Lake Ontario April prey fish survey results and Alewife assessment, 2022

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A report from the Lake Ontario Prey Fish Working Group to the Great Lakes Fishery Commission's Lake Ontario Committee

Abstract
The annual Lake Ontario April bottom trawl survey and Alewife, *Alosa pseudoharengus*, population assessment provide science to inform management decisions related to predator-prey balance and fish community dynamics. The 2022 survey was conducted from March 31 to April 26, included 235 trawls in the main lake and embayments, and sampled depths from 5 to 219 m (16 – 723 ft). The survey captured 311,770 fish from 30 species with a total weight of 7,740 kg (17,028 lbs.). Alewife were 85% of the catch by number while Rainbow Smelt, *Osmerus mordax*, Round Goby, *Neogobius melanostomus*, and Deepwater Sculpin, *Myoxocephalus thompsonii,* comprised 6%, 4%, and 4% of the catch, respectively. The 2022 biomass index for Rainbow Smelt decreased 80% relative to the high values observed in 2021 as did the value for Cisco, *Coregonus artedi,* (46% decline). Emerald Shiner, *Notropis atherinoides*, biomass index increased in 2021 and Threespine Stickleback, *Gasterosteus aculeatus*, biomass remained low. No Bloater, *Coregonus hoyi*, were captured during the 2022 survey.

In 2022, Alewife biomass in U.S. waters (58.1 kilograms per hectare, kg·ha^{-1}) was substantially higher than Canadian waters (26.3 kg·ha^{-1}). The 2022 Alewife biomass index (41.6 kg·ha^{-1}) decreased 10% from 2021 while the 2022 density index decreased 62% from 2021. Prediction modeling indicated the growth of the abundant 2020 Alewife year class, sampled as age-1 fish in 2021, would cause the adult Alewife biomass to increase in 2022. Although the adult Alewife biomass did increase relative to 2021 (61%), the increase was lower than predicted. The difference between the predictions and observations was because survival of age-1 fish from 2021 to 2022 was lower than had previously been observed. In the three previous years of observations the proportion of age-1 Alewife surviving to age 2 ranged from 0.33 to 0.53; however, that proportion was only 0.21 from 2021 to 2022. Survival estimates of Alewife age-5 through age-8 were higher than previously observed, possibly because salmonid predation focused on the abundant younger Alewife. The catch of age-1 Alewife in 2022, which is a measure of reproductive success in 2021, was below average and similar to the abundances of the 2018 and 2019 year classes. Simulation modeling results indicated the adult Alewife biomass is likely to increase slightly in 2023, whereas predictions for 2024 are less certain.

Hydroacoustic sampling was used to estimate prey fish densities in open-water, pelagic habitats not sampled by the bottom trawl. Bottom trawl-based densities from the lake bottom were at least 25 times greater than densities of prey fish in the water column above the trawl. These results support the idea that, in April, when the warmest, most dense water is on the lake bottom, Alewife and most other pelagic prey fish primarily inhabit deep, near bottom habitats and can be effectively sampled with bottom trawling.

Introduction

Why study Lake Ontario prey fish?

Lake Ontario fisheries are critical to the Canadian and U.S. economies, with a 2017 annual economic value estimate of $440 million in New York[1]. Managing these fisheries by altering salmonid stocking levels to stay in balance with lake productivity and available prey fish requires reliable status and trend information on prey fish populations[2]. Alewife, *Alosa pseudoharengus*, were first found in Lake Ontario in the 1860s, and within a few years were considered the most abundant prey species in the lake[3]. Since contemporary annual surveys began in 1978, nonnative Alewife have been the most abundant Lake Ontario prey fish and have supported most of the lake's predators[4–6]. Over time, food web productivity and prey fish abundance have declined in concert with mineral nutrient declines[7–9]. Concerns related to having sufficient prey fishes to support the lake's salmonids have resulted in stocking reductions, first in the mid-1990s [10] and again in 2016 – 2021[11,12]. As such, the status and trajectory of prey fish populations are critical to fisheries management. Prey fish surveys also track the introduction and status of nonnative species and the status of native species and restoration projects[13,14].

Why are bottom trawl surveys used to study Alewife and other prey fish?

Bottom trawling in April has been the most consistent method for quantifying the relative abundance of Lake Ontario Alewife and other pelagic prey fishes. For most of the year, Alewife inhabit pelagic or open-water lake habitat[15], but in winter and early spring they are near the lake bottom in deep, dark water (100-180 m, 330-594 ft). This is because winter surface water temperatures are well below Alewife's preferred temperature range (11 - 25°C, 52 - 77°F) and the warmest, most dense water (~ 4°C, 39°F) is on the lake bottom [16–19]. Alewife are near the lake bottom in April and are thus susceptible to being caught in bottom trawls[19]. Bottom trawl surveys in summer and fall only capture a small proportion of the Alewife captured in April because most of the Alewife are off the lake bottom at those times of year[15]. Summer hydroacoustic surveys have also indexed Alewife abundance[2], but abundance estimates are generally much lower than April trawl estimates. Studies have shown Alewife inhabiting surface waters[15] or those that swim away from the survey vessel[20] are not accurately counted by hydroacoustic techniques.

How is the bottom trawl survey improving?

The Lake Ontario Prey Fish Working Group continually evaluates assumptions about prey fish behavior and survey designs to improve the information provided. New embayment trawl sites added in 2016 have illustrated that prey fishes in these regions are different than those in the main lake. Alewife can be present in embayments, but their abundance is low, and these habitats are a small fraction of the lake area relative to the main lake where most Alewife are caught. The most important change in our understanding of Lake Ontario Alewife occurred when the survey expanded the spatial extent to include trawling in Canadian waters in 2016. Sampling the whole lake demonstrated Alewife abundance can be dramatically different in U.S. and Canadian waters in the same year[21]. The historical abundances, estimated by sampling only the U.S. waters, can be strongly biased if Alewife were not evenly distributed between U.S. and Canadian waters at the time of sampling. Starting in 2021, we have used hydroacoustics (acoustics), in conjunction with bottom trawling, to evaluate how many pelagic prey fishes may be suspended in the water column during the day and not susceptible to be caught in the bottom trawl.

Here we report results from the multi-agency, 2022 Lake Ontario spring prey fish survey and Alewife assessment. Results address the Lake Ontario Fish Community Objectives: "# 2.3 Increase prey fish diversity—maintain and restore a diverse prey-fish community including Alewife, Cisco, Rainbow Smelt, Emerald Shiner, and Threespine Stickleback" and "# 2.4 Maintain predator/prey balance—maintain abundance of top predators (stocked and wild) in balance with available prey fish" [2]. This research is also guided by the U.S. Geological Survey Ecosystems Mission Area science strategy that directs federal science to inform decision making related to ecosystem management, conservation, and restoration[22].

Methods

How is the bottom trawl survey conducted?

The Lake Ontario April bottom trawl survey has been collaboratively conducted by the USGS and NYSDEC since 1978. Daytime bottom trawling is conducted at fixed sites because substrate variability at random sites prohibitively damages trawls[23]. The initial survey design annually collected approximately 100 trawls in U.S. waters from 8 – 150 m (26 – 495 ft). Since 2016, sampling has included both U.S. and Canadian waters, a wider depth range of (5 – 225 m; 20 – 743 ft), embayment sites, and the OMNDMNRF research vessel (Fig. 1)[24]. From 1978 to 1996, the survey used a nylon Yankee trawl, but excessive dreissenid mussel catches forced the survey to use a trawl with lighter bottom contact in 1997. The current polypropylene trawl has an 18-m (59 ft) headrope and a head rope height of 3 – 4 m (10 – 13 ft). Trawl times vary from 4 – 10 minutes, and trawl speed is 2.8 – 3.4 mph. The area swept by the trawl is calculated based on trawl mensuration sensors attached to the foot rope and wings. This report includes data from 1997 to present, thus all data have been collected with a single trawl type. An external review of the trawl survey found the design generated suitable relative abundance estimates[23,25].

How are annual estimates calculated?

Bottom trawl catches are expressed as either the mean biomass (kilograms per hectare, $kg \cdot ha^{-1}$) or density (numbers per hectare, $N \cdot ha^{-1}$) and are reported as annual, lake area-weighted, depth stratified means. The lake area swept by each trawl is estimated based on tow time, vessel speed, and models for how trawl wing width and bottom contact time vary with depth[26]. Stratification is based on depth, where each strata is a 20-m (66-ft) depth interval (i.e., 0 – 20 m, 21 – 40 m). Strata weighting is based on the proportional area of those depth intervals within U.S. and Canadian portions of the lake. Annual indices are calculated for U.S. and Canadian waters, and whole-lake indices are the weighted sum of these indices (52% lake area in Canada, 48% in United States). Biomass and density values are considered indices because we lack estimates of trawl catchability (proportion of the true biomass or density captured by the trawl)[27].

How are Alewife population age structure and year class abundance determined?

Each year we interpret Alewife ages from otoliths to estimate the abundance of each Alewife year class (all the fish born in a year then tracked through time). Ages are interpreted by counting annuli from 500 to 1000 whole sagittae[28]. Year class abundances were estimated using an age-length key developed from annual age interpretations and length frequency distributions[29]. Estimating year class abundance through time allows us to quantify how survival and growth vary across time and fish ages, which in turn helps us estimate how the population may change in the future.

How are future Alewife biomass values predicted?

Simulations estimate how Alewife biomass is likely to change two years into the future. Simulations begin with the most recent year's biomass estimates for each age. For a given age, survival and growth into the next year were randomly selected from previously observed distributions for those parameters, and the next year's biomass was summed. The number and size of age-1 Alewife was randomly sampled from the previous years of age-1 observations. We conducted 1,000 simulations as described above to predict a range of possible biomass levels in 2023 and 2024, starting with the 2022 observations.

How were hydroacoustic data collected and analyzed?

Hydroacoustic data were collected using BioSonics 120 kHz-split beam echosounders following established standardized sampling procedures[20,30]. Acoustic data were collected during the day immediately preceding or following a bottom trawl sample, at depths from 5 to 210 m. Pelagic fish density was estimated for depths from 3 m from the surface to 3 m from the lake bottom. This depth range is not sampled by bottom trawls and hydroacoustic sampling can be effective in this range. Fish density estimates were computed in Echoview (V.11.1), assuming a mean target strength of -43 decibels (dB).

Results and Discussion

Survey timing, extent, and catch

The 2022 April bottom trawl survey conducted 235 trawls in main lake and embayments, at depths from 5 to 219 m (16 – 723 ft, Fig. 1). The survey collected 311,770 fish, totaling 7,745 kg (17,040 lbs.), from 30 different fish species, and 167 kg (367 lbs.) of dreissenid mussels (Table 1). Alewife were 84% of the fish catch while Rainbow Smelt, *Osmerus mordax*, Round Goby, *Neogobius melanostomus*, and Deepwater Sculpin, *Myoxocephalus thompsonii,* comprised 6%, 4%, and 4% of the catch, respectively (Table 1).

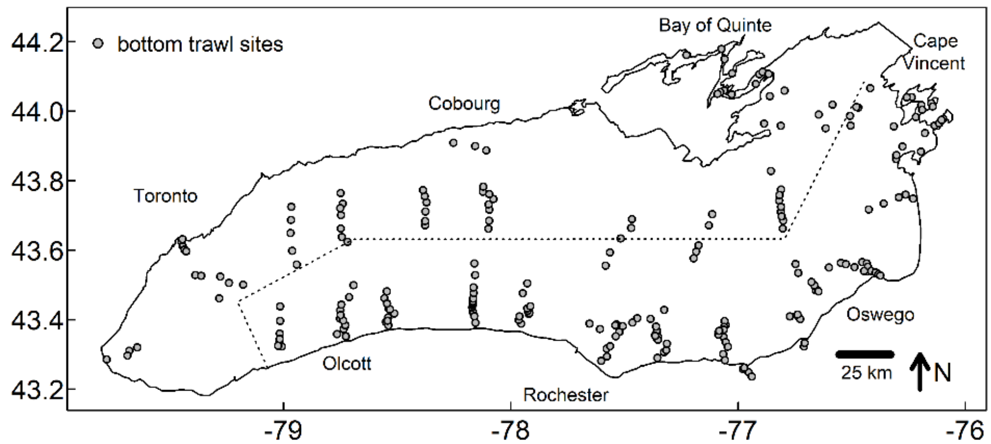


Figure 1. Lake Ontario bottom trawl sites from the 2022 multi-agency April prey fish survey. The dotted line represents the United States – Canada border.

Pelagic fish biomass indices (non-Alewife)

Rainbow Smelt biomass in 2022 (0.62 $kg \cdot ha^{-1}$) declined by 80% from the high value observed in 2021(3.06 $kg \cdot ha^{-1}$) and was similar to the previous five years of observation (Fig. 2). Cisco biomass also declined 46% in 2022 (0.03 $kg \cdot ha^{-1}$) relative to 2021 (0.05 $kg \cdot ha^{-1}$). The abundance of this native species remains low relative to historical estimates, and much of the remnant population is in northeastern Lake Ontario and the Bay of Quinte[31,32]. Emerald Shiner, *Notropis atherinoides*, biomass increased in 2022 while Threespine Stickleback, *Gasterosteus aculeatus*, abundance continues to be low when compared to that observed prior to 2005. No Bloater were captured during the 2022 survey. Bloater are a native pelagic prey fish that was extirpated from Lake Ontario and is currently being reintroduced[14].

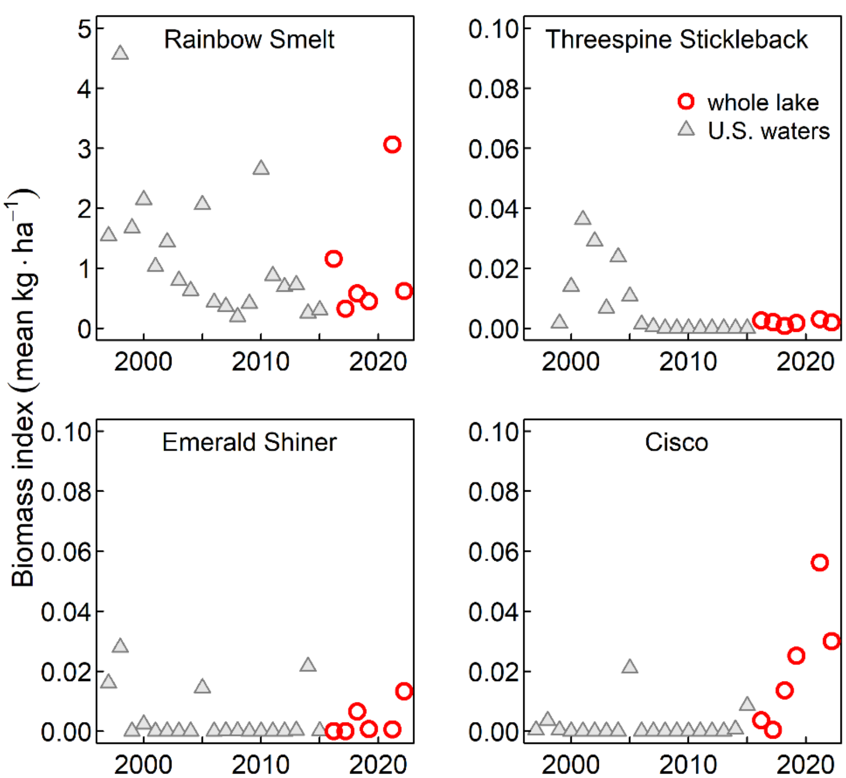


Figure 2. Biomass indices for Lake Ontario pelagic prey fishes from the April bottom trawl survey, 1997-2022. The species illustrated by these figures, along with Alewife, are specifically mentioned in the Lake Ontario Fish Community Objectives. For reference, a biomass value of 1 kilogram per hectare ($kg \cdot ha^{-1}$) is similar to 1 pound per acre. Note the ranges on the vertical axes vary between the plots.

Alewife Biomass and Density Indices

The 2022 total Alewife biomass index (41.6 kg·ha^{-1}) decreased 10% from 2021(45.4 kg·ha^{-1}) while the 2022 density index decreased 62% from 2021 (Fig. 3). Adult Alewife biomass was predicted to increase in 2022[33] and the 2022 value was 61% greater than the 2021 value. This increase was due to the abundant 2020 year class which contribute to the adult stock as age-2 fish in 2022. Alewife reproduction in 2021, as indexed by the catch of yearling or age-1 Alewife in 2022, was relatively low (Fig. 4, right panel).

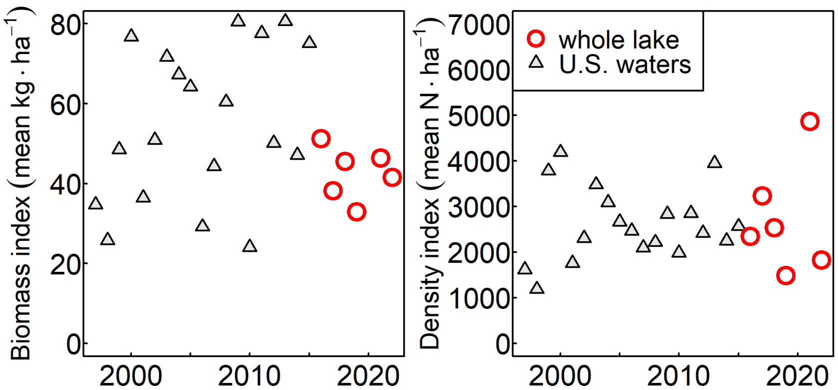


Figure 3. Biomass (left panel) and density (right panel) indices for Lake Ontario Alewife, from the April bottom trawl survey, 1997-2022. These values represent all ages of Alewife.

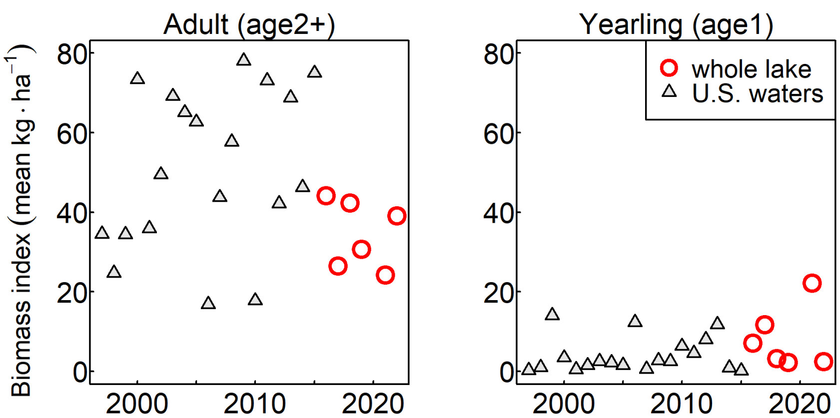


Figure 4. Biomass density indices for Lake Ontario adult (left) and yearling (right) Alewife from the April bottom trawl survey 1997-2022. Adult Alewife are considered as age-2 and greater.

The 2022 Alewife biomass in Canadian waters was lower than the U.S. value with an average of 26.3 kg·ha^{-1} as compared to 58.1 kg·ha^{-1} in U.S. waters (Fig. 5). Since 2016, when the survey began sampling the entire lake, we have observed U.S. biomass estimates can range from four times higher or three times lower than Canadian biomass values. The reason that Alewife density varies between U.S. and Canadian waters is unknown but may result from variable lake thermal conditions in late fall and winter. The distributional variability we have observed indicates that historical estimates based on U.S. only sampling can be biased. For instance, Figure 4 adult biomass levels in 2006 and 2010 are examples where we suspect most of the Alewife were in Canadian waters when trawls were collected in U.S. waters.

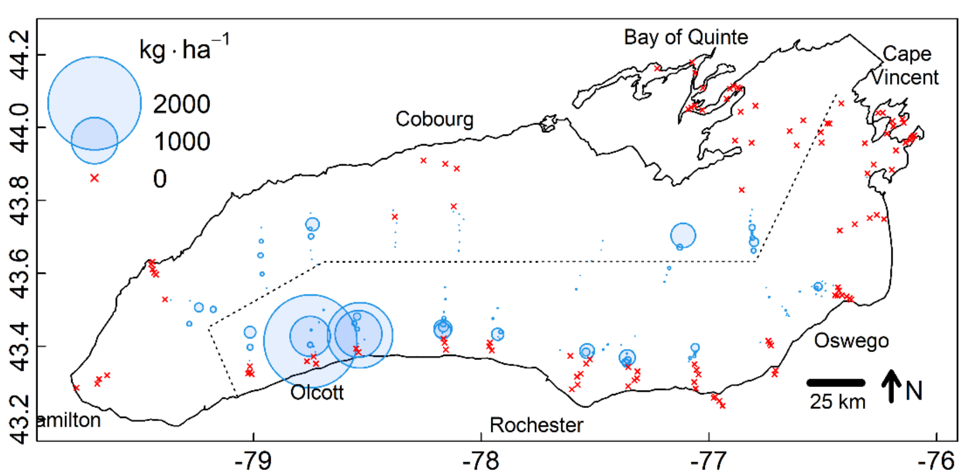
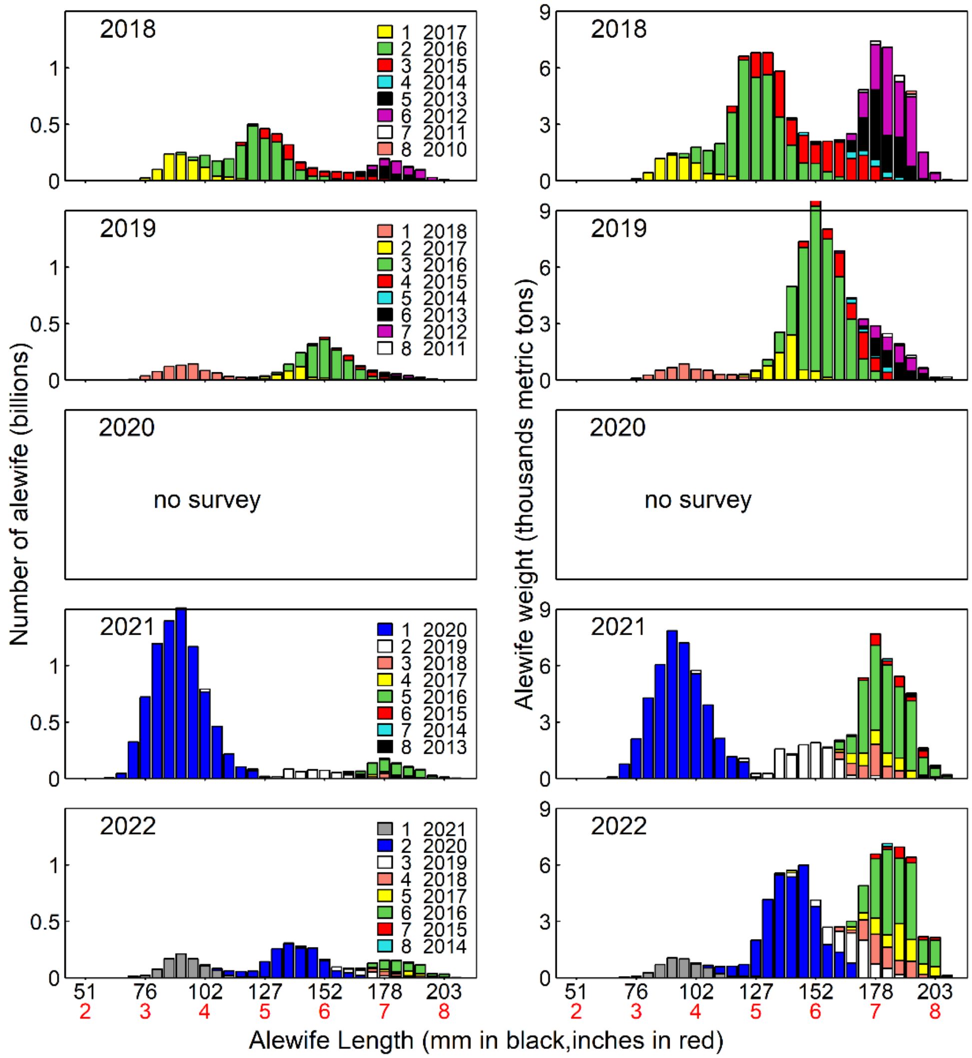


Figure 5. Distribution of Alewife biomass (all ages) in Lake Ontario from the April bottom trawl survey, 2022. The thin dashed line represents the border between U.S. and Canadian waters.

Alewife Age Structure

In 2022, a total of 980 Alewife ages were interpreted from otoliths 68 to 228 mm (2.6 – 8.9 inches). The oldest interpretation was age-8 and would have been from the 2014 year class. The 2016 and 2020 year classes comprised most of the Alewife biomass observed in 2022. However, other year classes also contributed to the spawning population in 2022 (Fig. 6, lower right panel)[34].



gure 6. Lake Ontario lewife size and age stribution from April ottom trawl surveys, 2018 – 022. Bar height represents e number of Alewife (left inels) or weight (right inels) for each size bin 1/5th inch or 5 mm). Bar olors represent a year-class id are consistent across the inels.

The survival of 2020 Alewife year class from age-1 – age-2 was the lowest observed yet (Fig. 7, upper panel). Previous estimates of proportional survival from age-1 to age-2 ranged from 0.33 – 0.53 (Table 2), whereas between 2021 and 2022 the survival proportion was 0.21. This low survival is also illustrated by the height decrease of the blue bars in the left side panels of Figure 6. Survival proportions greater than one, illustrated in the top panel of Figure 7 result when the abundance of an Alewife cohort is low and difficult to accurately estimate. We plan to test alternative analytical methods to increase the accuracy of survival estimates and better predict future Alewife abundance.

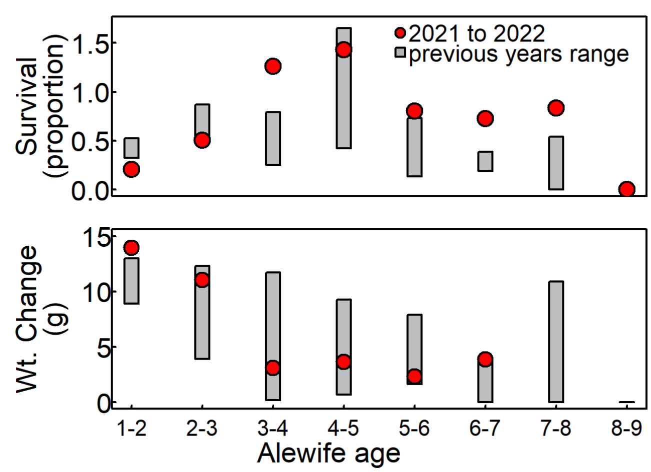


Figure 7. Alewife survival (top) and weight change (bottom). Gray boxplots represent the 2016-2019 range of values while red circles are values from 2021 to 2022.

Alewife simulation results

Simulations indicate that Alewife adult biomass may increase slightly in 2023 from the 2022 value, whereas the 2024 predicted values are less certain (Fig. 8). The uncertainty or variability in biomass predictions increases the farther into the future we predict. This is because year class strength is variable, and we currently lack a way to predict year class strength. It is important to note the simulations used are simple and based on relatively few years of observations; however, they provide decision makers and stakeholders estimates for how the adult Alewife biomass is likely to change in future years.

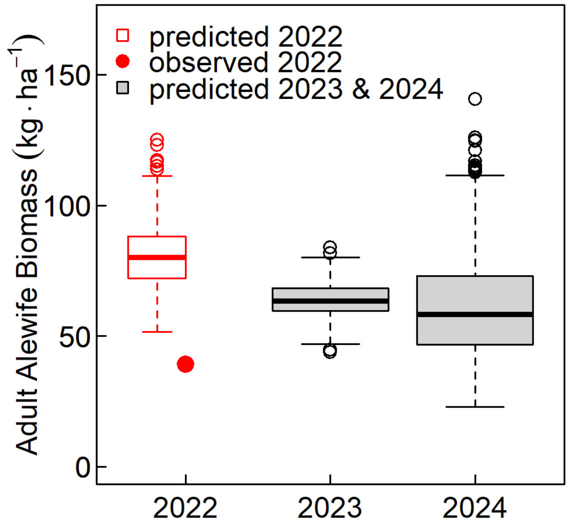


Figure 8. Simulated adult Alewife biomass (boxplots) and observed values (red circle) in Lake Ontario. Thick black bars represent the median, boxes represent the 25th and 75th quartiles, and whiskers and points represent the remaining range.

How many prey fish were above the bottom trawls?

Acoustic prey fish densities, in waters above the trawl, were at least 25 times lower than density estimates based on bottom trawls (Fig. 9). We do not know which species were sampled by acoustics, but their low target strength values indicated most were small fishes (Table 3). The low acoustic densities, relative to trawl densities indicate prey fishes in regions above the trawl would have a minimal change on whole lake abundance estimates. Interestingly, in 2022, acoustic-based prey fish densities were greatest over deep habitats, which is a sharp contrast to 2021 results, where the highest densities were in the 40- to 60-m depth region. Incorporating acoustic sampling in this survey provides observations how prey fish habitat use varies and corroborates that most prey fishes are susceptible to the bottom trawl. Continued evaluation of acoustic sampling would be beneficial to this survey.

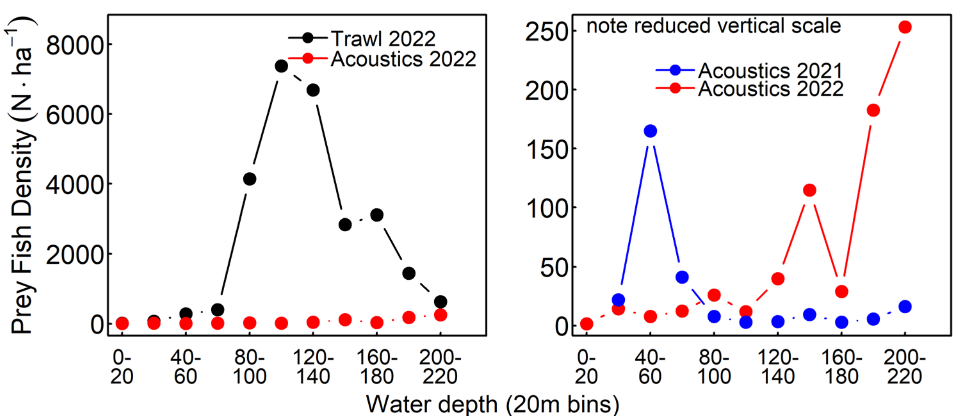


Figure 9. (left) Mean prey fish density from bottom trawl and acoustics by 20-m depth bin in Lake Ontario, April 2022. (right) Mean prey fish acoustic density from 2021 and 2022. Note the vertical scales differ between the plots.

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Table 1. Number of fish captured in Lake Ontario during the 2022 April bottom trawl survey. Individual dreissenid mussels are not counted; however, the total catch was 167 kilograms (367 lbs.). Bloater are a native deepwater fish in Lake Ontario that were extirpated and are currently being reintroduced [36]; none were captured in the 2022 survey. The "NA" represents not available.

Species	Genus Species	Number	Percent By Number	Mean Density ($N \cdot ha^{-1}$)	Mean Biomass ($kg \cdot ha^{-1}$)
Alewife	*Alosa pseudoharengus*	279714	0.85	1831.624	45.103
Rainbow Smelt	*Osmerus mordax*	19835	0.06	125.117	0.621
Round Goby	*Neogobius melanostomus*	13014	0.04	81.811	1.442
Deepwater Sculpin	*Myoxocephalus thompsonii*	12768	0.04	123.615	3.418
White Perch	*Morone americana*	1120	0	19.391	2.435
Yellow Perch	*Perca flavescens*	842	0	10.011	0.274
Trout-perch	*Percopsis omiscomaycus*	704	0	15.177	0.249
Spottail Shiner	*Notropis hudsonius*	685	0	5.196	0.054
Emerald Shiner	*Notropis atherinoides*	281	0	2.185	0.013
Threespine Stickleback	*Gasterosteus aculeatus*	119	0	1.007	0.002
Lake Trout	*Salvelinus namaycush*	100	0	0.430	0.726
Pumpkinseed	*Lepomis gibbosus*	99	0	0.759	0.050
Freshwater Drum	*Aplodinotus grunniens*	96	0	2.372	1.613
Walleye	*Sander vitreus*	75	0	1.592	0.339
Slimy Sculpin	*Cottus cognatus*	27	0	0.334	0.001
White Sucker	*Catostomus commersonii*	27	0	0.217	0.051
Lake Whitefish	*Coregonus clupeaformis*	18	0	0.324	0.052
Brown Bullhead	*Ameiurus nebulosus*	15	0	0.210	0.075
Cisco	*Coregonus artedi*	13	0	0.289	0.030
Rock Bass	*Ambloplites rupestris*	7	0	0.051	0.002
Bluegill	*Lepomis macrochirus*	6	0	0.044	0.001
Quillback	*Carpiodes cyprinus*	5	0	0.040	0.003
Unidentified Redhorse		2	0	NA	NA
Black Crappie	*Pomoxis nigromaculatus*	1	0	0.027	0.002
Common Carp	*Cyprinus carpio*	1	0	0.008	0.062
Channel Catfish	*Ictalurus punctatus*	1	0	0.010	0.008
Lake Sturgeon	*Acipenser fulvescens*	1	0	0.007	0.000
Logperch	*Percina caprodes*	1	0	0.027	0.000
Unidentified darters		1	0	NA	NA
White Bass	*Morone chrysops*	1	0	0.023	0.022
Bloater	*Coregonus hoyi*	0			

Table 2. Mean and standard deviations (s.d.) for Alewife weight change (grams) and survival proportion, by age for Lake Ontario population simulations. Weight change was calculated as the change in mean weight (in grams) for a given age class, from one age to the next. All the weight changes for that age transition create a distribution with a mean and a standard deviation (s.d.). Survival proportion is similarly calculated using the number of fish in a year class from one year to the next. These mean and s.d. values for the weight change and survival proportion are from four years of observations, (2016-2019, 2021-2022). No age-8 through age-10 Alewife were captured in successive years, so neither weight change nor survival could be estimated. Values for survival and weight change for these ages were conservatively assumed to be zero.

Age	Weight change			Survival		
(from-to)	mean	s.d.	n	mean	s.d.	n
1 - 2	11.87	2.19	4	0.36	0.13	4
2 - 3	8.15	4.14	4	0.63	0.16	4
3 - 4	5.37	4.95	4	0.65	0.48	4
4 - 5	4.44	3.56	4	1.01	0.62	4
5 - 6	3.66	2.87	4	0.48	0.34	4
6 - 7	2.95	1.74	3	0.38	0.25	4
7 - 8	10.91	0.00	1	0.39	0.37	4
8 - 9	0.00	0.00	0	0.00	0.00	3
9 - 10	0.00	0.00	0	0.00	0.00	1
10 - 11	0.00	0.00	0	0.00	0.00	1

Table 3. Hydroacoustic density estimates, single target detections, and mean target strength from the 2022 Lake Ontario April prey fish survey. Target strength is reported in decibels (dB).

Region	Mean density ($N \cdot ha^{-1}$)	Standard error	Sample size	Single targets (N)	Mean target strength (dB)
Fairhaven	2.9	1.6	731	3	-31.8
Little Sodus Bay	0.7		2	0	
Oak Orchard	2.0	1.1	781	157	-45.6
Olcott	9.0	3.0	1310	440	-39.8
Oswego	47.0	26.0	992	4	-34.7
Point Petre	5.0	1.6	633	292	-45.2
Scotch Bonnet	20.0	4.0	755	740	-42.7
Sodus	2.9	2.9	15		
Smoky Point	117.0	9.0	461	144	-42.5
Thirtymile Point	93.0	60.0	1150	3350	-34.1
Toronto	31.0	12.5	976	1725	-43.6
Youngstown	52.0	16.0	667	2312	-44.5