Lake Ontario April prey fish survey results and Alewife assessment, 2021

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Abstract

The Lake Ontario April bottom trawl survey and Alewife, *Alosa psuedoharengus* population assessment are conducted annually to track prey fish community status and inform management decisions related to predator-prey balance. No survey was conducted in 2020 due to the Covid-19 pandemic. The 2021 survey included 248 bottom trawls in both U.S. and Canadian waters, was conducted from March 30 - May 7 in the main lake and embayment regions, and at depths ranging from 5 – 221 m (16 - 729 ft). The survey captured 947,102 fish, from 30 species with a total weight of 9,191 kg (20,220 lbs). Alewife were 89.2% of the catch by number while Rainbow Smelt, *Osmerus mordax*, Round Goby *Neogobius melanostomus*, and Deepwater Sculpin *Myoxocephalus thompsonii* comprised 5.6, 2.3, and 1.7% of the catch, respectively. Rainbow Smelt biomass in 2021 was among the highest values observed since 1997, especially in U.S. waters. The biomass index for Cisco, *Coregonus artedii* also increased, primarily due to higher catches and greater survey effort in the Bay of Quinte. Three-spined stickleback, *Gasterosteus aculeatus* and Emerald Shiner, *Notropis atherinoides* biomasses remain low. No Bloater, *Coregonus hoyi* were captured during the 2021 survey.

In 2021, the lake-wide Alewife biomass index increased substantially from 2019 due to the presence of exceptionally high catches of age-1 Alewife (2020 year class). The biomass index of adult Alewife (age-2 and up) declined slightly since 2019, which was expected since Alewife reproduction was generally below average from 2017 to 2019. Expanding the bottom trawl survey spatial extent in 2016, from U.S. waters to a lake-wide survey, has improved our ability to estimate Alewife survival and has provided more accurate estimates of Lake Ontario Alewife biomass and density. Simulation modeling based on recent estimates of survival, growth, and reproduction suggests the adult Alewife biomass will likely increase in 2022 and 2023.

As part of a continued effort to improve prey fish surveys, we employed hydroacoustic sampling during the 2021 April bottom trawl survey to estimate fish densities in open-water, pelagic habitats not sampled by the bottom trawl. We found that pelagic fish density estimated by hydroacoustics, in waters above the trawl headline depth (3m off bottom to surface), were at least 100 times lower than prey fish densities estimated by bottom trawls. These results support the idea that at this time of year, when the warmest, most dense water is on the lake bottom, Alewife and most other prey fish primarily inhabit deep, near bottom regions and can be effectively sampled with bottom trawls. We were not able to apportion acoustics targets to species, however the low mean target strength (-43 decibels, dB) suggested these were small fishes (e.g., 100 mm). The greatest hydroacoustics densities were found near the Niagara River confluence and future surveys may use midwater trawls to determine which species these were and continue to improve this multi-agency survey.

Introduction

Why study Lake Ontario prey fish?

Managing Lake Ontario fisheries in an ecosystem-context requires reliable information on prey fishes, especially species that support predators and popular sport fisheries[1]. Since 1978, when contemporary surveys began, nonnative Alewife have been the most abundant prey fish in Lake Ontario and have supported most of the lake's predators [2–4]. Since that time, food web productivity and prey fish abundance have dramatically declined as mineral nutrient inputs and concentrations have declined [5–7]. Concerns related to having sufficient prey fishes to support the lake's predators have resulted in stocking reductions, first in the mid-1990s [8] and again in 2016 – 2021[9–11]. Lake Ontario fisheries are critical to the economies of Canada and the U.S., with a 2017 annual economic value estimate of $440 million in New York[12]. As such, the status of prey fishes that support fisheries, are critical to fisheries management. Prey fish surveys also track nonnative species introductions and the status of native species restorations[13,14].

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

Bottom trawling in April has proven to be the most consistent method for tracking relative abundance changes of Lake Ontario Alewife and other pelagic prey fishes. For most of the year, Alewife inhabit pelagic or open-water 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]. In April, Alewife are still near the lake bottom making them susceptible to bottom trawls[19]. Other trawl surveys conducted in summer and fall, target different fishes and capture a small proportion of the Alewife captured in April, because most of the Alewife are off bottom at these times[15]. Summer hydroacoustic surveys have also been used to index Alewife abundance[20], however research has shown Alewife inhabiting surface waters[15] or those that avoid the survey vessel[20] are not counted by the acoustic beam. Previous acoustic survey estimates did not account for these factors which contributed to indices being lower than April trawl survey results.

How is the bottom trawl survey improving?

The Lake Ontario Prey Fish Working Group is continually evaluating assumptions about prey fish behavior and habitat use to improve survey designs. New trawl sites have illustrated embayment prey fish communities are often unique and differ from main lake habitats. While Alewife can be present in these regions, their abundance is a small fraction of main lake, deep habitats. The most important change in our understanding of Lake Ontario Alewife occurred when the survey was expanded to Canadian waters in 2016. Five years of data has shown that whole lake Alewife abundance estimates can be two times higher or approximately half of the abundance indices in U.S. waters[21]. The U.S. waters time series still track the general abundance trends of prey fish over a range of years, but any one year of U.S. data, can be biased if Alewife were not evenly distributed between U.S. and Canadian waters when surveyed. In 2021, we began using hydroacoustic sampling, in conjunction with bottom trawling, to evaluate how many pelagic prey fishes may be suspended in the water column and not susceptible to be caught in the bottom trawl.

Here we report results from the multi-agency, 2021 Lake Ontario spring prey fish survey and Alewife population assessment. Results are compared to the 2019 survey since no survey was conducted in 2020 due to Covid-19 precautions. Results address the Lake Ontario Fish Community Objectives specifically: "FCO # 2.3 Increase prey-fish diversity—maintain and restore a diverse prey-fish community including Alewife, Cisco, Rainbow Smelt, Emerald Shiner, and Three-spined Stickleback" and "FCO # 2.4 Maintain predator/prey balance—maintain abundance of top predators (stocked and wild) in balance with available prey fish" [1]. This research is also guided by the U.S. Geological Survey (USGS) Ecosystems Mission Area science strategy that seeks to conduct science that informs decision making related to ecosystem management, conservation, and restoration[22].

Methods

How the survey is conducted?

The Lake Ontario April bottom trawl survey has been collaboratively conducted since 1978. Daytime bottom trawling is conducted at fixed sites since random sampling is not practical because substrate variability at random sites prohibitively damages trawls[23]. The original survey design focused on U.S. waters from 8 – 150 m (26–495 ft), at 12 transects, primarily in main lake habitats. Since 2016, trawling has occurred in both U.S. and Canadian waters in 5 – 225 m (20–743 ft), at 20 – 23 transects, including embayment habitats (Figure 1)[24]. From 1978 – 1996. the survey used a nylon Yankee trawl with an 11.8 m (39 ft) headrope and relatively low headline height (~1 m, 3.3 ft). In 1997, prohibitive dreissenid mussel catches forced the survey to adopt a different, "3N1" trawl, with an 18 m (59 ft) headrope that had lighter bottom contact and a higher head rope height. For simplicity, this report only illustrates data from 1997 to present so all data have been collected with a single trawl type. A external review of the Lake Ontario prey fish trawl program found the design generated a suitable estimate of relative abundance [23,25].

How are annual estimates calculated?

Bottom trawl catches are expressed as either the mean biomass (kilograms per hectare, kg/ha) or density (numbers per hectare, n/ha) and reported as annual, area-weighted, 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 extra 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 U.S.). Biomass and density values are considered indices because we lack estimates of trawl catchability (proportion of the true density captured by the trawl)[27].

How is Alewife population age structure determined?

Each year we interpret Alewife ages from otoliths so we can estimate the abundance of each Alewife year class (all the fish born in a year). Ages are interpreted by counting annuli from 500 - 1000 whole sagittae otoliths mounted in black plastic trays[28]. Year class parameters were estimated using an age-length key developed from annual age interpretations and the length frequency distributions[29]. Annual survival proportions and weight gain were estimated for all ages based on whole-lake year class estimates of abundance and mean size. Tracking year classes allows us to estimate how survival, and growth vary across ages, which helps us to simulate how the population may change in the future.

How are Alewife biomass simulations conducted?

Population simulations estimate how Alewife biomass is likely to change two years into the future. Simulations begin with the estimated whole-lake biomass for each year class. For a given age, survival and growth into the next year were randomly selected from observed distributions for those parameters and next year's biomass was calculated. The number and size of age-1 Alewife was randomly sampled from the previous years of age-1 observations. We conducted 1,000 simulations to predict 2021 biomass starting with 2019 values and predicted 2022 and 2023 Alewife biomass from the 2021 observed values.

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 20 – 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 where the bottom trawl does not sample, and acoustics are effective. Fish density estimates were computed in Echoview (V.11.1) assuming mean target strength of -43 dB.

Results and Discussion

Survey timing, extent, and catch

The 2021 April bottom trawl survey collected 248 trawls in main lake and embayments, at depths from 5–221 m (16 - 729 ft, Figure 1). The survey collected 947,102 fish, totaling 9,191 kg (20,220 lbs), from 30 different fish species and 497 kg (1,093 lbs) of dreissenid mussels (Table 1)[31]. Alewife were 89.2% of the fish catch by number while Rainbow Smelt, Round Goby, and Deepwater Sculpin comprised 5.6, 2.3, and 1.7% of the catch, respectively (Table 1).

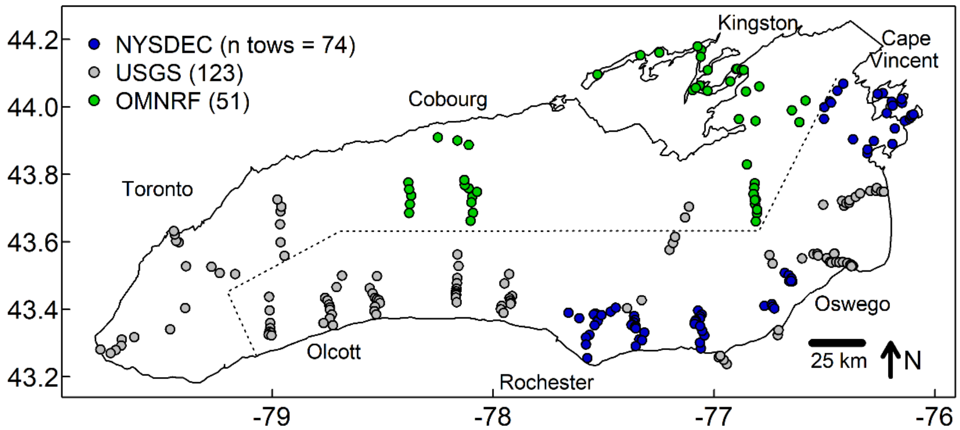

Figure 1. Lake Ontario bottom trawl sites in embayment and main lake habitats, from the 2021 collaborative April survey. The dotted line represents the U.S.- Canada border. Colors illustrate the different agencies contributing to the survey.

Pelagic fish biomass indices (non-Alewife)

Rainbow Smelt biomass in 2021 was among the highest values observed since 1997 in U.S. waters, however the Canadian estimate was approximately 50% less than the U.S. value, which lowered the whole-lake biomass estimate (Figure 2)[31]. The largest Rainbow Smelt trawl biomass value ever recorded in Lake Ontario (800 kg/ha) was captured in 2021, in 28 m of water off the Niagara River and included reproductively ripe male and female Rainbow Smelt, suggesting this aggregation may have been staging prior to running the Niagara River to spawn. The Cisco, biomass index also increased in 2021 in both U.S. and Canadian waters (Figure 2). A portion of those increases have been due to greater survey effort in the Bay of Quinte and above average reproduction since 2014[32]. Three-spined Stickleback and Emerald Shiner biomasses remain low, and no Bloater were captured during the 2021 April survey.

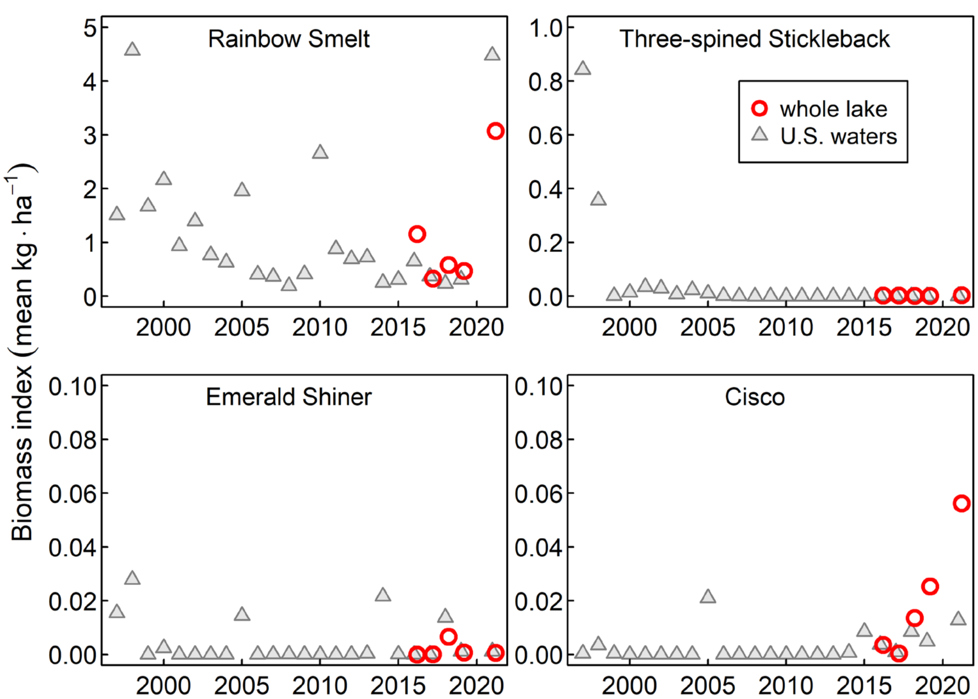

Figure 2. Biomass indices for Lake Ontario pelagic prey fishes from the April bottom trawl survey, 1997-2021. These species, along with Alewife are specifically mentioned in the Lake Ontario Fish Community Objectives. For reference, a biomass value of one kilogram per hectare is similar to one pound per acre. Note the vertical or y-axis ranges vary between species.

Alewife Biomass and Density Indices

Total Alewife biomass and density indices increased in 2021 relative to 2019 (Figure 3)[31]. Those increases were due entirely to the exceptionally large catch of yearling (age-1) Alewife (Figure 4, right panel). The adult Alewife (age-2 and older) biomass index for the whole-lake survey decreased slightly in 2021 (24.2 kg/ha) relative to 2019 value (27.7 kg/ha) and was the lowest observed in the five years of lake-wide sampling (Figure 4, left panel). This was expected because Alewife reproduction has been below average from 2017 – 2019[21]. In contrast, the 2021 age-1 Alewife biomass index value (20.5 kg/ha), which represents the 2020 year class, was among the largest observed since 1997 (Figure 4).

Whole-lake Alewife biomass and density index values can differ from U.S. index values in some years (e.g., 2016 – 2018). In 2021, age-1 Alewife density was higher on the U.S. side of Lake Ontario (Figure 4, right panel, Figure 5). Since the Canadian and the U.S. portions are approximately equal (52% vs 48% respectively), a whole-lake values represent a midpoint between the values separately estimated for Canadian and U.S waters. These strong and variable differences in Alewife distribution in April further highlight the importance of lake-wide sampling. These differences also demonstrate how previous estimates were potentially biased when the survey was conducted only in U.S. waters. The reason that Alewife distribution annually varies between U.S. and Canadian waters is not well understood but may result from variable lake thermal conditions in late fall and winter.

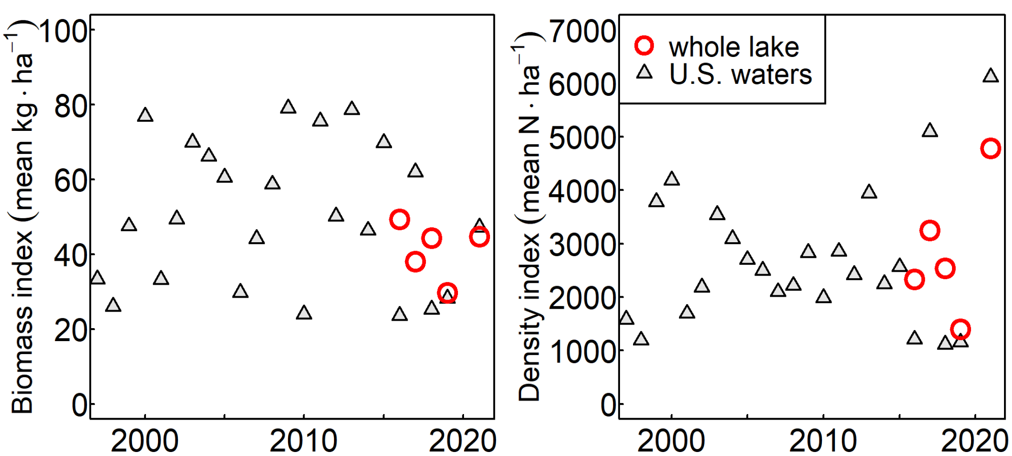

Figure 3. Biomass (left) and density (right) indices for Lake Ontario Alewife, from the April bottom trawl survey, 1997-2021. These values represent all ages of Alewife combined.

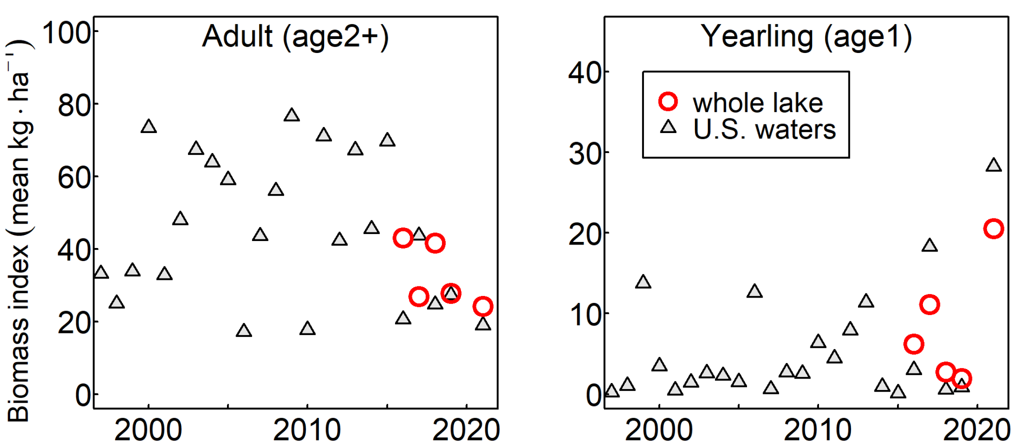

Figure 4. Biomass density indices for Lake Ontario adult (left) and yearling (right) Alewife from the April bottom trawl survey 1997-2021.

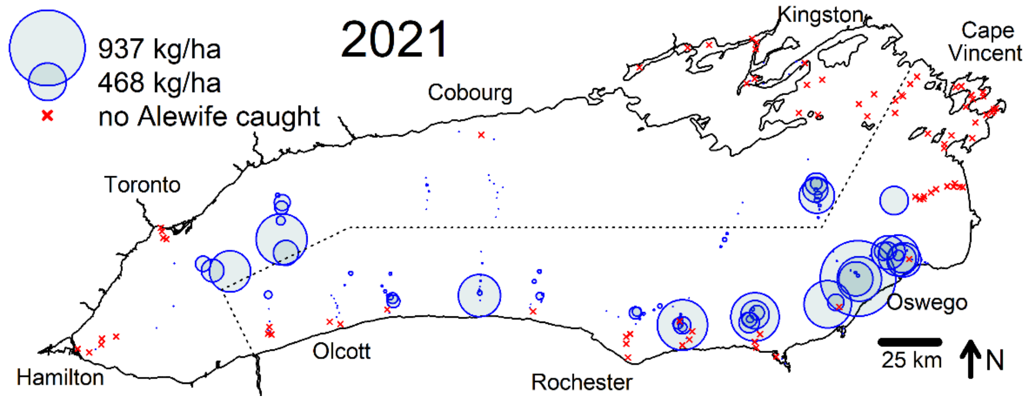

Figure 5. Biomass distribution for Alewife in Lake Ontario from the April bottom trawl survey, 2021. The thin dashed line represents the border between U.S. and Canadian waters.

Alewife Age Structure

A total of 793 Alewife otoliths were interpreted from the 2021 catches. The oldest Alewife was 9, making it part of the large 2012 year class. The 2016 and 2020 year classes comprise most of the Alewife biomass however other year classes are present and contribute to the spawning population (Figure 6, lower right panel)[31]. While no survey was conducted in 2020 due to Covid-19 precautions, angler collected piscivore diets suggested the 2019 Alewife year class was likely below average, and the relatively small blue bars in Figure 6 (lower panels) corroborates those diet-based interpretations [33].

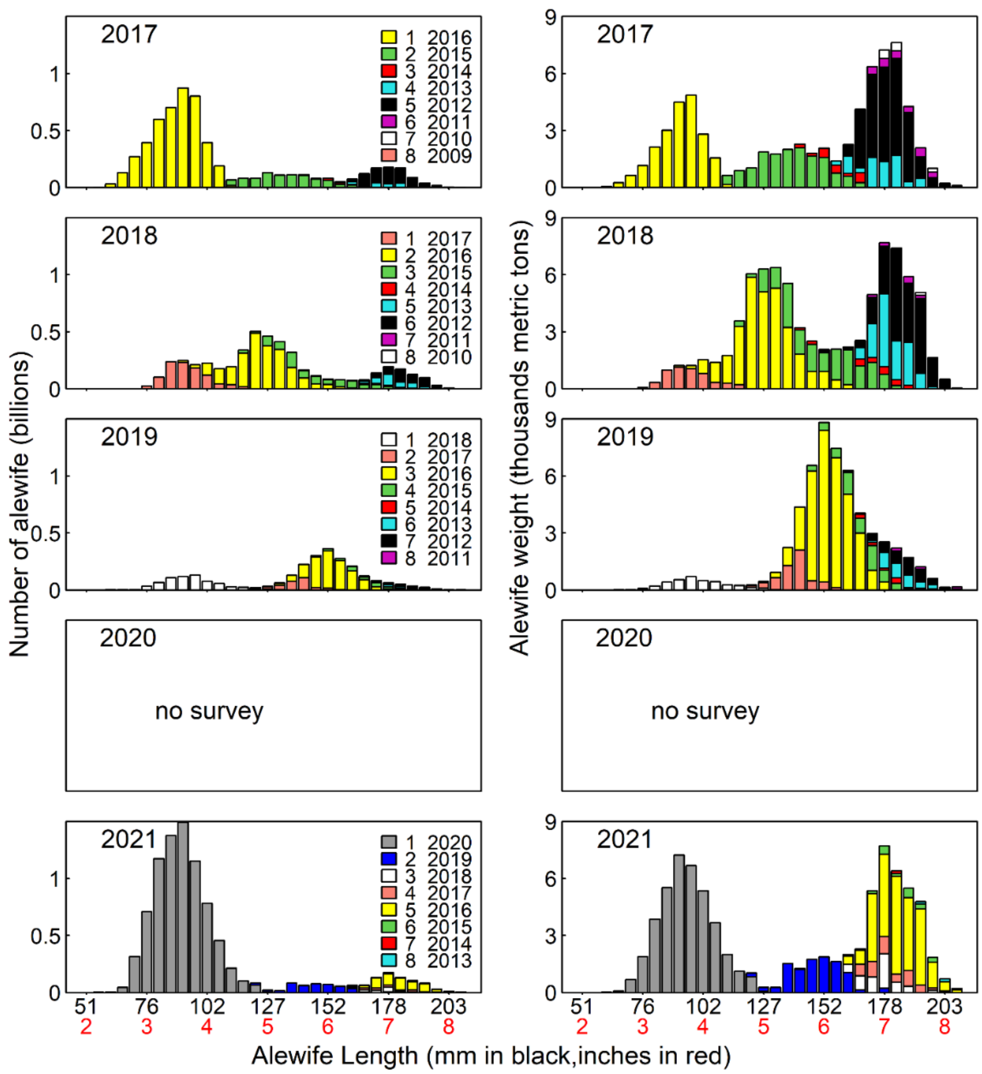

Figure 6. Lake Ontario Alewife size and age distribution from April bottom trawl surveys, 2017 - 2021. Bar height represents the number of Alewife (left panels) or weight (right panels) for each size bin (~1/5th inch or 5mm). Bar colors represent a year-class and are consistent across the panels. Plots illustrate how the number of Alewife in a year class declines quickly with time, but as they grow the total year class weight decreases more slowly. Alewife older than age 7 often comprise a small part of the biomass as most predators preferentially target the largest available Alewife.

Alewife survival, growth, and simulation results

Simulations that started with 2019 observations suggested 2021 biomass would likely be 20-30 kg/ha and the observed 2021 biomass was near the mean of those predictions (Figure 7, left panel). Looking ahead, the simulations that start with 2021 observations suggest that the 2022 and 2023 adult Alewife biomass values are likely to increase, when the abundant 2020 Alewife year class is age-2 and age-3 and contributes to the adult biomass (Figure 7, right panel). We note, these simulations assume that Alewife survival and growth will be similar to what has been observed from 2016-2019. These models 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 (Table 2).

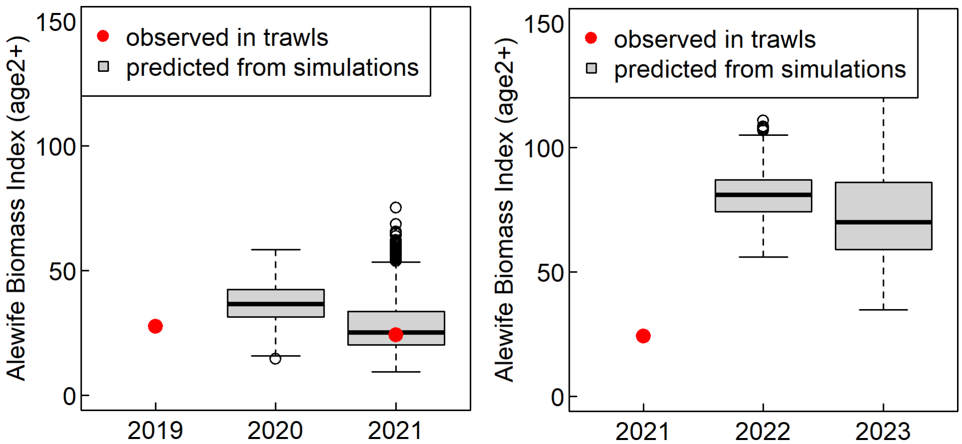

Figure 7. Simulated estimates of adult Alewife biomass (boxplots) and observed values (red circles) in Lake Ontario based on the April bottom trawl survey. Thick black bars represent the median, gray boxes represent the 25th and 75th quartiles, and whiskers and points represent the remaining range and outliers.

Alewife reproductive success

As with many fishes, the most important component driving Alewife population trajectory is reproductive success, which can be influenced by multiple environmental and biotic variables [24,34]. In Lake Ontario, Alewife reproductive success, or year class strength, tends to be above average when spring and early summer water temperatures are warmer, which allows earlier spawning, and longer growing conditions for recently hatched, or age-0, Alewife (Figure 8, red points). In contrast, colder spring temperatures delay spawning, yield a shorter, less productive growing environment (Figure 8, blue points). Back-to-back years of high reproductive success appear rare in Lake Ontario Alewife and large year classes seem to follow years with poor reproduction. These patterns would suggest that the density of Alewife may also negatively influence reproductive success, as older Alewife likely compete with, or prey on, recently hatched Alewife. Historically, winter severity was often discussed as a primary factor influencing Alewife reproductive success[24], however as Alewife density has declined and waters have warmed (Figure 8), we suspect this variable may be less influential. Future research should determine how biases in abundance estimates of age-1 and adult fish from U.S. only surveys may change our understanding of factors driving Alewife reproductive success. As lake productivity and thermal conditions in Lake Ontario continue to change, determining how these ecosystem factors influence Alewife reproduction will provide decision makers with better understanding for the resilience of the Lake Ontario Alewife population.

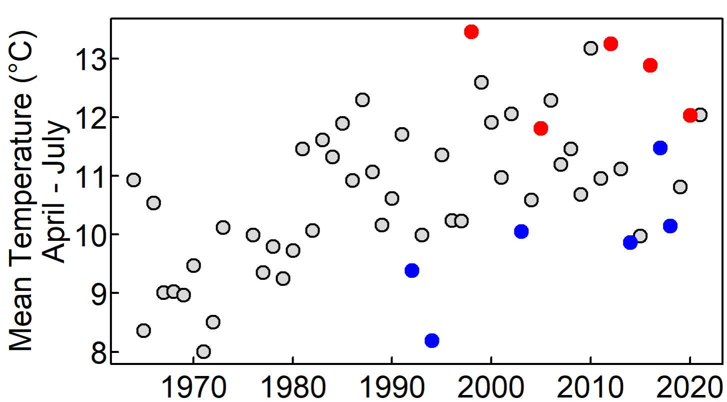

Figure 8. Mean Lake Ontario water temperature (°C) from April – July from the Monroe Water Authority. Water is drawn from a depth of ~ 14 m (46 ft) in the lake. Years when Alewife reproductive success was above average (1998, 2005, 2012, 2016, 2020) are noted in red, while years with notably low reproductive success are colored blue (1992, 1994, 2003, 2014, 2017, 2018).

How many prey fish were above the trawls?

Prey fish densities in waters above the trawl headline were at least 100 times lower than bottom trawl densities based on hydroacoustic estimates (Figure 9, note different vertical scales for different colors). Unfortunately, we do not know which species were counted by hydroacoustics, but their target strength suggested most were small fishes (Table 3). Even if we assume these fish were all Alewife, the relatively low densities indicates these fish would have had a minimal change on whole lake abundance estimates. The greatest densities observed with hydroacoustics were in western Lake Ontario on transects near the Niagara River confluence. Future surveys may use midwater trawls to better determine species and sizes of prey fishes detected by the hydroacoustics.

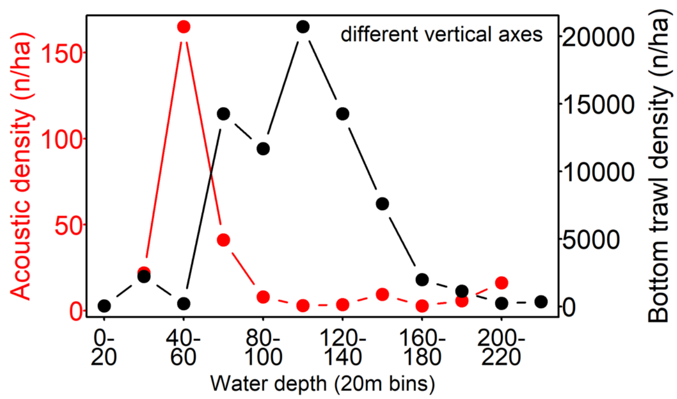

Figure 9. Mean density of pelagic prey fishes from bottom trawl (black) and hydroacoustics (red) by 20m depth bin in Lake Ontario, April 2021. Note the different vertical axes. Trawl values are the summed density of Alewife, Rainbow Smelt and other pelagic prey fish species. Including hydroacoustic sampling during bottom trawling is another example of the efforts to improve the survey and our understanding of Lake Ontario prey fishes.

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Literature Cited

1. Stewart, T. J., Todd, A. & Lapan, S. *Fish community objectives for Lake Ontario*. (2017).
2. Brandt, S. B. Food of trout and salmon in Lake Ontario. *J. Gt. Lakes Res.* **12**, 200–205 (1986).
3. Nawrocki, B. M., Metcalfe, B. W., Holden, J. P., Lantry, B. F. & Johnson, T. B. Spatial and temporal variability in lake trout diets in Lake Ontario as revealed by stomach contents and stable isotopes. *J. Gt. Lakes Res.* S0380133020301854 (2020) doi:10.1016/j.jglr.2020.08.004.
4. Stewart, Thomas. J. & Sprules, W. G. 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 (2011).
5. Dove, A. & Chapra, S. C. Long-term trends of nutrients and trophic response variables for the Great Lakes: Great Lakes nutrient trends. *Limnol. Oceanogr.* **60**, 696–721 (2015).
6. Mills, E. L. *et al.* Lake Ontario: food web dynamics in a changing ecosystem (1970 2000). *Can. J. Fish. Aquat. Sci.* **60**, 471–490 (2003).
7. Weidel, B. C., Connerton, M. J. & Holden, J. P. Bottom trawl assessment of Lake Ontario prey fishes. in *NYSDEC 2018 Annual Report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to the Great Lakes Fishery Commission's Lake Ontario Committee* (ed. NYSDEC) 12.1-12.18 (2019).

8. Jones, M. L., Koonce, J. F. & O'Gorman, R. Sustainability of Hatchery-Dependent Salmonine Fisheries in Lake Ontario: The Conflict between Predator Demand and Prey Supply. *Trans. Am. Fish. Soc.* **122**, 1002–1018 (1993).
9. Great Lakes Fishery Commission Lake Ontario Committee. Lake Ontario fisery agencies adjust lakewide predator stocking to promote Alewife population recovery. http://www.glfc.org/pubs/pressrel/2016%20-%20LOC%20stocking%20release.pdf (2016).
10. New York State Department of Environmental Conservation. NYSDEC announces Lake Ontario fisheries meetings, DEC experts to discuss changes to Chinook Salmon stocking for 2019. https://www.dec.ny.gov/press/114768.html (2018).
11. Ontario Ministry of Natural Resources and Forestry. *Lake Ontario fish communities and fisheries: 2017 Annual Report of the Lake Ontario Management Unit*. (2018).
12. Responsive Management. *New York angler effort and expenditures in 2017*. (2019).
13. Weidel, B. C. *et al.* Deepwater sculpin status and recovery in Lake Ontario. *J. Gt. Lakes Res.* (2017) doi:10.1016/j.jglr.2016.12.011.
14. Weidel, B. C. *et al.* Evidence for initial success in Lake Ontario Bloater reintroduction. (in prep).
15. Riha, M. *et al.* Vertical distribution of alewife in the Lake Ontario offshore: Implications for resource use. *J. Gt. Lakes Res.* **43**, 823–837 (2017).
16. O'Gorman, R. *et al.* 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 (2000).
17. O'Gorman, R. & Stewart, T. J. Ascent, dominance, and decline of the alewife in the Great Lakes: Food web interactions and management strategies. in *Great Lakes Policy and Management: A Binational Perspective* 489–513 (1999).
18. Otto, R. G., Kitchel, M. A. & Rice, J. O. Lethal and Preferred Temperatures of the Alewife (Alosa pseudoharengus) in Lake Michigan. *Trans. Am. Fish. Soc.* **105**, 96–106 (1976).
19. Wells, L. Seasonal depth distribution of fish in southeastern Lake Michigan. *Fish. Bull.* **67**, 1–15 (1968).
20. Elliott, C. W., Holden, J., Connerton, M. J., Weidel, B. C. & Tufts, B. L. Stationary hydroacoustics demonstrates vessel avoidance biases during mobile hydroacoustic surveys of alewife in Lake Ontario. *J. Gt. Lakes Res.* **47**, 514–521 (2021).
21. Weidel, B. C., O'Malley, B. P., Connerton, M. J., Holden, J. P. & Osborne, C. Bottom trawl assessment of Lake Ontario prey fishes. in *NYSDEC 2019 Annual Report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to the Great Lakes Fishery Commission's Lake Ontario Committee* (ed. NYSDEC) 12.1-12.25 (2020).
22. Williams, B. *et al.* U.S. Geological Survey Ecosystems Science Strategy—Advancing Discovery and Application through Collaboration. (2013).
23. MacNeill, D. B., Ault, J. S., Smith, S. & Murawski, S. *A technical review of the Lake Ontario forage base assessment program*. (2005).
24. O'Gorman, R., Lantry, B. F. & Schneider, C. P. 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 (2004).
25. ICES. *Report of the Workshop on Survey Design and Data Analysis (WKSAD)*. http://www.ices.dk/sites/pub/CM%20Doccuments/2005/B/WKSAD05.pdf (2004).
26. Weidel, B. C. & Walsh, M. G. Estimating the area-swept by the 11.8 m Yankee bottom trawl in Lake Ontario. in *NYSDEC 2012 Annual Report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to the Great Lakes Fishery Commission's Lake Ontario Committee* (ed. NYSDEC) 12.25-12.32 (2013).
27. Dean, M. J., Hoffman, W. S., Buchan, N. C., Cadrin, S. X. & Grabowski, J. H. The influence of trawl efficiency assumptions on survey-based population metrics. 17 (2021).
28. O'Gorman, R., Johannsson, O. E. & Schneider, C. P. Age and Growth of Alewives in the Changing Pelagia of Lake Ontario, 1978–1992. **126**, 112–126 (1997).
29. Isely, J. J. & Grabowski, J. H. Age and growth. in *Analysis and Interpretation of Freshwater Fisheries Data* (eds. Guy, C. S. & Brown, M. L.) (American Fisheries Society, 2007). doi:10.47886/9781888569773.ch5.
30. Parker-Stetter, S. L., Rudstam, L. G., Sullivan, P. J. & Warner, D. M. Standard operating procedures for fisheries acoustic surveys in the Great Lakes. *Gt. Lakes Fish. Comm. Spec. Publ. 09-01* (2009).
31. Weidel, B. C., Holden, J. P., Goretzke, J. A. & Connerton, M. J. Lake Ontario Spring Prey Fish Survey Data, 1997-2021. (2021) doi:https://doi.org/10.5066/P90DF8KE.
32. Weidel, B. C., Hoyle, J. A., Connerton, M. J., Holden, J. P. & Vinson, M. R. Lake Ontario Cisco dynamics based on long-term surveys. *Adv. Limnol.* (in press).
33. Weidel, B. C. *et al.* Angler-caught salmonid diets illustrate Lake Ontario Alewife population and predator prey dynamics. in *NYSDEC 2020 Annual Report, Bureau of Fisheries Lake Ontario Unit and St. Lawrence River Unit to the Great Lakes Fishery Commission's Lake Ontario Committee* (2021).
34. Madenjian, C. P. *et al.* Recruitment variability of alewives in Lake Michigan. *Trans. Am. Fish. Soc.* **134**, 218–230 (2005).
35. Use of Fishes in Research Committee. *Guidelines for the use of fishes in research*. https://fisheries.org/docs/wp/Guidelines-for-Use-of-Fishes.pdf (2014).
36. Warner, D. M., Rudstam, L. G. & Klumb, R. A. In Situ Target Strength of Alewives in Freshwater. *Trans. Am. Fish. Soc.* **131**, 212–223 (2002).

Table 1. Number of fish captured in Lake Ontario during the 2021 April bottom trawl survey. Individual dreissenid mussels are not counted however the total catch was 497 kilograms (1,093 lbs). Bloater are a native deepwater fish in Lake Ontario that was extirpated and is currently being reintroduced; none were captured in the 2021 survey.

Species	Number	Percent
Alewife	844640	89%
Rainbow Smelt	53660	6%
Round Goby	22057	2%
Deepwater Sculpin	16665	2%
Yellow Perch	3425	<1%
White Perch	2989	<1%
Spottail Shiner	1467	<1%
Trout-perch	657	<1%
Freshwater Drum	592	<1%
Pumpkinseed	231	<1%
Three-spined Stickleback	191	<1%
Walleye	126	<1%
Cisco	100	<1%
Lake Trout	95	<1%
Lake Whitefish	52	<1%
White Sucker	36	<1%
Emerald Shiner	27	<1%
White Bass	19	<1%
Slimy Sculpin	18	<1%
Brown Bullhead	15	<1%
Rockbass	11	<1%
Gizzard Shad	9	<1%
Bluegill	4	<1%
Shorthead Redhorse	4	<1%
Smallmouth Bass	4	<1%
Common Carp	2	<1%
Largemouth Bass	2	<1%
Tessellated Darter	2	<1%
Lake Sturgeon	1	<1%
Sea Lamprey	1	<1%
Bloater	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 weight, for a given age class, from one age to the next. All the weight changes for that age transition are then averaged. Survival proportion is similarly calculated. These mean and s.d. values for the weight change and survival proportion are from three years of observations, (2016-2017, 2017-2018, 2018-2019) because the survey was canceled in 2020. The exception was for survival from age-4 to age-5 (2017 to 2018) which was estimated as 1.6 (more fish at age-5 than were age age-4). This unrealistic value resulted because that year class abundance was exceptionally low in those years, which made it difficult to accurately assess abundance. This value was removed. From 2016 - 2019 there were no age-8 through age-10 captured in successive years, so weight change or survival could not be estimated. Values for survival and weight change for these ages were conservatively assumed to be the same as age-7 (in bold in the table). These assumed values had a negligible influence on simulated biomass given the small abundance of these age classes relative to other age classes (Figure 6) and the short number of years that the simulations are conducted over.

Age	Weight change			Survival		
	mean	s.d.	n	mean	s.d.	n
1	10.90	2.55	3	0.41	0.11	3
2	5.81	5.63	3	0.66	0.17	3
3	8.15	2.60	3	0.44	0.31	3
4	4.59	2.72	3	0.48	0.11	2
5	4.49	0.86	3	0.36	0.31	3
6	-0.23	1.16	3	0.29	0.09	3
7	5.17	3.02	3	0.21	0.27	3
8	**5.16**	**3.02**		**0.21**	**0.27**	
9	**5.16**	**3.02**		**0.21**	**0.27**	
10	**5.16**	**3.02**		**0.21**	**0.27**	

Table 3. Hydroacoustic density estimates, single target detections, mean target strength, and estimated length from the experimental sampling conducted in conjunction with the 2021 Lake Ontario April prey fish survey. Estimated length is provided for context and was calculated based on published fish length to target strength relationships[36].

Region	Mean density (n/ha)	Standard dev.	Sample size	Single targets (N)	Mean target strength (dB)	Estimated length (mm)
Cobourg	0.43	0.71	80	35	-43.6	100
Hamilton	0.09	0.04	3	0	NA	NA
Olcott	13.63	33.88	69	849	-44.6	90
Oswego	5.85	8.31	62	318	-40.3	146
Pickering	3.53	7.21	46	172	-42.8	111
Rocky Point	2.84	8.66	30	45	-46.0	77
Toronto	6.14	10.37	5	24	-41.9	122
Youngstown	144.83	280.25	38	397	-43.1	107