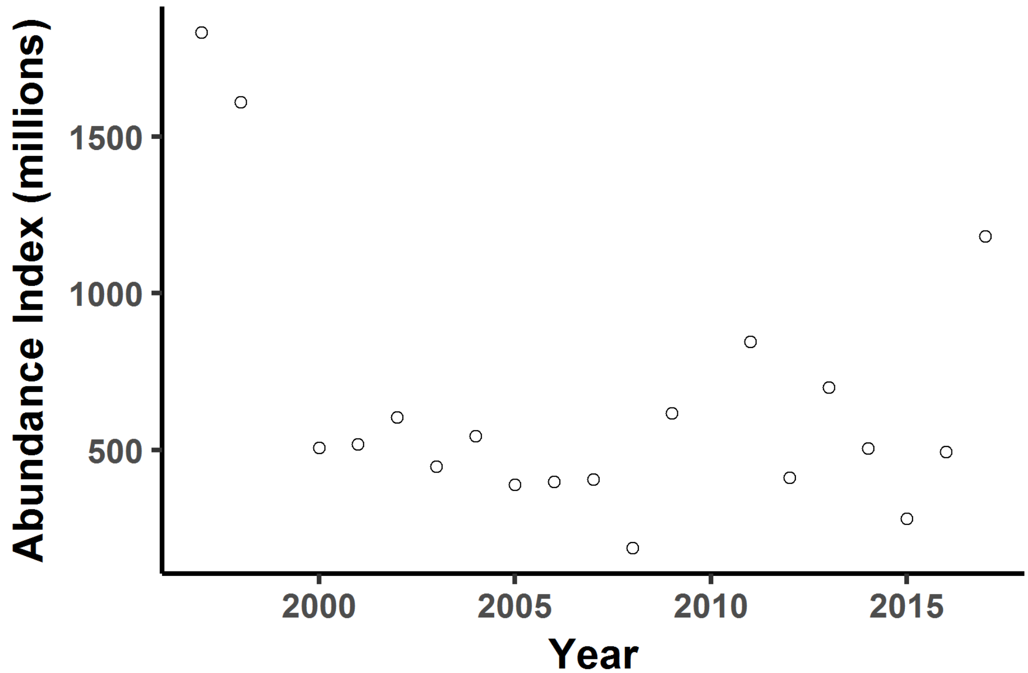

Figure 5. Abundance (in millions of fish) of yearling-and-older Alewife in Lake Ontario from 1997-2017 as determined by the area weighted method. No acoustic survey was conducted in 1999 and 2010.

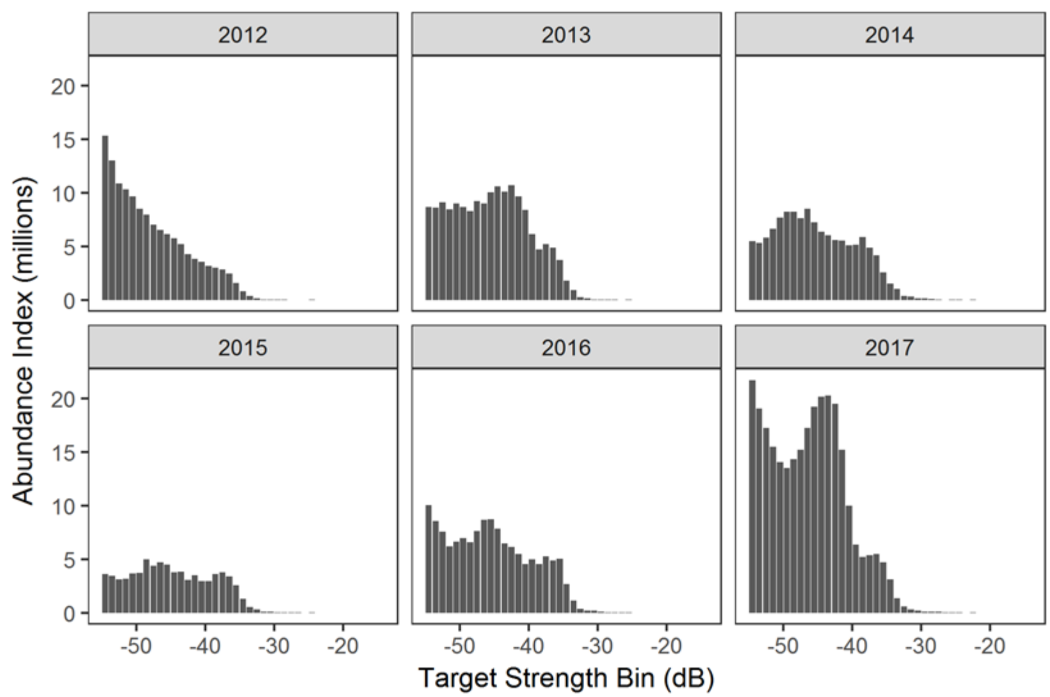

Figure 6. Target strength frequency histograms of single targets detected in the upper layer during summer hydroacoustic surveys conducted in July 2012-2017. Note the relatively low number of targets with small target strengths (i.e., small Alewife) in 2014 and 2015, compared to the relatively large numbers of these targets in 2017. These targets correspond to the low numbers of age-1 Alewife observed in Lake Ontario in 2014 and 2015, and the near record levels observed in 2017.

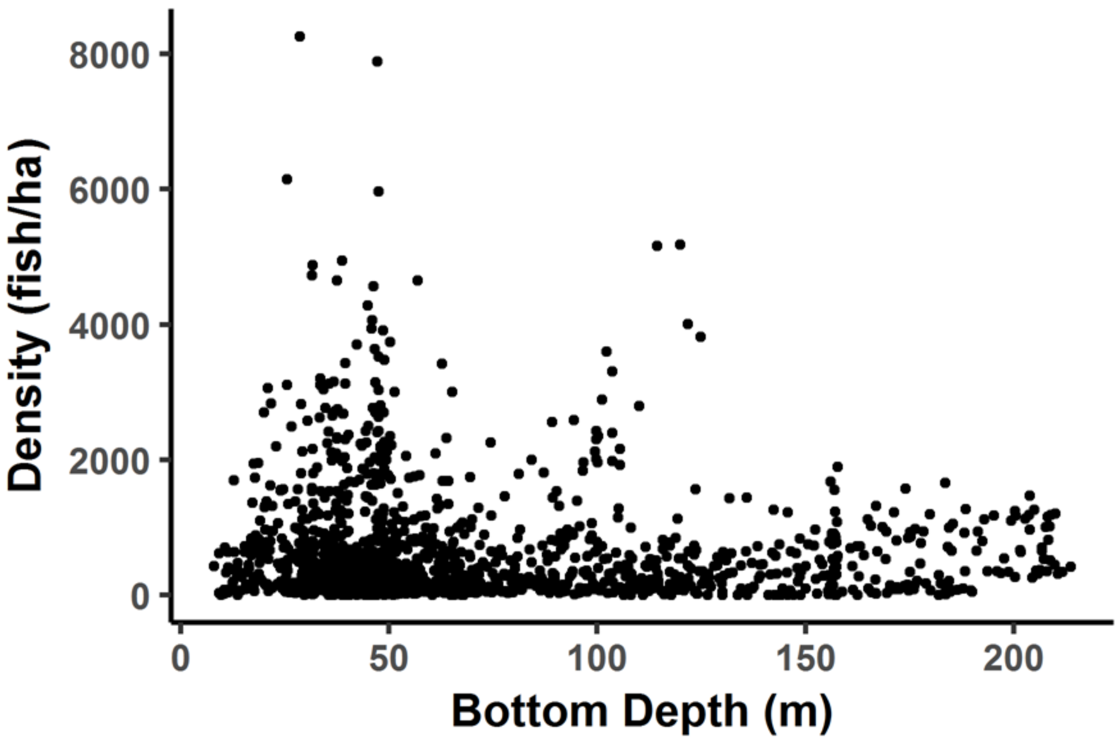

Figure 7. Distribution of Alewife (fish per ha) relative to bottom depth as determined by acoustics sampling in Lake Ontario, 2017..

Table 1. Summary of catch data for all species captured in mid-water trawls in 2017.

Species	Catch Total in Trawls below 10˚C	Catch Total in Trawls 10˚C and above	Number Sampled	Mean Total Length (mm)	Max. Total Length (mm)	Min. Total Length (mm)	Mean Weight (g)
Alewife	3547	6433	227	146	201	25	24.8
Rainbow Smelt	138	19	45	85	169	30	7.0
Cisco	15	2	17	318	371	257	271.4
Chinook Salmon	2	1	3	508	860	140	3329.0
Round Goby	1	0	1	30	30	30	0.1
Gizzard Shad	0	1	1	145	145	145	27
Threespine Stickleback	0	1	0	-	-	-	-

Fisheries Research and Monitoring Activities of the Lake Erie Biological Station, 2017[1]

Prepared by (in alphabetical order) Kevin R. Keretz, Patrick M. Kocovsky, Richard T. Kraus, and Christopher S. Vandergoot

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[1] **To cite this report**: LEBS 2018. Fisheries research and monitoring activities of the Lake Erie Biological Station, 2017. Prepared by Kevin R. Keretz, P.M. Kocovsky, R.T. Kraus, C.S. Vandergoot. Report of the Lake Erie Biological Station (LEBS) to the Great Lakes Fishery Commission at the Annual Meeting of Lake Committees, Markham, Ontario. 13 pp.

Scientific Names

Scientific and common names of common Lake Erie fishes:

Scientific name	Common name	Scientific name	Common name
Acipenser fulvescens	Lake Sturgeon	*Micropterus dolomieu*	Smallmouth Bass
Alosa pseudoharengus	Alewife	*Micropterus salmoides*	Largemouth Bass
Ambloplites rupestris	Rock Bass	*Morone americana*	White Perch
Ameiurus nebulosus	Brown Bullhead	*Morone chrysops*	White Bass
Aplodinotus grunniens	Freshwater Drum	*Moxostoma erythrurum*	Golden Redhorse
Carassius auratus	Goldfish	*Moxostoma macrolepidotum*	Shorthead Redhorse
Carpiodes cyprinus	Quillback	*Neogobius melanostomus*	Round Goby
Catostomus commersonii	White Sucker	*Notropis atherinoides*	Emerald Shiner
Coregonus clupeaformis	Lake Whitefish	*Notropis hudsonius*	Spottail Shiner
Cyprinus carpio	Common Carp	*Notropis volucellus*	Mimic Shiner
Dorosoma cepedianum	Gizzard Shad	*Osmerus mordax*	Rainbow Smelt
Esox masquinongy	Muskellunge	*Perca flavescens*	Yellow Perch
Ichthyomyzon unicuspis	Silver Lamprey	*Percina caprodes*	Logperch
Ictalurus punctatus	Channel Catfish	*Percopsis omiscomaycus*	Trout-perch
Labidesthes sicculus	Brook Silverside	*Salvelinus namaycush*	Lake Trout
Macrhybopsis storeriana	Silver Chub	*Sander vitreus*	Walleye
Petromyzon marinus	Sea Lamprey		

Executive Summary

A comprehensive understanding of fish populations and their interactions is the cornerstone of modern fishery management and the basis for Fish Community Goals and Objectives for Lake Erie. This report is responsive to U.S. Geological Survey (USGS) obligations via Memorandum of Understanding (MOU) with the Great Lakes Council of Lake Committees (CLC) to provide scientific information in support of fishery management. Goals for the USGS Great Lakes Deepwater Fish Assessment and Ecological Studies in 2017 were to understand long-term changes in fish community and population dynamics of key fishes of interest to management agencies. For Lake Erie, expectations of this agreement were sustained investigations of native percids, forage (prey) fish populations, and Lake Trout.

Our 2017 deepwater program operations began in April and concluded in December, and utilized trawl, gillnet, hydroacoustic, lower trophic sampling, and telemetry methods. This work resulted in 115 bottom trawls covering 90 ha of lake-bottom and catching 45,609 fish totaling 2,650 kg during four separate trawl surveys in the western and central basins of Lake Erie. Gillnet assessments for cold water species in the western and eastern basins of Lake Erie consisted of 7.5 km of gill nets, which caught an additional 628 fish, including 129 native coldwater species: Lake Trout, Burbot, and Lake Whitefish. USGS hydroacoustic surveys of forage fish produced 313 km of transects, and lower trophic sampling provided zooplankton samples (n=60), benthic grabs (n=15), and water quality profiles (n=60) for the interagency database. USGS also assisted CLC member agencies with deployment and maintenance of the Great Lakes Acoustic Telemetry Observation System (GLATOS) throughout all three Lake Erie sub-basins, supporting multiple coordinated telemetry investigations.

Lake trout investigations from annual gill net surveys and more recent acoustic telemetry of spawning migration and habitat use in coordination with Ontario, New York, and Pennsylvania were reported in the Coldwater Task Group annual report to the Great Lakes Fishery Commission (GLFC) and the CLC (http://www.glfc.org/lake-erie-committee.php). Likewise, interagency forage fish assessments conducted with hydroacoustics were summarized and reported in the Forage Task Group annual report (http://www.glfc.org/lake-erie-committee.php).

Additionally, at the request of the Lake Erie Committee (LEC) in 2016, we worked with Ohio and Ontario to develop a bottom trawl survey in the central basin that addressed current uncertainties in the yellow perch stock assessment. The USGS contribution to this effort has been incorporated into the Ontario database, which included a trawl comparison study in 2017, summarized in the Yellow Perch Task Group annual report (http://www.glfc.org/lake-erie-committee.php).

This report presents biomass-based summaries of fish communities in western Lake Erie derived from USGS bottom trawl surveys from 2013 to 2017 during June and September. The survey design provided temporal and spatial coverage that does not exist in the interagency trawl database, and thus complemented the August Ohio-Ontario effort to reinforce stock assessments with more robust data. Analyses herein evaluated trends in: total biomass, abundance of dominant predator and forage species, non-native species composition, biodiversity and community structure.

Data from this effort can be explored interactively online (https://lebs.shinyapps.io/western-basin/), and future analyses will be supported by public data and metadata records available on ScienceBase (https://doi.org/10.5066/F7KK9B1R).

Introduction

Lake Erie is the most populated of the Great Lakes basins (approximately 12 million people; https://www.glerl.noaa.gov/education/ourlakes/lakes.html), and as such has undergone dramatic anthropogenic changes. Since the 1800s, stresses such as overexploitation, habitat destruction, exotic species introduction, industrial contamination, and changes in nutrient loading have resulted in substantial changes to the fish community (Bogue 2001). The most notable changes have been declines in or extirpation of many native species (Hartman 1973; Leach & Nepszy 1976; Ludsin et al. 2001). Since the implementation of the Clean Water Act and Great Lakes Water Quality Agreement in the 1970s, habitat conditions for fish improved, which in part resulted in several strong percid year-classes. These strong year-classes benefited from more restrictive management that ultimately rehabilitated Lake Erie percid stocks (Hatch et al. 1987; Nepzy 1999).

Today, the primary goal of fishery resource managers in Lake Erie is "To secure a balanced, predominantly cool-water fish community characterized by self-sustaining indigenous and naturalized species that occupy diverse habitats, provide valuable fisheries, and reflect a healthy ecosystem (Ryan et al. 2003)," yet there is little guidance on what fish community characteristics indicate a balanced and healthy Lake Erie ecosystem. Historically, Lake Erie's mesotrophic cool water habitats supported harmonic percid and salmonid fish communities, and it is the aim of management to re-establish these communities.

Although Lake Erie management agencies have traditionally focused on numerical indices of a few economically important species (primarily Walleye, Yellow Perch, Lake Trout, and Smallmouth Bass), aquatic ecosystem models are typically evaluated in terms of biomass (Christensen & Walters 2004). Most time series of fish community data from Lake Erie do not contain measurements of biomass. Therefore, our understanding of fish community structure and ecosystem dynamics from mass-balance models has been limited to short-term investigations and proxy measurements (e.g., length-weight conversion).

In 2012, the USGS trawl program was revised to provide biomass-based measurements of fish population dynamics and ecosystem condition for Lake Erie. This was coincident with the switch to a new research vessel, the R/V Muskie. Trawl gear used by the previous vessel, the Musky II, did not maintain proper orientation in the water when fished with the R/V Muskie, therefore a different bottom trawl was developed. As this situation marked the beginning of a new time series of data, the sampling design was expanded for greater spatial coverage and increased sample size. Note that traditional numerically-based catch data (e.g., number per hectare) for individual species can be explored and downloaded online (from 2013 to present - https://lebs.shinyapps.io/western-basin/, https://doi.org/10.5066/F7KK9B1R) or obtained via ScienceBase for earlier years (https://doi.org/10.5066/F75M63X0). The purpose of this report is to develop a more comprehensive understanding of the long-term changes and population dynamics of key fishes of interest to management agencies, including native percids and their forage. Here, we summarize survey results for the most recent series of western basin trawl data from 2013 through 2017.

Methods

Survey Area and Sampling Design

We conducted sampling using a grid-based design in both June and September, referred to here as spring and autumn, respectively (Figure 1). This sampling design complemented the time series of combined trawling efforts between the Ohio Department of Natural Resources (ODNR) and the Ontario Ministry of Natural Resources and Forestry (OMNRF) in August, and together they provided the foundation for addressing ongoing and emerging issues facing Lake Erie Committee task groups (http://www.glfc.org/lake-erie-committee.php). The sampling domain was based upon the height of the net when fishing (ca. 3 m), the Lorain ridge to the east, and the mouths of major rivers. The spacing of the grid was six minutes of longitude (E-W) and latitude (N-S), and the origin of the six-minute intersections of latitude and longitude was chosen to provide the maximum number of sampling locations that could be completed within a week (n=41). Due to interference from shipping lanes, the entire grid was shifted south by 1.85 km after the spring sampling trip in 2013 to avoid conflict with large boats using the shipping lanes. In spring of 2017, only 36 sites were sampled due a structural failure of the trawl gallows when the net became snagged on the bottom.

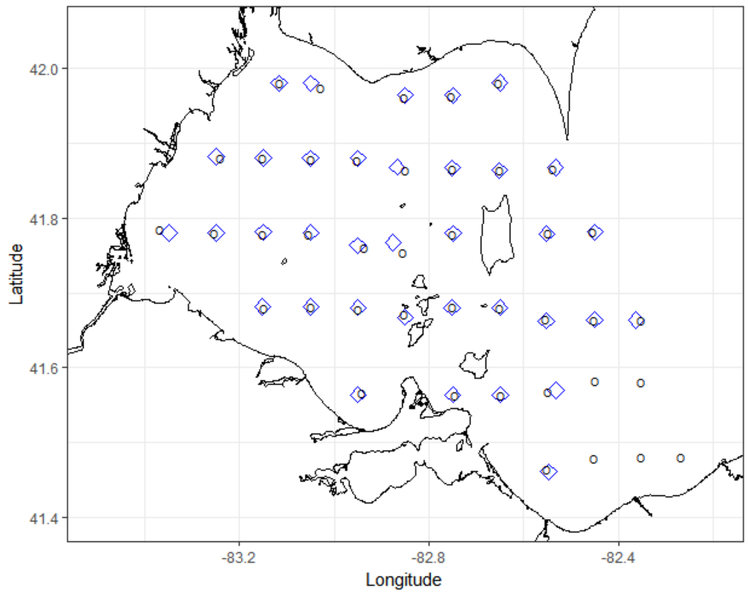

Figure 1. Western Lake Erie trawl survey sites sampled by Lake Erie Biological Station in spring (diamonds) and autumn (circles) in 2017.

Results and Discussion

The 2017 spring and autumn surveys took place during the weeks of June 18 and September 17, respectively. We trawled a total area of 57 hectares (27 ha spring, and 30 ha autumn), and caught a total fish biomass of 2,057 kg (34,765 fish). Catches were largest in the spring, totaling 1,266 kg (5,691 fish from 21 species). Autumn catches totaled 791 kg (29,074 fish from 20 species).

Trends in Biomass and Community Composition

Total biomass in trawl catches declined by approximately 90 percent from 310 kg/ha in 2013 to 27 kg/ha in 2017 (Table 1). This decline was not attributed to any single taxon, but was observed across the assemblage and functional groups, including predators (percids and moronids), forage fishes (Emerald Shiners, Gizzard Shad, and Rainbow Smelt), and large benthic species (Freshwater Drum, Quillback, Common Carp, and Channel Catfish).

Table 1: Survey summaries of catch (kg/ha) for total and forage species, biomass proportion of non-native species, and Shannon Diversity Index values.

Year	Season	n	Total	Forage	Non-Native Proportion	Shannon Diversity
2013	Spring	41	310 ± 249	52.2 ± 111.4	0.12	0.35
2013	Autumn	41	235 ± 154	4.9 ± 8.98	0.24	1.63
2014	Spring	41	194 ± 173	11.8 ± 25.75	0.13	1.08
2014	Autumn	41	178 ± 113	12.2 ± 21.04	0.25	1.63
2015	Spring	41	122 ± 100	5.4 ± 19.22	0.10	1.39
2015	Autumn	41	86 ± 66	4.9 ± 5.79	0.15	1.89
2016	Spring	41	101 ± 75	0.1 ± 0.12	0.09	1.63
2016	Autumn	41	74 ± 57	3.5 ± 6.35	0.22	2.02
2017	Spring	36	49 ± 36	0.2 ± 0.63	0.17	1.98
2017	Autumn	41	27 ± 29	1.3 ± 2.36	0.16	1.24

Forage biomass averaged 0.19 and 1.32 kg/ha during 2017 spring and autumn sampling, respectively, (Table 1). Catches of Emerald Shiner peaked at 51.49 kg/ha in spring 2013 and were <0.01 kg/ha in autumn 2017 (Figure 2). Rainbow Smelt catches were low and varied from <0.01 kg/ha to 4.99 kg/ha (Figure 2). Similarly, Gizzard Shad were also low and variable, but typically higher in autumn than spring, reflecting the occurrence of young-of-year fish (Figure 2).

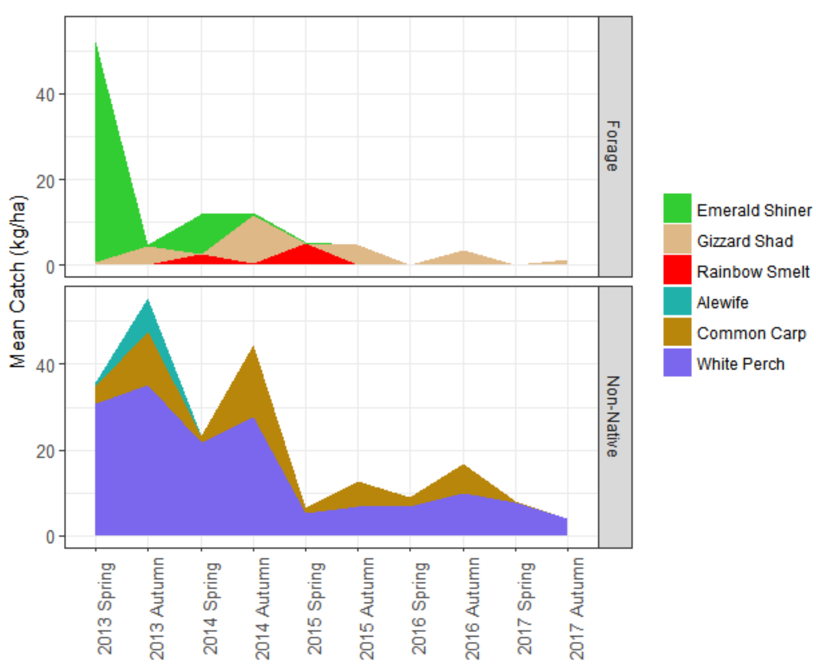

Figure 2. Stacked area plots of catch of primary forage (upper panel) and non-native (lower panel) fishes from trawls in western Lake Erie. Note, Rainbow Smelt belong to both categories but are only plotted in the upper panel. Also, note that Round Goby, Sea Lamprey, and Goldfish are non-native species that were not plotted due to very low abundances in trawls.

The biomass proportion of catch of non-native species was generally less than 25%, averaging 0.16 (s.d. = 0.06) over the five years (Table 1). The dominant non-native species either declined or showed little evidence of trends. White Perch averaged 15.69 kg/ha (s.d. = 32.36) across the series, with catch rates of 7.74 kg/ha and 2.20 kg/ha respectively in spring and autumn caught of 2017 (Figure 2). Common Carp represented the second most abundant non-native species by biomass, and varied from 0.2 to 17 kg/ha (mean = 5.1 kg/ha, s.d. = 5.6; Figure 2). After relatively large mean catches of Alewife in 2013 (0.69 kg/ha and 7.69 kg/ha in spring and autumn, respectively) none were captured from 2014-2016, and few were captured in 2017 (<0.01 kg/ha, Figure 2). Other non-native species (Round Goby, Goldfish, Sea Lamprey) were captured in low abundances (<0.1 kg/ha).

Despite decreasing trends in total biomass (Table 1), biodiversity of trawl catches varied seasonally with an increasing trend in spring (Shannon Diversity Index increased from 0.35 to 1.98) and no prominent trend in autumn (Shannon Diversity Index ranged from 1.24 to 2.02; Table 1). In previous years, Shannon Diversity Index values were higher autumn than spring; but in 2017, increased diversity was observed in spring rather than autumn due to one additional species (Lake Whitefish, Table 1).

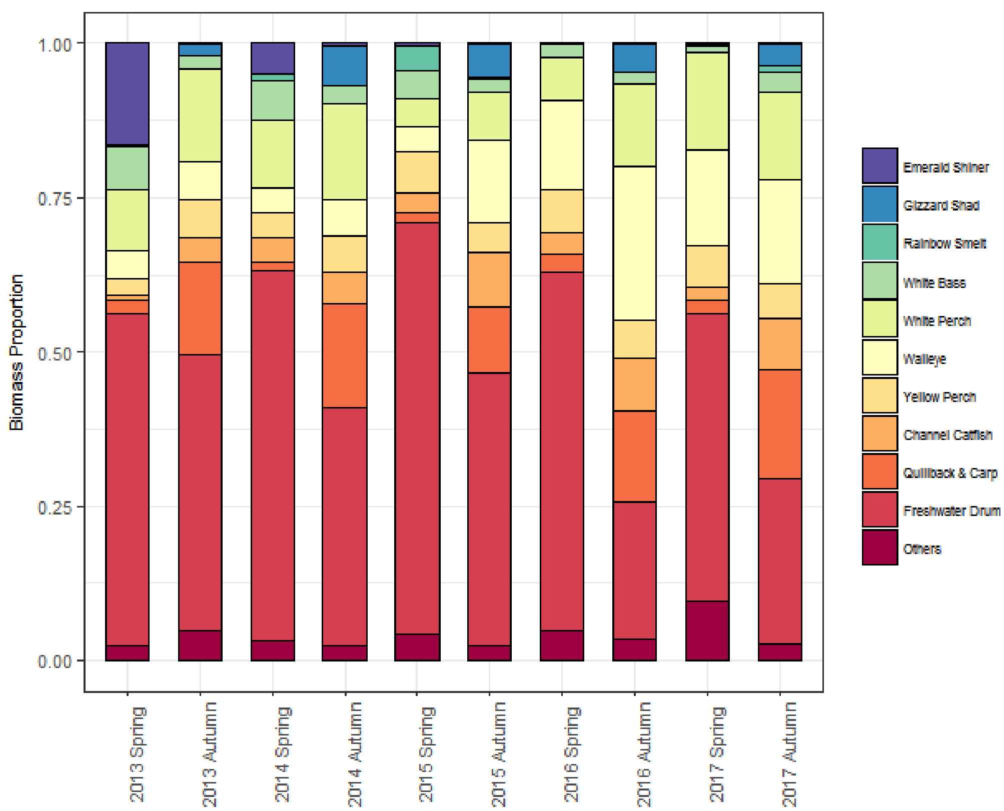

Figure 3. Biomass proportion of fish in bottom trawls in western Lake Erie.

Like the numerically-based Shannon Diversity Index estimates of fish community structure, species biomass composition varied little across the series. While large benthic species were not numerically dominant, they accounted for 50% or more of the total catch biomass during nearly every sampling season (Figure 3; numerical versus biomass summaries can be explored here: https://lebs.shinyapps.io/western-basin/). Freshwater Drum dominated the biomass proportion with percentages as high as ~70% in spring 2015 (Figure 3). Although it has remained the dominant single species by biomass (except in autumn 2016), Freshwater Drum biomass fluctuated from 25% to 53% since autumn 2016 (Figure 3). By comparison, the proportions of other large benthic species, such as Channel Catfish, Common Carp and Quillback, have remained relatively constant across the series (Figure 3). Other non-forage species that dominated the biomass composition of the catch were percids (Walleye and Yellow Perch) and moronids (White Perch and White Bass). Both moronid species and Yellow Perch biomass proportions were relatively constant across the series, but Walleye (adults and juveniles) increased since 2014 from 10% to 20% of the catch biomass (Figure 2). The proportion of Gizzard Shad to the overall catch has remained stable over the 5-year survey (~5-10%), while contributions from other forage species (Emerald Shiner and Rainbow Smelt) declined across the series to below 5%.

Trends in Percids

Young-of-year (YOY) Yellow Perch catch rates in 2017 were low (32.31 fish/ha), varying little compared to the previous two years, and smaller than 2013 and 2014 catch rates by an order of magnitude (Figure 3). Young-of-year Yellow Perch catch rates peaked in 2014, and although we expected a corresponding peak in age-1 catch rates one year later, the data did not exhibit such a pattern (Figure 3). By comparison for Walleye, a lagged year-class signal was evident in YOY and age-1 catch rate peaks corresponding to the 2015 year-class (69.67 fish/ha; Figure 3). Further, an increase in YOY catch rate from 2013 to 2014 was also reflected in an increase in age-1 catch rates from 2014 to 2015. Similar cross-validations of Walleye year-class variability from this survey will depend upon additional years of data.

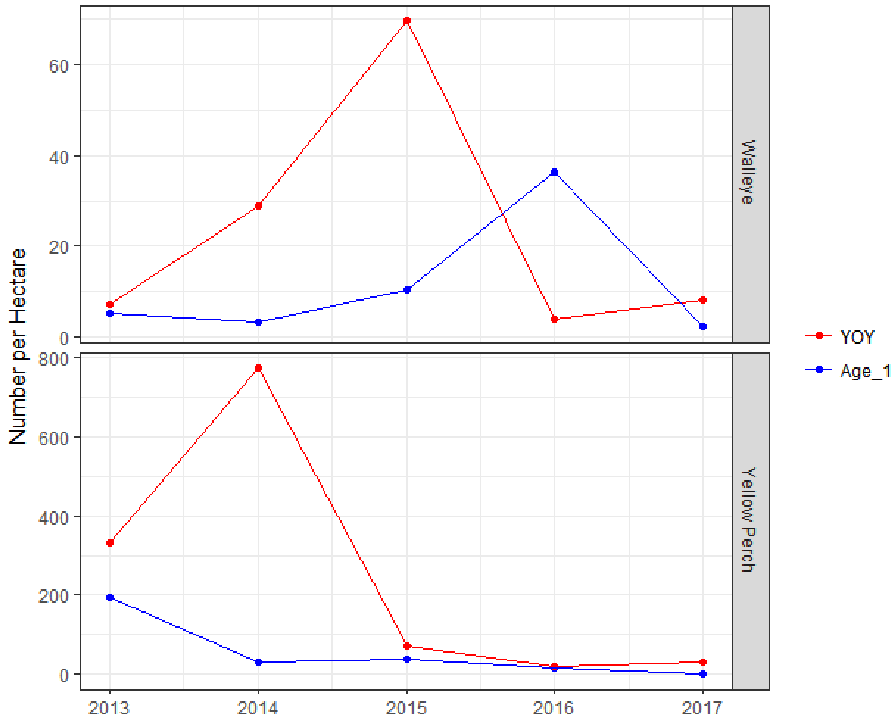

Figure 4. Mean number per hectare of young-of-year (YOY) and age-1 Walleye (upper panel) and Yellow Perch (lower panel) in bottom trawls from western Lake Erie during autumn of years 2013-2017.

Summary

Although biomass of bottom trawl catches from western Lake Erie has declined dramatically over the past five years, in other the Great Lakes, cycles of fish population abundance are often longer than five years (GLSC 2014). Thus, trends from a five-year data series should be interpreted cautiously. The survey results reported here provide new perspectives not immediately available from existing monitoring efforts to support fish community goals of a mesotrophic ecosystem with a harmonic cool-water species assemblage of forage fish and percids (Ryan et al. 2003). Notably, other Lake Erie surveys have underemphasized the importance of Freshwater Drum because they tend to report numerical instead of biomass-based measures of relative abundance. The potential for Freshwater Drum to impact invasive Dreissenid mussels has only been evaluated superficially (French & Bur 1996), but due to its dominance in the fish community, this species has potential to contribute substantially to the remineralization of phosphorous in Lake Erie through the consumption of mussels (e.g., Bunnell et al. 2005). These data also highlight the need to better understand mechanisms driving forage fish abundance. Adult Walleye and Yellow Perch rely on Gizzard Shad and Emerald Shiner as primary forage (Knight et al. 1984). Particularly for Walleye, which have experienced a strong recent year-class in 2015, the low abundance of forage in western Lake Erie may result in reduced growth and early emigration (Madenjian et al. 1996; Weng et al. 2007). Diet investigations that incorporate ontogenetic changes in spatial distribution may be needed to better inform potential management actions that would ensure sustainable fisheries in Lake Erie. Such efforts will require surveys like the one presented in this report.

Acknowledgments

We thank H. Bontrager, D. Hall, J. Ludwig, J. McKenna, D. Panos, and G. Rutz for assistance in the field. Constructive reviews were provided by J. Kerns and B. Lantry. Field collections were carried out in accordance with guidelines for the care and use of fishes by the American Fisheries Society (http://fisheries.org/docs/wp/Guidelines-for-Use-of-Fishes.pdf). Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

References

Bogue, M. B. 2001. Fishing the Great Lakes: an environmental history, 1783–1933. University of Wisconsin Press.

Christensen, V., and C. J. Walters. 2004. Ecopath with Ecosim: methods, capabilities and limitations. Ecological Modelling 172(2-4):109-139.

Johnson, T. B., D. B. Bunnell, and C. T. Knight. 2005. A potential new energy pathway in central Lake Erie: The Round Goby connection. Journal of Great Lakes Research 31, Supplement 2(0):238-251.

French, J. R. P., and M. T. Bur. 1996. The effect of Zebra Mussel consumption on growth of Freshwater Drum in Lake Erie. Journal of Freshwater Ecology 11(3):283-289.

GLSC. 2014. Compiled reports to the Great Lakes Fishery Commission of the annual bottom trawl and acoustics surveys, 2014. Prepared by the U.S. Geological Survey, Great Lakes Science Center. http://www.glfc.org/lakecom/common_docs/Compiled%20Reports%20from%20USGS%202015.pdf

Hatch, R. W., S. J. Nepszy, K. M. Muth, and C. T. Baker. 1987. Dynamics of the recovery of the western Lake Erie Walleye (Stizostedion vitreum vitreum) stock. Canadian Journal of Fisheries and Aquatic Sciences 44(S2):s15-s22.

Hartman, W. L. 1973. Lake Erie: effects of exploitation, environmental changes, and new species on the fishery resources. Journal of the Fisheries Research Board of Canada. 29: 899-912.

Hartman, K. J. and F. J. Margraf. 1992. Effects of prey and predator abundances on prey consumption and growth of Walleyes in western Lake Erie. Transactions of the American Fisheries Society. 121(2).

Knight, R. L., F. J. Margraf, and R. F. Carline. 1984. Piscivory by Walleyes and Yellow Perch in western Lake Erie. Transactions of the American Fisheries Society. 113: 677-693.

Leach, J. H., and S. J. Nepszy. 1976. The fish community in Lake Erie. Journal of the Fisheries Research Board o f Canada 33: 622-638.

LEBS. 2014. Fisheries research and monitoring activities of the Lake Erie Biological Station, 2013. Prepared by Kraus, R., M. Rogers, P.M. Kočovský, W.H. Edwards, B. Bodamer-Scarbro, K. Keretz., and S. Berkman. Annual Report to the Great Lakes Fisheries Commission, Ann Arbor, MI, 52 pp.

LEBS. 2015. Fisheries research and monitoring activities of the Lake Erie Biological Station, 2014. Prepared by B. Bodamer Scarbro, W.H. Edwards, C. Gawne, P.M. Kočovský, R.T. Kraus, M.R. Rogers, and T. R. Stewart. Report of the Lake Erie Biological Station (LEBS) to the Great Lakes Fishery Commission at the Annual Meeting of Lake Committees, Ypsilanti, Michigan. 30 pp.

LEBS. 2016. Fisheries research and monitoring activities of the Lake Erie Biological Station, 2015. Prepared by B. Bodamer Scarbro, W.H. Edwards, P.M. Kočovský, R.T. Kraus, M. R. Rogers, A.L. Schoonyan, and T.R. Stewart. Report of the Lake Erie Biological Station (LEBS) to the Great Lakes Fishery Commission at the Annual Meeting of Lake Committees, Niagara, Ontario. 35 pp.

LEBS. 2017. Fisheries research and monitoring activities of the Lake Erie Biological Station, 2016. Prepared by B. Bodamer Scarbro, P.M. Kočovský, R.T. Kraus, C.S. Vandergoot. Report of the Lake Erie Biological Station (LEBS) to the Great Lakes Fishery Commission at the Annual Meeting of Lake Committees, Ypsilanti, Michigan. 37 pp.

Ludsin, S. A., M. W. Kershner, K. A. Blocksom, R. A. Stein, and R. L. Knight. 2001. Life after death in Lake
Erie: nutrient controls drive fish species richness, rehabilitation. Ecological Applications. 11: 731-746.

Madenjian, C.P., J. T. Tyson, R. L. Knight, M. W. Kershner, and M. J. Hansen. 1996. First-year growth, r ecruitment, and maturity of Walleyes in western Lake Erie. Transactions of the American Fisheries Society. 125(6).

Miller, R.R. 1957. Origin and dispersal of the Alewife, *Alosa pseudoharengus*, and the Gizzard Shad, Dorosoma cepedianum, in the Great Lakes. Transactions of the American Fisheries Society. 86:97-111.

Nepszy, S. J. 1999. The changing fishery regime in Lake Erie. Pages 233-239 in M. Munawar, T. Edsall, and I. F. Munawar, editors. State of Lake Erie (SOLE)—Past, Present and Future. Backhuys, Netherlands.

Ryan, P. A., R. Knight, R. MacGregor, G. Towns, R. Hoopes, and W. Culligan. 2003. Fish-community goals and objectives for Lake Erie. Great Lakes Fishery Commission Special Publication 03-02. 56 p.

Trautman, M. B. 1957. The fishes of Ohio. Ohio State University Press. 683 pp.

Wang, H. Y., E. S. Rutherford, H. A. Cook, D. W. Einhouse, R. C. Haas, T. B. Johnson, R. Kenyon, B. Locke, and M. W. Turner. 2007. Movement of Walleyes in Lakes Erie and St. Clair inferred from tag return and fisheries data. Transactions of the American Fisheries Society 136(2):539-551.