Bottom trawl assessment of Lake Ontario prey fishes

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Abstract

*Multi-agency, collaborative Lake Ontario bottom trawl surveys provide information for decision making related to Fish Community Objectives including predator-prey balance and understanding prey fish community diversity. In 2019, bottom trawl surveys in April (n = 252 tows) and October (n = 160 tows) sampled main lake and embayments at depths from 5–226 m. Combined, the surveys captured 283,383 fish from 39 species. Alewife were 67% of the total catch by number while round goby, deepwater sculpin, and rainbow smelt comprised 13, 10, and 4% of the catch, respectively. In 2019, the lake-wide adult alewife biomass index declined from 2018 and age-1 biomass, a measure of reproductive success the previous year, was low. Year-class catch curve models identified years where estimates from surveys conducted only in U.S. waters were biased, potentially due to a greater portion of the alewife population inhabiting unsampled Canadian waters. Accounting for spatial survey bias, these model estimates indicated the 2019 adult alewife biomass was the lowest value in the 42-year time series. Models also identified the extent to which age-1 alewife biomass was historically underestimated, however lake-wide results from 2016-2019 appear less biased. If below-average year-class estimates from 2017 and 2018 are accurate, adult alewife biomass will continue to decline in 2020. Abundance indices for other pelagic prey fishes such as rainbow smelt, threespine stickleback, emerald shiner, and cisco were low and similar to 2018 values. Pelagic prey fish diversity is low because a single species, alewife, dominates the community. Deepwater sculpin and round goby were the most abundant demersal (bottom-oriented) prey fishes in 2019. Despite declines in slimy sculpin and other nearshore prey fishes, demersal prey fish community diversity has increased as deepwater sculpin and round goby comprise more even portions of the community. New experimental trawl sites in embayment habitats generally captured more species, a higher proportion of native species, and higher densities relative to main lake habitats. In 2019, a western tubenose goby (*Proterorhinus semilunaris*) was captured for the first time in the trawl surveys.*

Introduction

Lake Ontario Fish Community Objectives (herein FCOs) call for maintaining predator-prey balance and for maintaining and restoring pelagic and benthic (bottom–oriented, demersal) prey fish diversity (Stewart et al., 2017). Collaboratively-conducted bottom trawl surveys have measured Lake Ontario prey fish community status and trends since 1978 to provide information for decision making relative to those objectives.

Alewife are the most abundant fish in Lake Ontario and, as prey, support most of the lake's piscivores (Mills et al., 2003; Stewart and Sprules, 2011; Weidel et al., 2018). Accordingly, their abundance and population abundance trajectories are critical to achieving FCOs and maintaining sport fishing quality. Recent bottom trawl prey fish surveys have documented lower-than-average alewife reproduction in 2013 and 2014 resulting in reduced adult abundances (Weidel et al., 2018). Concerns over maintaining alewife in balance with the lake's predators has resulted in management agencies reducing the number of Chinook salmon and lake trout stocked in 2016 – 2019 (Great Lakes Fishery Commission Lake Ontario Committee, 2016; New York State Department of Environmental Conservation, 2018; Ontario Ministry of Natural Resources and Forestry, 2018).

In addition to providing information for managing sport fisheries, prey fish surveys also quantify the status of native species and prey fish communities, providing information for other FCOs and basin-wide prey fish status assessments (Environment and Climate Change Canada and U.S. Environmental Protection Agency, 2017). These surveys documented the natural recovery of native deepwater sculpin, a bottom-oriented prey fish once thought to be extirpated from the lake (Weidel et al., 2017). Bottom trawl surveys also measure the progress of bloater restoration, a native species that historically inhabited deep Lake Ontario habitats. Trawl surveys also provide lake-wide surveillance for nonnative species and their effects, such as round goby and its apparent negative impact on native demersal fishes (Weidel et al., 2018). In addition to standardized sampling, surveys also conduct targeted research to better interpret historic bottom trawl data. For instance, video cameras attached to the bottom trawls determined the extent to which trawls were in contact with the lake bottom and found the area swept by deep trawls was, for some trawls, three times what had been previously estimated based on recorded tow times (Weidel and Walsh, 2013). The prey fish trawl survey design and timing has changed over time to reduce duplicative results, increase sampling efficiency, and expand the spatial extent of surveys (Weidel et al., 2015). Lake-wide surveys began in 2015 for the October survey and in 2016 for the April survey, and have provided critical new insights related to prey fish distribution. Whole lake surveys have demonstrated that alewife spatial distribution in April can vary substantially between U.S. and Canadian waters (Weidel et al., 2018). This new understanding of annual variability in spatial distribution has affected the interpretation of results from surveys conducted only in U.S. waters.

This report describes the status of Lake Ontario prey fishes with emphasis on information addressing the bi-national (OMNRF, NYSDEC) Lake Ontario Committee's FCOs (Stewart et al., 2017). This research is also guided by the U.S. Geological Survey (USGS) Ecosystems Mission Area science strategy that seeks to understand how ecosystems function and provide services, what drives ecosystems, and to develop science and tools that inform decision making related to ecosystem management, conservation and restoration (Williams et al., 2013).

Methods

Estimating trawl conversion factor

Prey fish bottom trawl surveys have primarily used two different bottom trawl and door designs over the past 42 years. The original Yankee trawl was nylon with an 11.8-m (39 ft) headrope and was spread with flat, rectangular, wooden trawl doors (2.1m x 1m). Large catches of dreissenid mussels in 1990s caused a change to a 3n1 polypropylene trawl. This trawl has an 18-m (59 ft) headrope and is spread with slotted, metal, cambered V-doors (1.2 m x 0.5m). The footrope of the 3n1 trawl includes a rubber cookie sweep and is raised to reduce lake bottom contact and reduce dreissenid mussel and shell catches. To determine a conversion factor for comparing data collected with the smaller Yankee trawl (1–2 m vertical opening) to the 3n1 trawl (3–4 m vertical opening), the Seth Green and Kaho conducted comparison trawling at the same sites and depths in 1995–1998 (O'Gorman et al., 1999). We calculated a conversion factor to apply to the data collected with the smaller Yankee trawl (1978–1997) in order to compare it to data collected with the larger 3n1 trawl (1997 – present). For all paired trawls, biomass values were calculated based on boat and trawl specific area swept estimates for both the Yankee and 3n1 trawls as described in Weidel and Walsh (2013). A single conversion value was based on the linear model relating Yankee biomasses (independent variable) to 3n1 biomasses (dependent variable). Linear models were fit using untransformed, paired data and the glm function in R and observations met the assumptions for linear models (R Core Team, 2013).

April survey

The Lake Ontario April bottom trawl survey has been collaboratively conducted in April and early May since 1978. The survey targets alewife at a time when their winter behaviors place them on the lake bottom, which maximizes their susceptibility to bottom trawls (Wells, 1968). Daytime trawling is conducted at fixed sites located along transects extending from shallow (~6m) to deep (228m) habitats. While random sampling is preferable for trawl-based estimates, it is not practical because of varied substrates that can prohibitively damage trawls at randomly selected sites (MacNeill et al., 2005). A review of the Lake Ontario prey fish trawl program 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. Changes in fish depth distribution and the need for lake-wide information have resulted in survey expansion. For instance, the depth distributions of alewife and other prey fish have shifted deeper as water clarity increased and in 2004, trawling was expanded to 170m (557 ft) in U.S. waters (O'Gorman et al., 2000). In 2016, the survey was further expanded to a whole-lake extent and the OMNRF research vessel joined the survey. Since 2016, trawls have generally been collected from 6–225m (20–743 ft), with sites organized in 20–23 transects or regions distributed around the lake (Figure 1).

Bottom trawl catches are separated to species, counted, and weighed in aggregate. Subsamples of all species are also measured for individual length and weight. Stomach contents, muscle tissue, and various aging structures are sampled from representative subsets of the catch from species of key management priority.

Trawl effort was historically based on tow time and abundance indices were reported as number or weight per 10-minute trawl. Area-swept estimates calculated using trawl mensuration sensors and video cameras indicated trawl effort, expressed as area swept, differed substantially from effort based on tow time. Models were developed to estimate area swept based on fishing depth and were applied to all historic and current trawl catches (Weidel and Walsh, 2013). Currently, trawl catches are expressed in kilograms per hectare of trawl area swept based on trawl wing widths. Annual mean biomass estimates are lake area-weighted from thirteen 20 m (66 ft) strata depth intervals and the proportional area of those depth intervals within the U.S. and Canadian portions of the lake (Table 1). Mean and standard error calculations are from Cochrane (1977). Time series are still regarded as biomass indices because we lack estimates of trawl catchability (proportion of the true density within a surveyed area captured by the trawl). Reporting indices as biomass units provides data in a more readily useable form to address ecosystem-scale management questions and facilitates comparisons across lakes.

To estimate the mean stratified abundance from a consistent lake area, stratified means for all years are calculated using all 13 depth strata (0 – 244 m). In years when trawling was not conducted in the deepest 3-4 strata (160 – 244 m), we assumed prey fish catch was zero in those strata. Separate abundance indices are calculated for trawls collected in U.S. and Canadian waters. Statistics reported for trawl catches in Canadian waters follow a similar analysis, however the area within 20m strata in Canadian waters differ from U.S. waters (Table 1). We also report a lake-wide alewife biomass index expressed in kilograms per hectare combining biomass estimates from U.S. and Canadian portions of the lake, assuming 48% lake area is in U.S. and 52% is in Canada.

Log-linear catch curve models were created for each alewife year-class from 1972 – 2017 to identify years when biomass estimates from surveys in U.S. waters may have been biased. Natural log-transformed (log) abundance estimates of a given year-class for each year they were in the lake are plotted according to age. If we assume sampling was unbiased and year-to-year survival was consistent, the log-transformed points should decline in a straight line. Often values at young ages (age-1 and age-2) are estimated to be less than age-3 values and represent either size or spatial bias in the sampling. When plotted these biased points appear as curved sets of points, off of the straight line. Model-predicted estimates of abundance were multiplied by the observed mean weight for each age in a year, and then weights were summed for all age-2 and older alewife. We compared this modeled-based biomass estimate to our observations from the survey conducted in U.S. waters. Catch curve models assume survival is constant, but their simplicity helps to identify patterns in sampling bias in any given year and provide estimates for us to understand how likely our observed survey values are relative to the modeled population estimates.

Adult alewife condition indices are estimated using linear models with length and weight observations from fish over a length range from 150 mm to 180 mm. Observations met the assumptions for linear models. Condition is illustrated as the predicted weight of a 165-mm (6.5 inch) alewife in the April and October surveys. Pelagic and demersal prey fish community diversity are quantified using the Shannon index, based on trawl catch by weight (Shannon and Weaver, 1949). New experimental trawl sites in Sodus Bay, and Little Sodus Bay were established and sampled during the 2019 April survey.

October survey

From 1978–2011, the October bottom trawl survey sampled six to ten transects along the southern shore of Lake Ontario, from Olcott to Oswego, NY, and targeted 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 using doors described above. Abundant dreissenid mussel catches led to the survey abandoning the standard trawl and experimenting with a variety of alternate polypropylene bottom trawls and metal trawl doors (2004–2010). Comparison towing indicated alternate trawls caught few demersal 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 doors but has reduced tow times to reduce mussel catches. Experimental sampling at new transects and in deeper habitats began in 2012. More notably, in 2015, the survey spatial extent was doubled to include Canadian waters. At that time the NYSDEC and OMNRF research vessels joined the survey, which greatly expanded the spatial extent and diversity of habitats surveyed. Demersal prey fish time series are illustrated in this report from 1978 to present and no adjustments are available for data when the alternative trawls were used. Trawl catch processing is the same as the April survey. Trawl results are expressed as biomass (kilograms of fish per hectare) and account for depth-based differences in the lake area swept by the trawl (Weidel and Walsh, 2013). Time series are still regarded as biomass indices because we lack estimates of trawl catchability (proportion of the true density within a surveyed area captured by the trawl).

Results and Discussion

In 2019, bottom trawl surveys in April (n = 252 tows) and October (n = 160 tows) sampled main lake and embayments at depths from 5–226 m. Combined, the surveys captured 283,383 fish from 39 species (Table 2). Alewife were 67% of the total catch by number while round goby, deepwater sculpin, and rainbow smelt comprised 13, 10, and 4% of the catch, respectively (Table 2).

Trawl Conversion Factors – The regression model slope coefficient for converting Yankee trawl biomass to 3n1 equivalents was 1.71 (N=104, S.E. = 0.06, *p-value* < 0.00001) for adult alewife and was 3.51 (N=104, S.E.= 0.13, *p-value* < 0.0001) for age-1 alewife (Figure 2). Greater catches in the 3n1 relative to the Yankee trawl can partially be explained by a difference in the vertical opening of the trawl. The vertical opening of the 3n1 is 3 – 4 m depending on the fishing depth while the Yankee trawl vertical opening ranges from 1 – 2 m. In addition, the Yankee trawl door arrangement 'overspreads' the trawl pulling the wings wider than would be typical for a trawl this size. This could allow fish to avoid or go through the wing sections relative to the 3n1 wings that are not overspread.

Previous conversion analyses 'connected' the alewife abundance time series collected with different trawls by reducing 3n1 trawl catches to match the Yankee trawl catches. The trawl conversion factor previously used reduced 3n1 catches from depths greater than 70m to approximately 30% of the observed catch. While statistically valid, this type of conversion did not account for alewife depth distribution changes. As the proportion of alewife caught at depths greater than 70m increased over time, the conversion factor had an increasingly large effect on the alewife abundance estimate. This resulted in the reported converted 3n1 catches appearing as though they were decreasing during the 2000s and early 2010s however more recent time series that did not use the historic conversion factor did not illustrate a decline over this time period (Brian C. Weidel et al., 2019). The conversion factors we applied in this analysis are likely conservative (low) but they provide interpretative context for the current alewife biomass estimates. Future research should evaluate alternative conversion factor estimates and add additional comparison trawl data.

Alewife – The adult alewife (age-2 and older) biomass index for the lake-wide survey decreased in 2019 (27.7 $kg{\bullet}ha^{-1}$) relative to 2018 value (39.1 $kg{\bullet}ha^{-1}$) and was the lowest observed in the four years of lake-wide sampling (Figure 3). Similarly, the 2019 age-1 alewife biomass value declined slightly from 2018 (Figure 4, Table 3) and was also the lowest value observed in the four years of lake-wide sampling. Biomass values in U.S. and Canadian waters were generally similar in 2019 (Table 3, Figure 5).

The age distribution of adult alewife in 2019 was dominated by age-3 fish from the 2016 year-class (Figure 6). Lower than average abundances of the 2017 and 2018 year-classes suggest the 2016 year-class comprised much of the spawning alewife population in 2019 and will also likely be the most abundant spawning year-class in 2020. The low age-1 alewife biomass estimated for 2019 suggests the adult biomass will decline further in 2020 (Figure 6).

In the previous three years of lake-wide surveys, U.S. and Canadian values differed substantially within a year (Table 3). The environmental factors driving this spatial variability in alewife distribution are unknown, but this variability would partly explain aberrant alewife biomass estimates in the U.S. time series. For instance, the alewife biomass value observed in 2010 was uncharacteristically below both the 2009 and 2011 values (Figure 3). Estimates from 2010 are likely an example where alewife biomass was higher in the unsampled Canadian waters than the U.S. waters where the survey was conducted. This bias in the 2010 U.S-only survey is also evident in the year-class catch curve plots from 2005 – 2007 where the single point representing the 2010 catches in each of these year-class plots (2005: age-5, 2006: age-4, 2007: age-3) are uncharacteristically low, and then abundance increases in the 2011 catches (Figure 7). Catch curves also indicate when U.S.-only survey results are likely higher than the actual lake-wide biomass such as the 2011 catch which appears higher-than-expected in the 2002–2004 year-class plots at ages 7–9 (Figure 7).

Identifying bias in survey results does not invalidate the survey, but rather it strengthens inference from the results and supports the need for lake-wide approaches. While 2019 biomass estimates appear to be generally similar to observations from 1978, 1979, and 2010, model estimates indicate estimates in those years were likely biased low (Figure 8). This further strengthens our conclusion that the 2019 adult alewife biomass values represent the lowest value yet observed in the 42-year Lake Ontario time series.

Lake-wide sampling has illustrated age-1 alewife spatial distribution can also vary between U.S. and Canadian portions of Lake Ontario. This may partly explain why historical observations from U.S.-only surveys often underestimated age-1 abundance (Figure 8). Lake-wide sampling with the larger 3n1 trawl has apparently improved our ability to assess age-1 abundance relative to historic procedures, however it is important to recognize the potential for underestimating the year class size with only a single year of observation.

Adult alewife condition in April 2019 was similar to 2018 and below the 10-year average while the October 2019 value was much higher than 2018 and well above the 10-year average (Figure 9).

Other Pelagic Fishes – Bottom trawl abundance indices for other pelagic species noted in the FCOs (threespine stickleback, rainbow smelt, emerald shiner, and cisco) either declined or remained at low levels in 2019 (Figure 10).

Bloater – Bloater are a pelagic species native to Lake Ontario that historically inhabited deep, offshore habitats. While records are sparse, commercial fishery catches suggest the species was historically abundant in Lake Ontario, but by the 1970s, was rare (Christie, 1973). Restoration in Lake Ontario began in 2012 by stocking bloater raised from eggs collected from Lake Michigan (Connerton, 2018). Catches have been sporadic since restoration stocking began but may be reasonable based on the survey's power to detect species at low abundance (Brian C. Weidel et al., 2019). In 2019, a single bloater (87 mm) was captured during the spring survey and none were captured during the October survey. An additional two bloater were captured near Niagara on the Lake, Ontario (123 mm) and Southwicks Beach, NY (160 mm) during the July-conducted juvenile lake trout bottom trawl survey.

Slimy Sculpin – Slimy sculpin biomass indices in 2019 were among the lowest observed for the entire time series (Figure 11). Once the dominant demersal prey fish in Lake Ontario, slimy sculpin declines in the 1990s were attributed to the collapse of their preferred prey, the amphipod *Diporeia* (Owens and Dittman, 2003). The declines of slimy sculpin that occurred in the mid-2000s appear to be related to round goby introduction. 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% (Weidel et al., 2018). These data suggest round goby may be limiting slimy sculpin by interfering with reproduction or consuming eggs and or juvenile life stages.

Deepwater Sculpin - In 2019, deepwater sculpin were among the most abundant demersal prey fishes in Lake Ontario, and their biomass estimates increased from 2018 (Figure 11). Reduced abundance of non-native planktivores, rainbow smelt and alewife, and shifts in the depth distributions of these species has been suggested as contributing to deepwater sculpin recolonization (Brian C Weidel et al., 2019). Lake-wide biomass estimates in Lake Ontario are similar or greater than estimates from Lakes Superior, Huron and Michigan (Brian C Weidel et al., 2019). Dead deepwater sculpin continue to be occasionally captured in both April and October surveys however the frequency of dead deepwater sculpin declined from 24% of October trawls in 2018 to 18% of trawls in 2019 (15 of 82 tows).

Round Goby – Round goby biomass decreased in 2019, relative to 2018, for both the U.S. biomass index and the whole lake index based on data from the October survey (Figure 11). Estimating round goby abundance using bottom trawls can be complicated by this fish's preference for rocky substrate and seasonal changes in depth distribution (Ray and Corkum, 2001; Walsh et al., 2007). Biomass indices from trawl surveys are likely lower than actual biomass because of trawls can not sample in rock substrates although rock substrates comprise a relatively small portion of the Lake Ontario bottom (Thomas et al., 1972).

Prey Fish Diversity - Lake Ontario FCOs seek to increase prey fish diversity (Stewart et al., 2017). Based on bottom trawl catches, the pelagic prey fish community diversity remains low because a single species, alewife, dominates the catch (Figure 12). Current management efforts to improve pelagic prey fish community diversity include bloater restoration and cisco rehabilitation (Connerton, 2018). Despite slimy sculpin declines, demersal prey fish community diversity has generally increased during recent decades. In the 1970s – 1990s, a single species, slimy sculpin, dominated the catch, resulting in lower diversity values. More recently, deepwater sculpin and round goby comprise similar proportions of the trawl catch, increasing diversity relative to when only slimy sculpin dominated the catches (Figure 12).

Embayment Catches – Trawl catches at embayment sites (Quinte, Chaumont, Black River, Henderson, Little Sodus, Sodus) differed markedly from trawl catches in the main lake (Table 4). As in 2018, the 2019 embayment samples suggested these habitats had a higher species diversity and a higher proportion of native species relative to main lake habitats (Table 4). These habitats, especially Black River Bay and the Bay of Quinte, are the only sites where trawls routinely capture trout-perch and spottail shiner, native species that were ubiquitous in the main lake in the 1970s – 1990s. Alewife density in the embayments was either zero or low relative to the main lake (Table 3).

The lake-wide trawling program is also valuable for detection of new invasive species. For example, in 2019, a western tubenose goby (*Proterorhinus semilunaris*) was captured for the first time in the trawl surveys. Tubenose goby are a recent invader to Lake Ontario and have been detected previously in the eastern Lake Ontario- St. Lawrence River Basin (Goretzke, 2019). The addition of embayment trawl sites more thoroughly addresses Lake Ontario FCOs by providing consistent sampling methods across different lake habitats. Expanding the survey into these more diverse habitats serves to quantify the biomass of alewife or other prey fishes of interest and better provide a more holistic observation of the Lake Ontario prey fish community.

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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).

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Table 1. Lake Ontario area in square kilometers within different depth strata in U.S. and Canadian (CA) waters. The proportional area columns illustrate how the area-weighting of stratified abundance mean indices would vary if different depth ranges were considered in analyses.

Range	Area U.S	Area CA	Proportional Area U.S.			Proportional Area CA
(m)	(km^2)	(km^2)	0-160m	0-180m	0-244m	0-160m
0-20	1155	1749	0.19	0.15	0.12	0.18
20-40	905	1616	0.15	0.12	0.10	0.16
40-60	680	1248	0.11	0.09	0.08	0.13
60-80	514	1426	0.08	0.07	0.06	0.14
80-100	441	1198	0.07	0.06	0.05	0.12
100-120	527	1293	0.09	0.07	0.06	0.13
120-140	822	964	0.13	0.11	0.09	0.10
140-160	1112	353	0.18	0.14	0.12	0.04
160-180	1598	0		0.21	0.18	NA
180-200	737	0			0.09	NA
200-220	448	0			0.05	NA
220-240	79	0			0.01	NA
240-260	<1	0			<.01	NA

Table 2. Number of fish captured in Lake Ontario during the 2019 April and October prey fish bottom trawl surveys. The catch of dreissenid mussels is represented by weight in kilograms. The classification column denotes which species are used in pelagic and demersal prey fish community diversity calculations. Species not classified are rarely and not included in community diversity calculations.

Species	Spring	Fall	Total	Percent	Classification
Alewife	177952	11783	189735	67	pelagic
Round goby	6542	31845	38387	14	demersal
Deepwater sculpin	16074	12699	28773	10	demersal
Rainbow smelt	6376	5526	11902	4	pelagic
Yellow perch	4853	1449	6302	2	demersal
Trout-perch	1543	1654	3197	1	demersal
White perch	333	1687	2020	1	pelagic
Spottail shiner	876	156	1032	< 1	demersal
Slimy sculpin	197	421	618	< 1	demersal
Pumpkinseed	146	254	400	< 1	
Brown bullhead	8	224	232	< 1	
Lake trout	119	76	195	< 1	
Freshwater drum	98	25	123	< 1	
Walleye	108	0	108	< 1	
Threespine stickleback	82	6	88	< 1	pelagic
Gizzard shad	0	51	51	< 1	pelagic
White sucker	13	37	50	< 1	
Lake whitefish	42	4	46	< 1	
Emerald shiner	12	15	27	< 1	pelagic
Bluntnose minnow	0	26	26	< 1	
Rock bass	9	4	13	< 1	
Logperch	3	7	10	< 1	demersal
Carp	5	4	9	< 1	
White bass	9	0	9	< 1	
Johnny darter	5	0	5	< 1	demersal
Lake sturgeon	4	1	5	< 1	
Cisco	4	0	4	< 1	pelagic
Northern pike	4	0	4	< 1	
Bluegill	2	0	2	< 1	
American eel	1	0	1	< 1	
Black crappie	1	0	1	< 1	
Bloater	1	0	1	< 1	pelagic
Brown trout	1	0	1	< 1	
Chain pickerel	1	0	1	< 1	
Largemouth bass	1	0	1	< 1	
Longnose sucker	1	0	1	< 1	
Sea lamprey	1	0	1	< 1	
Smallmouth bass	1	0	1	< 1	
Tubenose goby	1	0	1	< 1	demersal
dreissenid mussels (kg)	611	4848	5459		

Table 3. Lake Ontario alewife biomass estimates in kilograms per hectare based on the April bottom trawl survey (2016-2019). Lake-wide estimates assumed 52% of the lake area was represented by the estimate from Canadian waters and 48% was represented by the estimate from U.S. waters.

Year	Adult (Age-2+)			Age-1		
	Lake-wide	U.S.	Canada	Lake-wide	U.S.	Canada
2016	44.8	26.2	61.9	5.9	2.5	9.0
2017	28.6	47.5	11.1	11.9	20.3	4.2
2018	39.1	23.3	53.7	2.6	0.5	4.6
2019	27.7	26.3	29.0	2.2	1.1	3.2

Table 4. Mean fish density (number per hectare) based on bottom trawls from Lake Ontario embayment and main lake trawls during the 2019 April survey.

Species (# trawls)	Quinte (16)	Chaumont (5)	Black River (7)	Henderson (1)	Little Sodus (3)	Sodus (4)	Main Lake (204)
Yellow perch	386.5	414.4	225.9	98.7	10.00.00.0.8	10.097.2	0.0.7
Trout-perch	38.9	0.0	778.9	0.0	0.0	0.0	0.0.9
Spottail shiner	6.3	11	472.7	0.0	0.0	9	0.0
Rainbow smelt	3.1	17.5	121.1	9.2	10.0.4	2.2	61.8
White perch	55.1	0.0	1.7	0.0	0.0	9.1	3.7
Pumpkinseed	4.7	56.5	0.0	0.0	0.0	0.0	0.0
Round goby	25.3	1.7	2.9	0.0	0.0	0.0	61.3
Walleye	15.9	0.0.9	0.0.6	0.0	0.0	9	0.0.7
Freshwater drum	13.2	0.0.4	0.0	0.0	0.0	0.0	0.0.9
Alewife	0.0.3	0.0	8.2	0.0	0.0	0.0	1716.4
White sucker	1.1	0.0.5	1.4	0.0	2.9	2.3	0.0
Emerald shiner	0.0.2	0.0	6.6	0.0	0.0	0.0	0.0
Lake whitefish	5.8	0.0	0.0	0.0	0.0	0.0	0.0.5
Northern pike	0.0	0.0	0.0	0.0	4.5	1.1	0.0
Carp	0.0	0.0	0.0	0.0	0.0	4.5	0.0
Slimy sculpin	3.3	0.0	0.0	0.0	0.0	0.0	2
Johnny darter	0.0	0.0	2.9	0.0	0.0	0.0	0.0
Rock bass	1.3	0.0	1.1	0.0	0.0	0.0	0.0
White bass	1.5	0.0	0.0	0.0	0.0	0.0	0.0
Brown bullhead	1.3	0.0	0.0	0.0	0.0	0.0	0.0
Largemouth bass	0.0	0.0	0.0	0.0	0.0	1.2	0.0
Cisco	0.0.6	0.0.5	0.0	0.0	0.0	0.0	0.0
Unidentified coregonine	0.0	0.0	0.0	0.0	0.0	1.1	0.0
Logperch	0.0.7	0.0	0.0	0.0	0.0	0.0	0.0
Chain pickerel	0.0	0.0.5	0.0	0.0	0.0	0.0	0.0
Smallmouth bass	0.0	0.0	0.0.5	0.0	0.0	0.0	0.0
Lake trout	0.0.5	0.0	0.0	0.0	0.0	0.0	1.2
Bluegill	0.0.4	0.0	0.0	0.0	0.0	0.0	0.0
Black crappie	0.0.2	0.0	0.0	0.0	0.0	0.0	0.0
American eel	0.0.2	0.0	0.0	0.0	0.0	0.0	0.0
Common mudpuppy	0.0.2	0.0	0.0	0.0	0.0	0.0	0.0
Tubenose goby	0.0.2	0.0	0.0	0.0	0.0	0.0	0.0
Deepwater sculpin	0.0.1	0.0	0.0	0.0	0.0	0.0	148.4
Longnose sucker	0.0.1	0.0	0.0	0.0	0.0	0.0	0.0

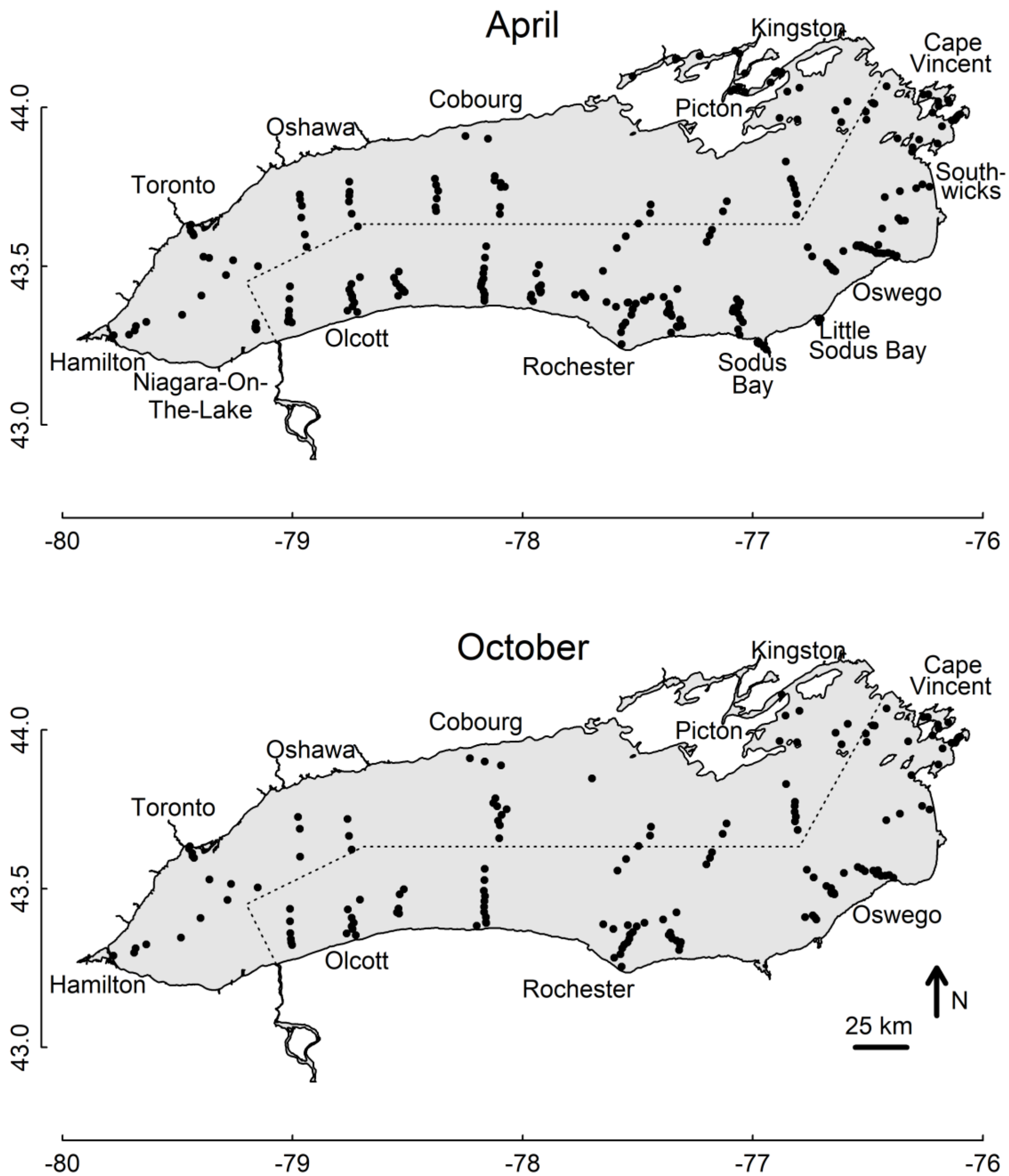

Figure 1. Lake Ontario bottom trawl sites from the 2019 collaborative (USGS, NYSDEC, OMNRF, USFWS) April and October surveys. The April survey targets alewife and other pelagic prey fishes that are found near bottom at this time of year and the October survey targets demersal or benthic prey fishes. A total of 252 tows were conducted in April and 160 tows were conducted in the October survey. Dashed line represents U.S. Canada border.

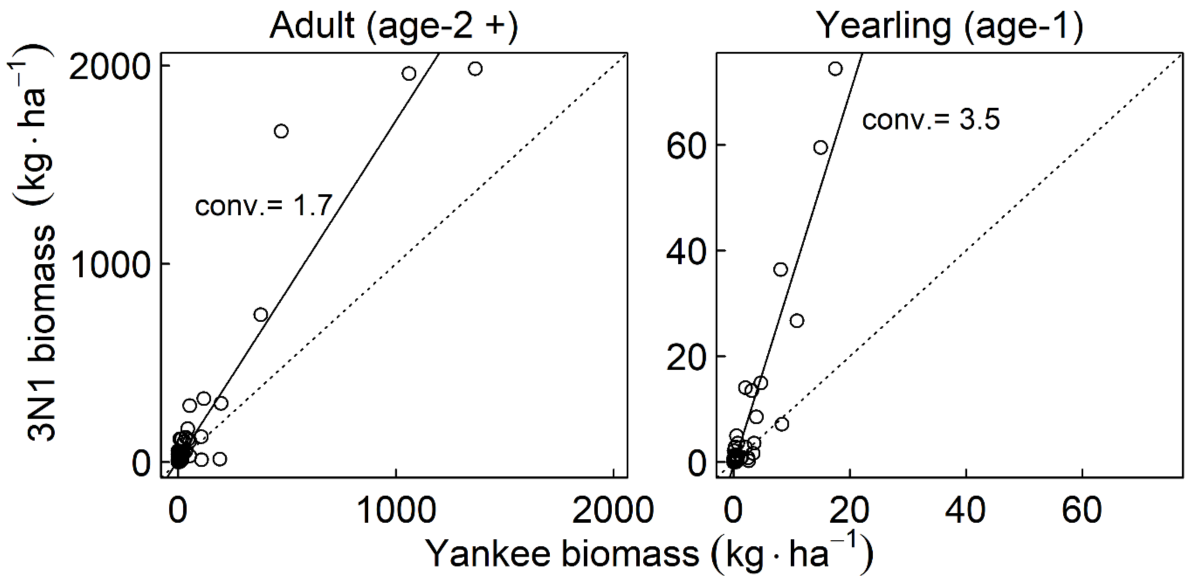

Figure 2. Paired trawl comparison results for the 11.8m headrope Yankee trawl (horizontal axis) and the 18m headrope 3n1 trawl used in Lake Ontario bottom trawl surveys. The open circles represent the alewife biomass estimates from the 104 paired trawls collected from 1995-1998 at the same depths. Trawl depths ranged from 8 to 157 m. The solid black line is a linear regression model and the slope of that model represents a conversion factor to be multiplied by Yankee trawl biomass values to convert them to 3n1 values. The dashed line represents unity, or the 1:1 line, if both trawls caught similar alewife biomasses.

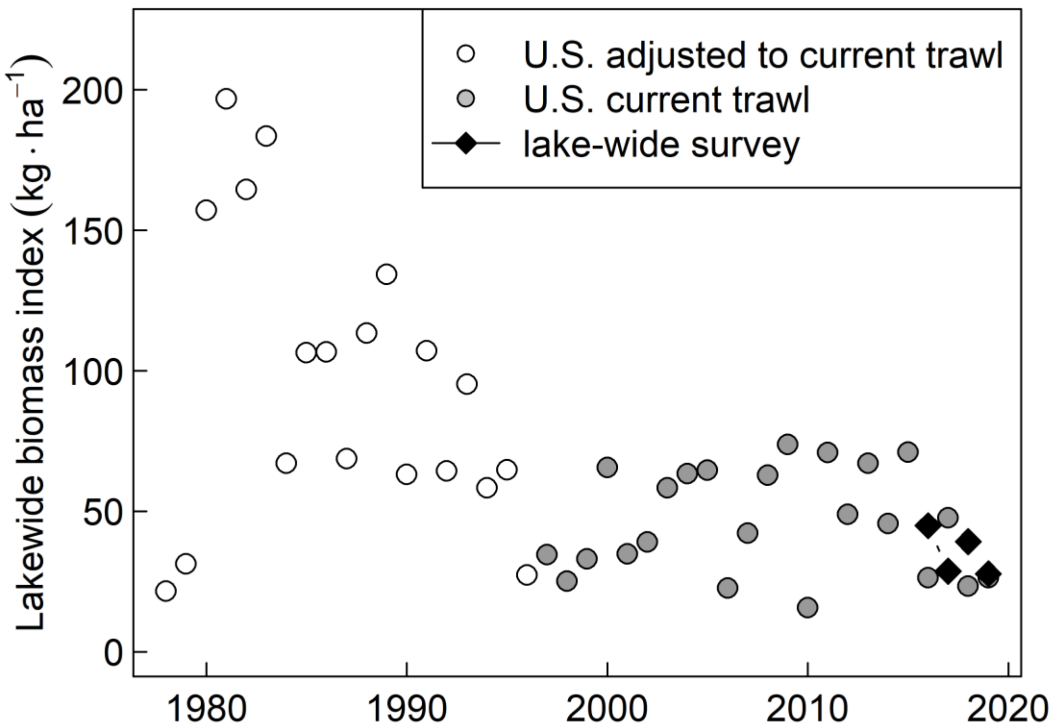

Figure 3. Lake Ontario April bottom trawl-based biomass index for adult alewife (age-2 and older) for trawl surveys in U.S. waters (circles, 1978-2019) and lake-wide (diamonds,2016-2019). Values represent a depth-stratified (20m strata), area-weighted mean biomass expressed as kilograms per hectare. Bottom trawl area swept is based on wing widths, biomass indices are not corrected for trawl catchability. Surveys from 1978-1996 were conducted with a smaller Yankee trawl. Open circles represent biomass values that were adjusted to be equivalent to the current trawl (gray circles) by multiplying them by 1.7.

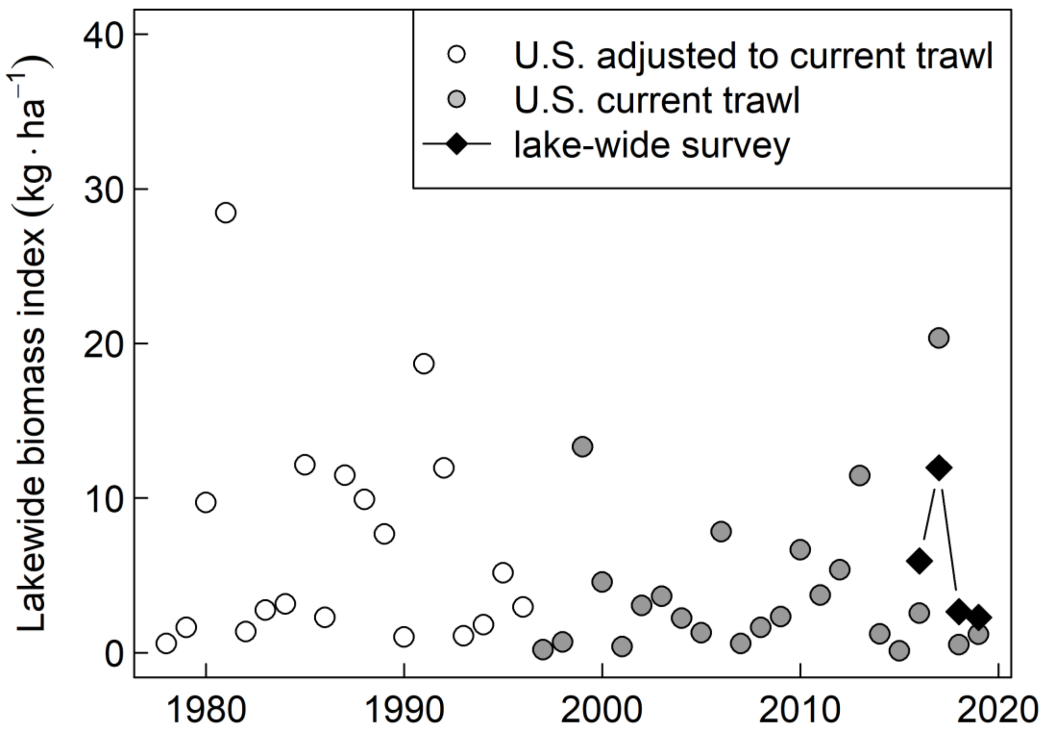

Figure 4. Lake Ontario April bottom trawl-based biomass index for age-1 alewife for trawl surveys in U.S. waters (circles, 1978-2019) and lake-wide (diamonds,2016-2019). Values represent a depth-stratified (20m strata), area-weighted mean biomass expressed as kilograms per hectare. Bottom trawl area swept is based on wing widths, biomass indices are not corrected for trawl catchability. Surveys from 1978-1996 were conducted with a smaller Yankee trawl. Open circles represent biomass values that were adjusted to be equivalent to the current trawl (gray circles) by multiplying them by 3.52.

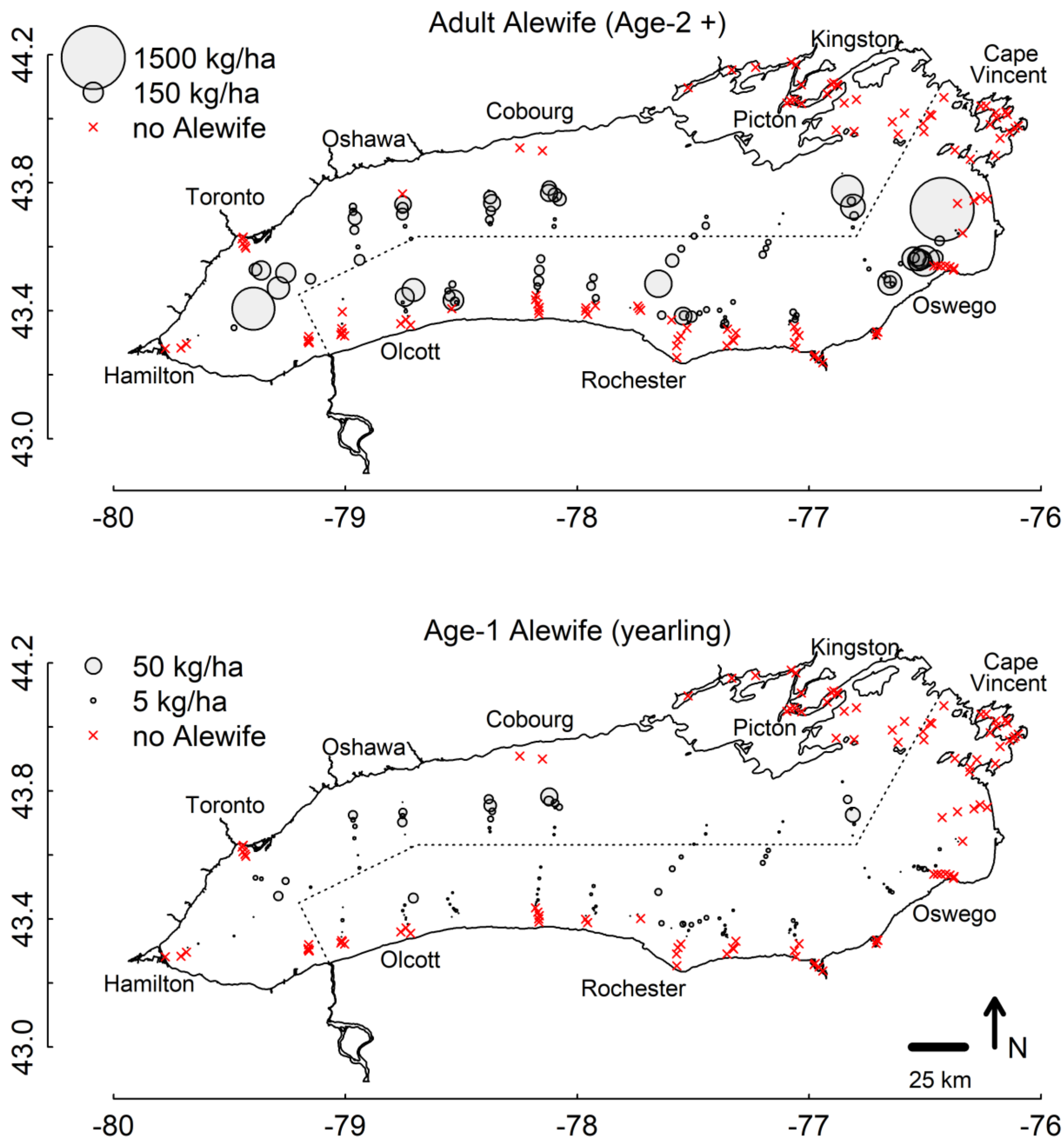

Figure 5. Spatial distribution of alewife biomass index values from the 2019 collaborative Lake Ontario April bottom trawl survey. The size of the gray circles represents the biomass in kilograms per hectare of alewife captured, while a red "x" signifies a location where no alewife were captured. Note the difference in age-1 alewife abundance between the Canadian and U.S. portions of the lake.

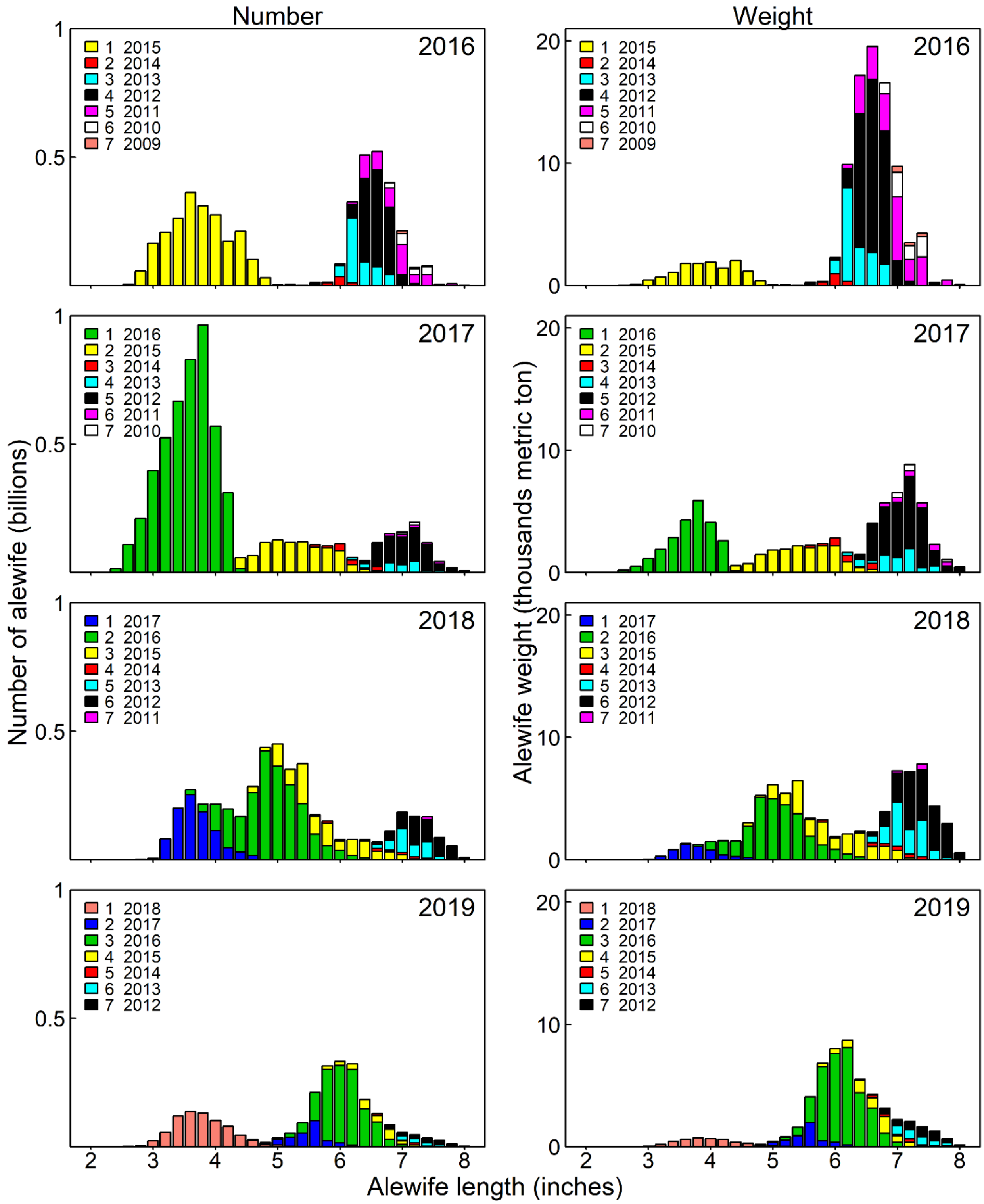

Figure 6. Lake Ontario alewife size and age distribution from April bottom trawl surveys, 2016-2019. Height of the bars represent number of alewife (in billions) or weight of alewife (thousands of metric tons) for each size bin (1/5th inch or 5mm). Colors represent a year-class and are consistent across the different years.

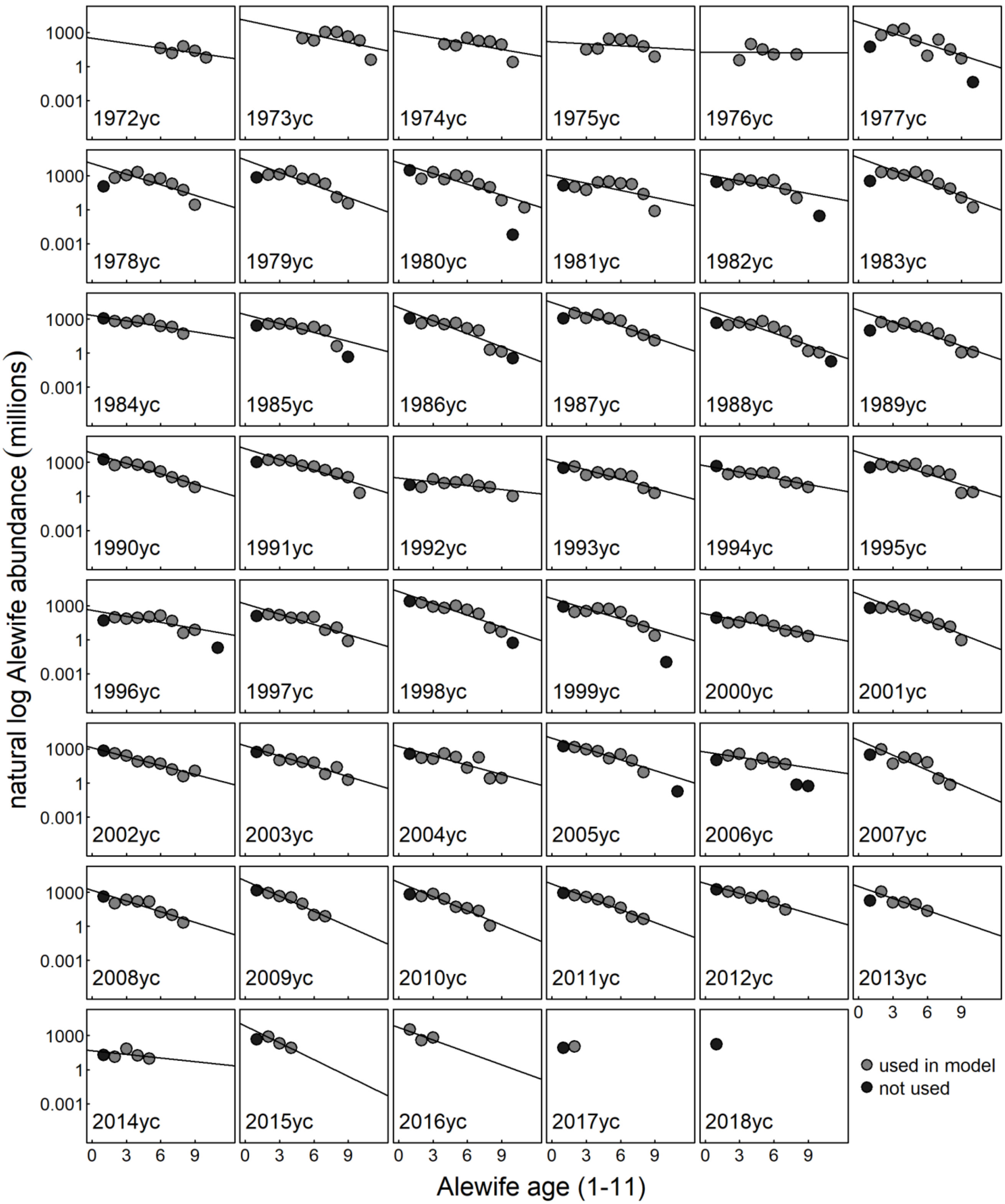

Figure 7. Alewife year-class catch curve observations (points) and models (lines) for Lake Ontario alewife year-classes (1972-2018). Values on the y-axis are natural log transformed. Black filled circles are points not used in the model because either the mean length of the cohort was below 120mm or the total number estimated was below 700,000 fish (horizontal dotted line).

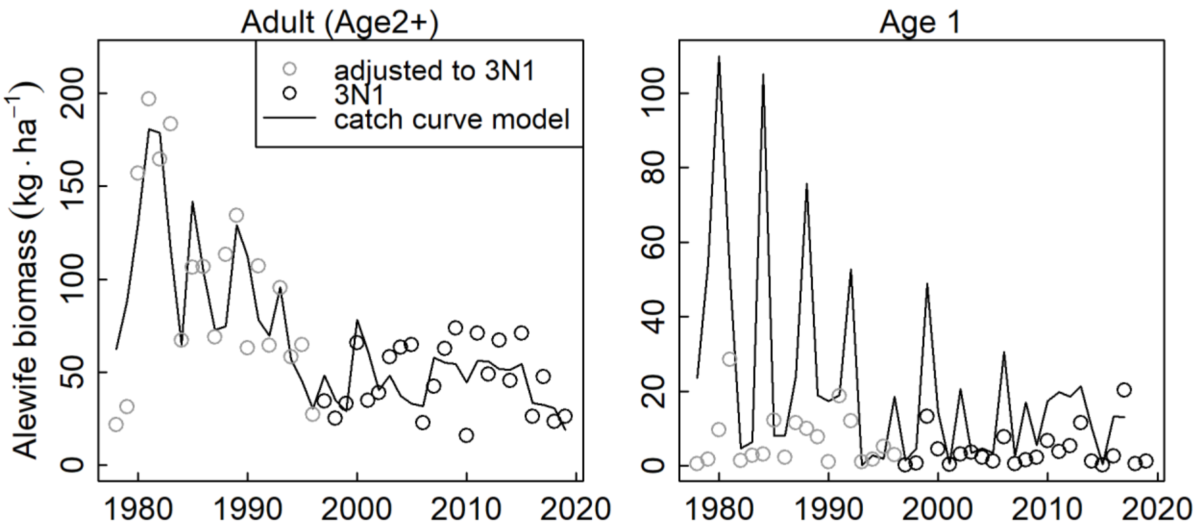

Figure 8. Alewife biomass estimates based on catch curve models (black line) and bottom trawl survey mean values in U.S. waters (circles) for adult (left panel) and age-1 (right panel) alewife in Lake Ontario, 1978-2019. Gray circles represent estimates collected with the smaller Yankee trawl (1978-1996) that have been converted to correspond with survey results from 1997-2019 collected with a larger 3n1 bottom trawl. Example years where there was evidence that survey results were biased low include 1978, 1979, 1990, and 2010. Example years where adult biomass values may have been biased high include 1983, 1995, 2004, and 2011. In contrast to the adults, model estimates for age-1 alewife are more frequently much larger than observed values. These differences are most evident from the observations collected with the smaller Yankee trawl (1978-1997) and less evident since the 3n1 trawl was adopted.

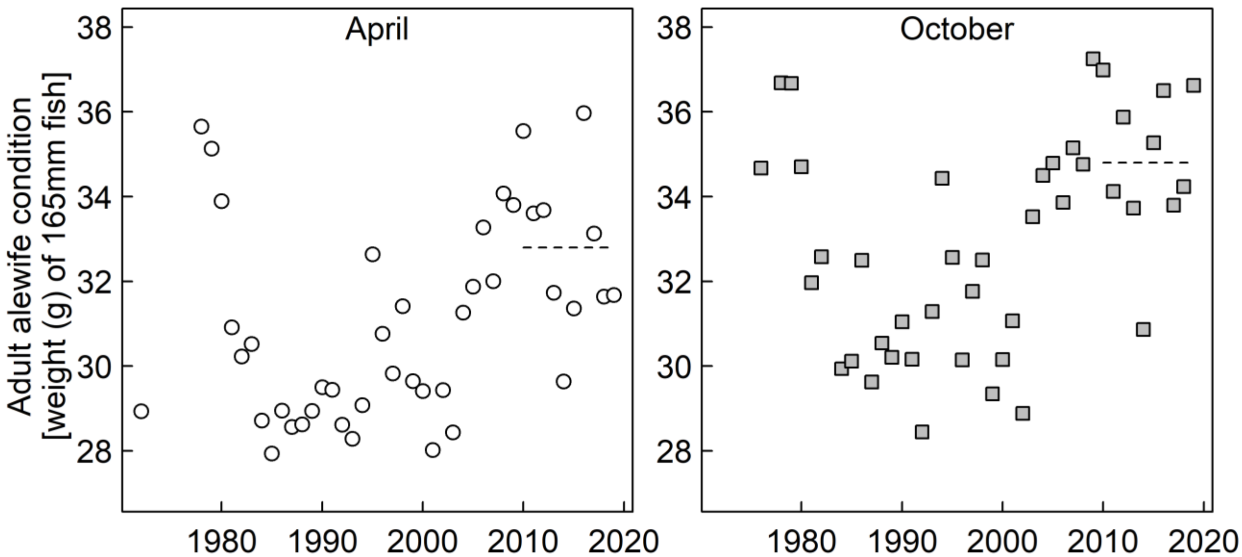

Figure 9. Lake Ontario alewife condition represented as the predicted weight of a 165mm (6.5 inch) fish from the April (left panel) and October (right panel) bottom trawl surveys. Linear models are based on observations from 150-180mm total length (5.9 to 7 inches). Dashed horizontal lines represent mean values from the past 10 years. Data from 1978-2015 represent trawls in U.S. waters while data from 2016-2019 also include observations from Canadian waters.

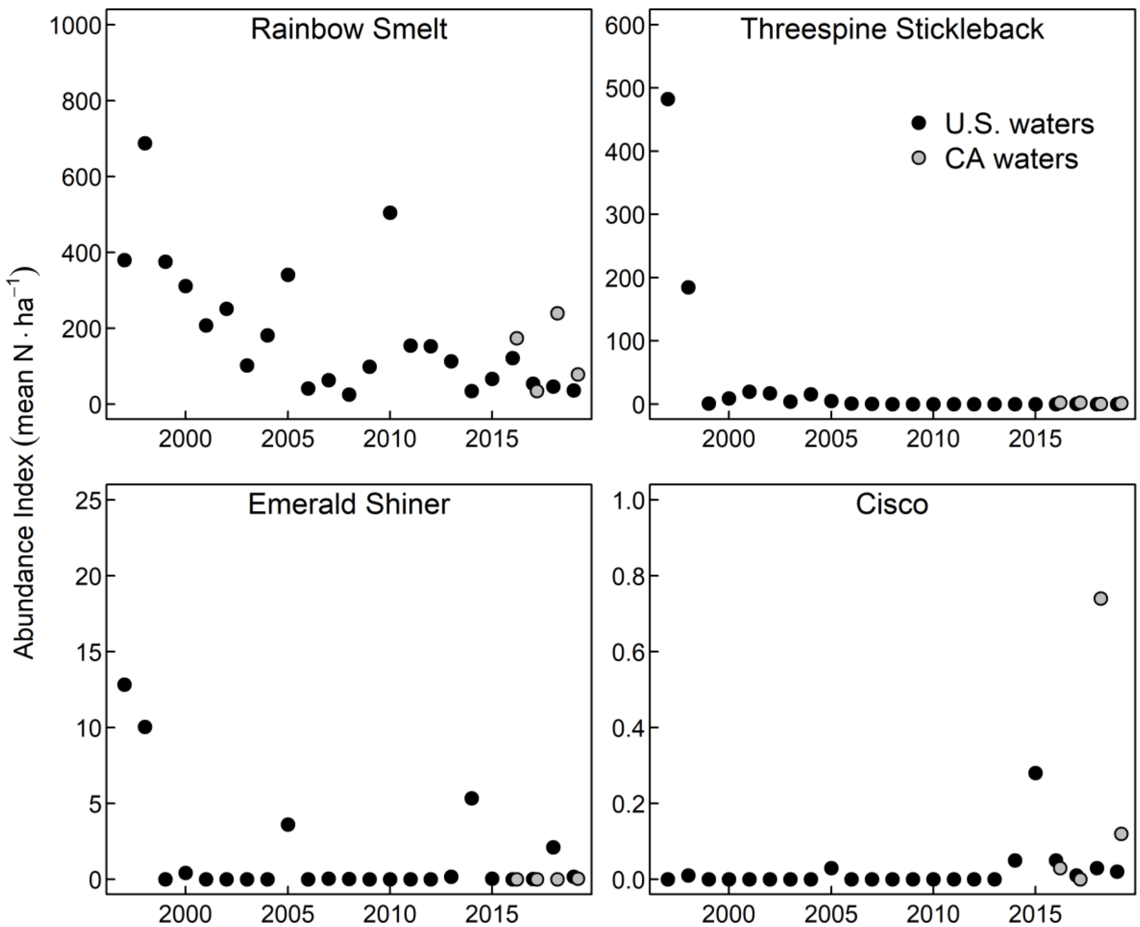

Figure 10. Abundance indices for Lake Ontario pelagic prey fishes based on bottom trawls in U.S. and Canadian waters, 1997-2019. These species are specifically mentioned in Fish Community Objectives related to diverse prey fish communities (Stewart et al., 2017).

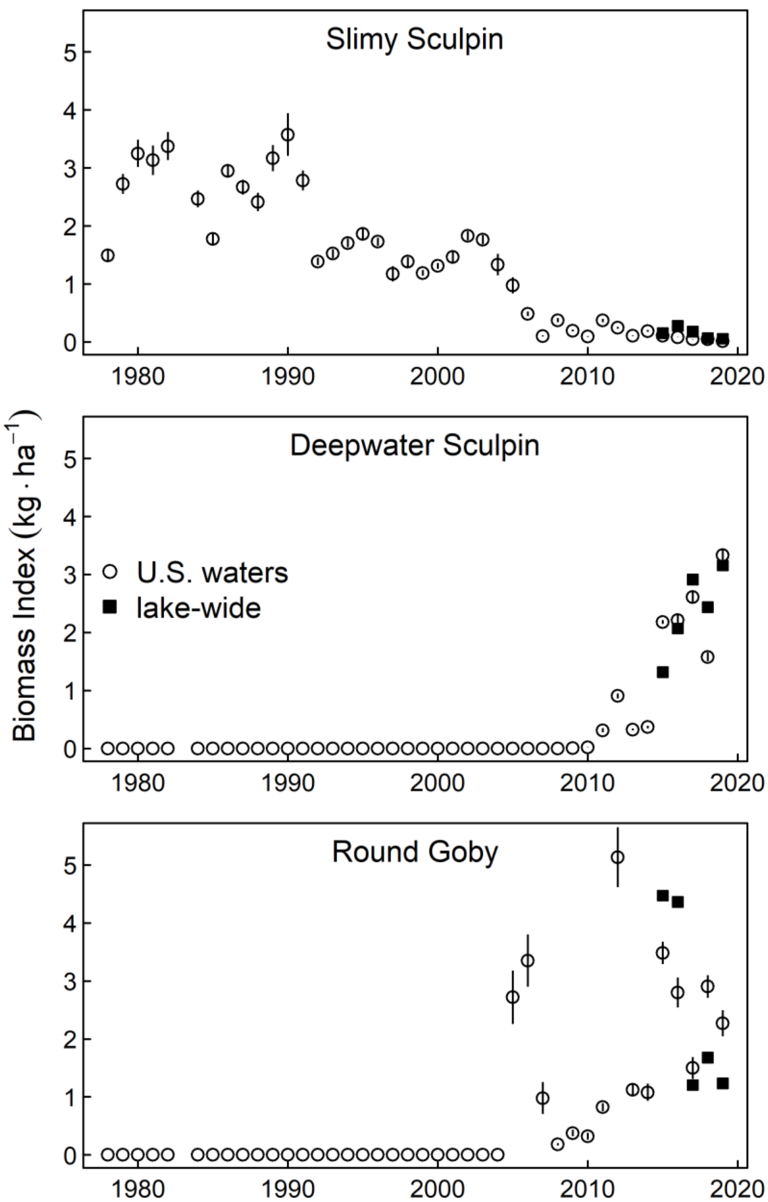

Figure 11. Lake Ontario biomass indices for demersal (bottom-oriented) prey fishes from the October bottom trawl survey, 1978-2019. Values represent a depth-stratified (20m strata), area-weighted mean biomass expressed as kilograms per hectare in either U.S. waters, open circles, or lake-wide surveys, filled squares. Bottom trawl area swept is based on wing widths, biomass indices are not corrected for trawl catchability.

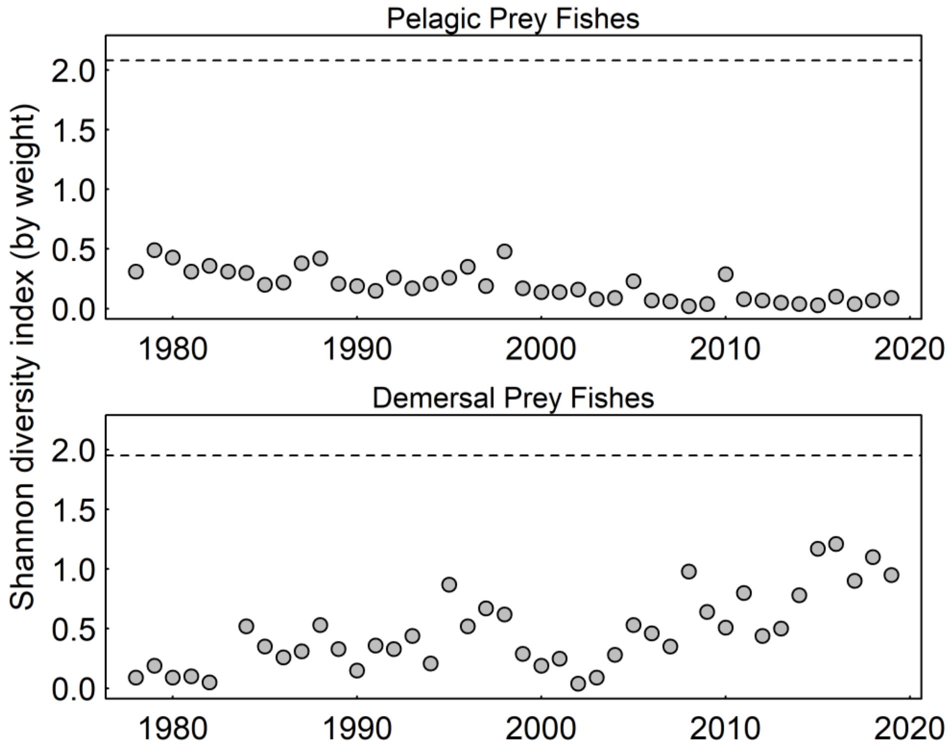

Figure 12. Lake Ontario prey fish diversity indices for pelagic and demersal prey fish communities, based on bottom trawl catch weights 1978-2019. Species used for calculations are identified in Table 2. Diversity is represented with the Shannon index (Shannon and Weaver, 1949), using commonly encountered species in the April (targets pelagic prey fishes) and October (targets demersal prey fish) surveys. The dashed lines represent the maximum diversity index value if all species made up equal proportions of the catch by weight. Lake Ontario Fish Community Objectives seek to improve pelagic and demersal prey fish diversity (Stewart et al., 2017).