Status and Trends of the Lake Huron Prey Fish Community, 1976-2022[1,2]

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Abstract

The United States Geological Survey-Great Lakes Science Center has monitored annual changes in the offshore prey fish community of Lake Huron since 1973. Monitoring of prey fish populations in Lake Huron is based on a bottom trawl survey that targets demersal (benthic) species and an acoustic-midwater trawl survey that targets pelagic species and life stages. Status of the main basin prey fish community in 2022 was considered 'Fair' due to sustained improvements in native species status but species diversity that remains below desired levels. Current lake conditions, characterized by ongoing oligotrophication, seem to favor native coregonines like Bloater (*Coregonus artedi*), which in the main basin has exhibited signs of population growth and strong recruitment in recent years, and Cisco (*Coregonus artedi*), whose biomass in the North Channel increased for the second consecutive year in 2022. In contrast, conditions in the main basin are less favorable for exotic prey fish such as Alewife (*Alosa pseudoharengus*), whose population collapsed in 2014 and has not recovered, and Rainbow Smelt (*Osmerus mordax*), which remains the second-most abundant prey species in the main basin but has produced multiple weak year classes over the past decade including in 2022. Status of benthic prey fish in the main basin in 2022 depended on species. As in prior years, the native sculpin community in 2022 consisted primarily of Deepwater Sculpin (*Myoxocephalus thompsoni*) because Slimy Sculpin (*Cottus cognatus*) has become exceedingly rare. In contrast, biomass of the ecologically similar Round Goby (*Neogobius melanostomus*), an exotic species, reached an all-time high in 2022. Use of complementary surveys (bottom trawl, acoustics) remains important for evaluating prey fish status in Lake Huron, where prey fish community dynamics vary by basin and prey fish responses to changing environmental conditions depend on species and/or habitat.

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[1]The data associated with this report are currently under review and will be publicly available in 2023. Previous versions of the data may be accessed at U.S. Geological Survey, Great Lakes Science Center, 2019, Great Lakes Research Vessel Operations 1958-2018. (ver. 3.0, April 2019): U.S. Geological Survey data release, https://doi.org/10.5066/F75M63X0. Please direct questions to our Data Management Librarian, Sofia Dabrowski, at sdabrowski@usgs.gov

[2]Sampling and handling of fish during GLSC surveys are carried out in accordance with Guidelines for the Use of Fish in Research, a joint publication of the American Fisheries Society, the American Institute of Fishery Research Biologists, and the American Society of Ichthyologists and Herpetologists.

Introduction

Monitoring of prey fish communities is a critical need of the Lake Huron fishery management community. Prey fish are the primary forage for sport fish that support valuable fisheries (Riley and Ebener 2020), and, historically, prey species themselves supported productive fisheries (Berst and Spangler 1972). Prey fish also respond to perturbations at lower and upper trophic levels, so their status can serve as an important indicator of ecosystem health (Bunnell et al. 2014, Dobiesz et al. 2005).

The United States Geological Survey-Great Lakes Science Center (USGS-GLSC) began annual bottom trawl surveys of the Lake Huron prey fish community in 1973, and the first full survey with ports covering the Michigan waters of the lake was conducted in 1976. An integrated acoustics-midwater trawl survey (hereafter, "acoustics survey") was started in 2004 to better monitor pelagic species and life stages that were potentially underrepresented in the bottom trawl survey (Fabrizio et al. 1997). Data from these surveys are used to quantify relative abundance, species composition, and size/age structure of prey fish in "offshore" waters (i.e., depth ≥ 9 m).

The purpose of this report is to describe status and trends in the offshore prey fish community of Lake Huron from 1976 through 2022, the most recent year of data collection. Report objectives are to 1) characterize status of the main basin prey fish community in 2022 based on trends in species composition and diversity; 2) describe differences in prey fish abundance and species composition by lake basin (main basin vs. North Channel vs. Georgian Bay); and 3) describe population status of individual prey fish species based on trends in relative abundance, and when possible, year class strength, and demographics (e.g., size or age structure).

Methods

Bottom Trawl Survey—Since 1976, USGS has monitored demersal prey fish using 12-m headrope (1973-1991) or 21-m headrope (1992-2022) bottom trawls towed at fixed transects at up to eleven depths (9, 18, 27, 36, 46, 55, 64, 73, 82, 91, and 110 m) at five ports (De Tour, Hammond Bay, Alpena, Au Sable Point, and Harbor Beach) in Michigan waters of Lake Huron (Figure 1). A sixth port, Goderich (Ontario), was added to the survey in 1998. Bottom trawl surveys typically commence in early October and are completed by late October or early November, except for the 1992 and 1993 surveys, which occurred in September. Single 10-min. bottom trawl tows were conducted during daylight at each transect each year. Trawl catches are sorted by species, counted, and weighed. For Alewife (*Alosa pseudoharengus*), Rainbow Smelt (*Osmerus mordax*), and Bloater (*Coregonus hoyi*), length cut-offs determined from length-frequency data were used to apportion bottom trawl catches into age-0 fish (young-of-the-year, or YOY) and those age-1 or older (yearling and older, or YAO) (Hondorp et al. 2022, Riley et al. 2008). Mean catch weighted by the area of the main basin occurring within 10-m depth strata is used to generate a main-basin estimate of prey fish abundance expressed in density (number/ha) or biomass (kg/ha). The bottom trawl survey was not conducted in 2000, and data from the 2008 survey were excluded because all three southern ports (Au Sable Point, Harbor Beach, Goderich) were not sampled. Additional details concerning survey design and data analysis are summarized in Riley et al. (2008) and Hondorp et al. (2022).

Acoustic-midwater trawl survey—The GLSC has monitored pelagic prey fish abundance annually since 2004 using a scientific echosounder system deployed along randomly-selected transects within five geographic regions: main-basin east, main-basin west, main-basin south, Georgian Bay, and the North Channel (Figure 1). Each year, the first transect within each region was selected randomly based on latitude and longitude; subsequent transects were spaced equidistant (north to south, east to west for North Channel only) from the first within the constraints of region boundaries (O'Brien et al. 2022). Final transect locations were selected by alternating deep and shallow depths to achieve a spatially balanced survey design within each region. Acoustic surveys are typically conducted in September through early October. In all years, sampling was initiated one hour after sunset and ended no later than one hour before sunrise. Fish catches from midwater trawl tows conducted along each acoustic transect were used to identify the species composition of acoustic targets. Information from acoustic surveys was combined with trawl data to produce region-specific fish abundance estimates expressed as density (number/ha) or biomass (kg/ha). Acoustic density of Alewife, Rainbow Smelt, and Bloater was apportioned by age group (YOY vs. YAO) using length cut-offs determined from age-length relationships (O'Brien et al. 2022). No sampling occurred in Georgian Bay or the North Channel in 2006 and 2020. Additional details concerning survey design and data analysis are provided in O'Brien et al. (2022).

Data analysis— Status of the main basin prey fish community in 2022 (objective 1) was assessed based on relative importance of native species (estimated as the percent of total prey fish biomass comprised of native prey species) and species diversity as estimated by the Shannon Index (*H*):

$$H = -\sum_{i=1}^{s} p_i \ln(p_i)$$

where *p* is the proportion (by biomass) of species *i* in the community, and *s* is the total number of species sampled. Status was classified as 'Good,' 'Fair,' or 'Poor' based on indicator thresholds outlined in the 2022 State of the Great Lakes Report (Environment and Climate Change Canada and the U.S. Environmental Protection Agency 2022) and summarized in Table 1. If status categories for the two indicators did not agree, status was rated as 'Fair' if indicator categories were opposite (i.e., one 'Good,' and one 'Poor'), or the lower-rated status when indicators were in adjacent categories (e.g., Good' and 'Fair' = 'Fair'; 'Poor' and 'Fair' = 'Poor').

Table 1. Prey fish community status indicators and status category thresholds for each indicator.

		Status Category		
Indicator	**Measure**	Good	Fair	Poor
Native Species Importance	% Prey fish biomass comprised of native species	% Native ≥ 75	75 > % Native ≥ 25	% Native < 25
Species Diversity	Shannon Diversity (*H*)	$H \geq 0.75 \times H_{max}$	$0.75 \times H_{max} > H \geq 0.25 \times H_{max}$	$H < 0.25 \times H_{max}$

Trends in prey fish community status were assessed based on the slope of each indicator regressed against time (year) for two time periods: 1) the last 10 years of the survey (short-term trend), and 2) the entire time series (long-term trend). Indicator trends were classified as 'Improving' when slopes were positive and statistically significant ($P < 0.10$), and 'Deteriorating' for significant negative relationships. Otherwise, trends in the indicators were classified as 'Unchanging.' Condition of the main basin prey fish community was evaluated separately for each survey.

Spatial variability in prey fish abundance and species composition (objective 2) was quantified solely on fish biomass estimates from the acoustics survey, which samples all three lake basins.

Status of individual prey fish species (objective 3) was determined from short- and long-term trends in biomass (all species), size/age structure (Bloater, Rainbow Smelt, and Alewife only), and year class strength (Bloater, Rainbow Smelt, and Alewife only). Relative year-class strength was calculated as the mean density (#'s/ha) of YOY-sized fish divided by the maximum observed density in the time series (index range: 0-1). When applicable, separate indices were calculated for both the bottom trawl and acoustics time series. Data from the acoustics survey also was used to describe current and long-term trends in the lake-wide distribution of dominant species (Bloater, Rainbow Smelt, and Alewife).

Results and Discussion

Survey overview—The Lake Huron acoustic and bottom trawl surveys were completed during 7 September - 8 October 2022 and 11-30 October 2022, respectively. The bottom trawl survey was conducted aboard the R/V *Arcticus*, and all standard ports and transects were sampled (Table 1, Figure 1). The acoustic survey was conducted jointly by the GLSC (R/V *Sturgeon*) and U.S. Fish and Wildlife Service (M/V *Spencer F. Baird*). Twenty-five acoustic survey transects were sampled, and 47 midwater trawl tows were conducted in conjunction with acoustic data collection (Table 1, Figure 1). Nearly 55,000 fish representing 13 prey fish species were sampled in bottom trawls in 2022, and over 7,000 fish representing 9 prey fish species were sampled in midwater trawls (Table 1). Below we describe status and trends for the entire prey fish community and for the most common individual species. Appendix Tables A1 and A2 summarize biomass and density for all prey fish species sampled in 2022.

Table 2. Sampling effort and fish catch by survey, 2022.

	Survey	
Effort/catch metric	*Bottom Trawl*	*Acoustics-midwater trawl*
No. sites or transects	47	25*
No. Trawls	47	47
No. prey fish species sampled (all species)	13 (18)	9 (13)
No. prey fish sampled (all species)	54,976 (55,165)	7,135 (7,187)

*Number of acoustic transects

Main Basin Status and Trends— Status of the main basin fish community in 2022 was categorized as 'Fair,' with native species status considered 'Good' and species diversity considered 'Fair' in both surveys (Table 3). Neither indicator exhibited a positive or negative trend over the past decade (Table 3, Figure 2), during which time conditions in the main basin have consistently favored native species, mainly Bloater, over exotic species like Alewife and Rainbow Smelt (Figures 2a, 3, 4). In 2022, Bloater (or "chubs"), accounted for 71% of prey fish biomass in bottom trawls and 89% of acoustic fish biomass. Positive long-term trends in the native species index observed in both surveys reflect persistent low abundance of Alewife and Rainbow smelt since the early-to-mid 2000s combined with increased relative abundance of Bloater over the same period (Table 3, Figures 3, 4). The negative long-term trend in prey fish species diversity observed in the bottom trawl survey (Table 3) is concerning because species diversity is positively correlated with ecosystem stability (Ives and Carpenter 2007); however, low species diversity in the contemporary main basin prey fish community also reflects the reduced importance of exotic species, which is consistent with fish community objectives focused on native species restoration.

Prey fish abundance (biomass) was not considered as a factor in the evaluation of prey fish community status in the main basin because of changes in lake trophic state that have the potential to affect fish production potential. Mean prey fish biomass estimated from main basin bottom trawls in 2022 was 11.7 kg/ha (9.4 kg/ha acoustic fish biomass), which was below levels observed prior to basin-wide declines in prey fish biomass that occurred during the early 2000s (Figure 3). However, offshore areas of Lake

Huron have become increasingly oligotrophic in recent years (Barbiero et al. 2012), so the prey fish biomass that can be supported by current levels of primary production is probably lower than in the past. Prey fish population sizes that are in balance with lake productivity is consistent with Lake Huron fish community objectives (DesJardine et al. 1995).

Table 3. Ecological status of the main basin prey fish community in 2022 by survey. "Max." is the maximum indicator value over the entire survey time series.

	Native Species Index				**Species Diversity Index**				
Survey	2022	2017-2021 mean ± SE	Max.	Status	2022	2017-2021 mean ± SE	Max.	Status	**Overall Status**
Bottom trawl	75	72 ± 7	90	good	1.03	0.86 ± 0.14	1.59	fair	**fair**
Acoustics	90	91 ± 2	97	good	0.40	0.50 ± 0.05	0.84	fair	**fair**

Table 4. Trends in main basin prey fish community indicators by survey and time period.

		Whole Time Series		2013-2022
Survey	Indicator	Years	Trend	Trend
Bottom Trawl	Native Species	1976-2022	improving	unchanging
	Species Diversity	1976-2022	deteriorating	unchanging
Acoustics	Native Species	2004-2022	improving	unchanging
	Species Diversity	2004-2022	unchanging	unchanging

Community Trends by Basin—Prey fish abundance and species composition determined from the 2022 acoustics survey varied by lake basin (Figure 4). Prey fish biomass was highest in the North Channel (25.6 kg/ha) and lower in the main basin (9.4 kg/ha) and Georgian Bay (4.4 kg/ha. The most important species in the main basin in 2022 was Bloater (89% of prey fish biomass), whereas the most important species in the North Channel and Georgian Bay were Cisco (*Coregonus artedi*; 63% of prey fish biomass) and Rainbow Smelt (65% of prey fish biomass), respectively (Figure 4). In 2022, Cisco also replaced Rainbow Smelt as the dominant prey fish species in the North Channel. Georgian Bay was the only basin where exotic species, primarily Rainbow Smelt, comprised the majority of prey fish biomass (Figure 4).

Bloater— While Bloater abundance remains lower than peak levels observed during the late 1980s to early 1990s, results of both surveys indicate the main basin population is in good condition. Mean (±SE) YAO biomass estimated from the 2022 acoustics survey (7.9±1.8 kg/ha) was the 7th highest in the time series, and the bottom trawl estimate (7.7±2.5 kg/ha) was the 4th highest observed over the same period (Figure 5a). Biomass of YAO Bloater has exhibited an increasing trend since 2004 in the acoustic time series, and since 2017 in the bottom trawl time series (Figure 5a). Recent increases in YAO biomass likely were fueled by the 2018 and 2019 year-classes, which were the largest ever recorded in both surveys (Figure 5b, 5c). The 2018 and 2019 year-classes (now aged 3 and 2, respectively) accounted for over 38% of the population in 2021, the last year for which age composition data are available (Figure 6). Adult biomass also is spread across multiple year classes (Figure 6), which can stabilize population dynamics in fish species where reproduction is size- or age-dependent (Stige et al. 2017). However, changing demographics soon could trigger a decrease in Bloater population growth. Adult sex ratio (M:F) decreased from 1.17 in 2017 to 0.68 in 2022, which indicates the main basin Bloater population is becoming increasingly female-dominated. Bloater recruitment in Lake Michigan declined during periods of female predominance (Bunnell et al. 2006), so large year classes may become less frequent in Lake Huron until abundance of adult males increases. In 2022, areas of high Bloater biomass occurred in

Canadian waters of the southeastern main basin and in the northern main basin at the outflow of the St. Mary's River, which was consistent with long-term species distribution (Figure 7).

Rainbow Smelt—Status of the main basin Rainbow Smelt population varied by survey. Biomass of YAO Rainbow Smelt estimated from the bottom trawl survey exhibited a weak declining trend during the period covered by both surveys (2004-2022), whereas acoustic biomass fluctuated without trend over the same period (Figure 8a). From 2021 to 2022, YAO biomass estimated from the acoustic survey more than doubled (0.36 kg/ha to 0.88 kg/ha) while the bottom trawl estimate increased by less than 20% (0.93 kg/ha to 1.10 kg/ha; Figure 8a). Only three relatively strong Rainbow Smelt year classes have occurred over the past decade (2013, 2019, 2021), and 2022 projects as another weak year class (Figures 8b, 8c). USGS does not currently age Rainbow Smelt, so their population demographics are poorly understood. The main basin population over the past 4 years has consisted mainly of individuals with total length between 40 mm and 80 mm (Figure 9), which are assumed to be age-0 fish (Gorman 2007). Rainbow Smelt biomass historically is higher in the North Channel than elsewhere in Lake Huron, but in 2022, areas of high biomass also included western Georgian Bay and the southern main basin (Figure 10).

Alewife— Abundance of Alewife in Lake Huron has remained at historically low levels since the collapse of the adult population in 2003 (Figure 11a). In 2022, biomass of YAO alewife essentially was below detectable limits, which has been the case since 2015 (Figure 11a). Despite the rarity of adults, YOY have been sampled in both surveys since 2017. However, recent year classes, including 2022, are consistently smaller than when the adult population was at its peak (Figures 11b, 11c). Alewife populations in the main basin of Lake Huron during 2019-2022 consisted almost exclusively of age-0 individuals with total length less than 115 mm (Figure 12). Since 2004, Alewife biomass has been greatest in the western main basin between Hammond Bay and Thunder Bay (Figure 13), which indicates that small adult populations still exist in bays along the Michigan shoreline.

Sculpin— Slimy Sculpin *Cottus Cognatus* and Deepwater Sculpin *Myoxocephalus thompsonii* are demersal species that are sampled only in the bottom trawl survey. Sculpin abundance in the main basin peaked in the late 1990s, decreased during the 2000s, and has remained relatively low ever since (Figure 14a). Biomass of Deepwater Sculpin has fluctuated without trend over the past decade, although the 2022 estimate (0.32 kg/ha) was the second highest observed in the past decade. Only 3 Slimy Sculpin were sampled in 2022, all from a single bottom trawl tow at the Detour 46-m station. Slimy Sculpin have become exceptionally rare since 2010, with surveys failing to collect a single individual during the years 2007-2010, 2014, 2015, 2019, and 2020.

Round Goby—Round Goby (*Neogobius melanostomus*) is an exotic, bottom-dwelling fish species that was first captured in Lake Huron bottom trawls in 1997. Round Goby biomass in 2022 (0.68 kg/ha) was the highest observed in the time series (Figure 14b). Round Goby is more common in nearshore (depth < 9-m) areas but may seasonally migrate offshore (Pennuto et al. 2021, Walsh et al. 2007), which explains why they are sometimes caught in high numbers in the bottom trawl survey. However, bottom trawls may not provide a robust estimate of Round Goby abundance because of the species' preference for rocky, untrawlable habitats.

Cisco—Cisco is a pelagic species that is sampled only during the acoustics survey. Cisco have been most consistently sampled in Georgian Bay and the North Channel. Biomass of YAO Cisco in Georgian Bay has fluctuated without trend, with the 2022 estimate (0.55 kg/ha) near the survey mean of 0.82 kg/ha (Figure 15a). In contrast, biomass of YAO Cisco in the North Channel has exhibited an increasing trend since 2014, and the 2022 estimate (16.03 kg/ha) was the highest in the time series (Figure 15b).

Summary and Conclusions

1. Status of the main basin prey fish community in 2022 was considered ‘Fair’ due to sustained improvements in native species status but species diversity that remains below desired levels.

2. Current lake conditions, characterized by ongoing oligotrophication, seem to favor native coregonines like Bloater, which in the main basin has exhibited signs of population growth and strong recruitment in recent years, and Cisco, whose biomass in the North Channel increased for the second consecutive year in 2022.

3. In contrast, conditions in the main basin are less favorable for exotic prey fish such as Alewife, whose population collapsed in 2014 and has not recovered, and Rainbow Smelt, which remains the second-most abundant prey species in the main basin but has produced multiple weak year classes over the past decade including in 2022.

4. Status of benthic prey fish in the main basin in 2022 depended on species. As in prior years, the native sculpin community in 2022 consisted primarily of Deepwater Sculpin because Slimy Sculpin has become exceedingly rare. In contrast, biomass of the ecologically similar Round Goby, an exotic species, reached an all-time high in 2022.

5. Use of complementary surveys (bottom trawl, acoustics) remains important for evaluating prey fish status in Lake Huron, where prey fish community dynamics vary by basin and species responses to changing environmental conditions are non-uniform.

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Literature Cited

Barbiero, R.P., Lesht, B.M., and Warren, G.J. 2012. Convergence of trophic state and the lower food web in Lakes Huron, Michigan and Superior. J. Great Lakes Res. **38**(2): 368-380.

Berst, A.H., and Spangler, G.R. 1972. Lake Huron: Effects of exploitation, introductions, and eutrophication on the salmonid community. Journal of the Fisheries Research Board of Canada **29**(6): 877-887.

Bunnell, D.B., Barbiero, R.P., Ludsin, S.A., Madenjian, C.P., Warren, G.J., Dolan, D.M., Brenden, T.O., Briland, R., Gorman, O.T., He, J.X., Johengen, T.H., Lantry, B.F., Lesht, B.M., Nalepa, T.F., Riley, S.C., Riseng, C.M., Treska, T.J., Tsehaye, I., Walsh, M.G., Warner, D.M., and Weidel, B.C. 2014. Changing Ecosystem Dynamics in the Laurentian Great Lakes: Bottom-Up and Top-Down Regulation. BioScience **64**(1): 26-39.

Bunnell, D.B., Madenjian, C.P., and Croley Ii, T.E. 2006. Long-term trends of bloater (*Coregonus hoyi*) recruitment in Lake Michigan: evidence for the effect of sex ratio. Can. J. Fish. Sci. **63**(4): 832-844.

DesJardine, R.L., Gorenflo, T.K., Payne, R.N., and Schrouder, J.D. 1995. Fish-community objectives for Lake Huron. Great Lakes Fishery Commission Special Publication 95-1, Ann Arbor, MI.

Dobiesz, N.E., McLeish, D.A., Eshenroder, R.L., Bence, J.R., Mohr, L.C., Ebener, M.P., Nalepa, T.F., Woldt, A.P., Johnson, J.E., Argyle, R.L., and Makarewicz, J.C. 2005. Ecology of the Lake Huron fish community, 1970-1999. Can. J. Fish. Sci. **62**(6): 1432-1451.

Environment and Climate Change Canada and the U.S. Environmental Protection Agency. 2022. State of the Great Lakes 2022 Technical Report. Cat No. En161-3/1E-PDF. EPA 905-R22-004. United States Environmental Protection Agency/Environment and Climate Change Canada.

Fabrizio, M.C., Adams, J.V., and Curtis, G.L. 1997. Assessing prey fish populations in Lake Michigan: Comparison of simultaneous acoustic-midwater trawling with bottom trawling. Fisheries Research **33**(1-3): 37-54.

Gorman, O.T. 2007. Changes in a Population of Exotic Rainbow Smelt in Lake Superior: Boom to Bust, 1974–2005. J. Great Lakes Res. **33**: 75-90.

Hondorp, D.W., O’Brien, T.P., Esselman, P.C., and Roseman, E.F. 2022. Status and Trends of the Lake Huron Prey Fish Community, 1976-2019. U.S. Geological Survey, Ann Arbor, MI.

Ives, A.R., and Carpenter, S.R. 2007. Stability and Diversity of Ecosystems. Science **317**(5834): 58-62.

O’Brien, T.P., Hondorp, D.W., Esselman, P.C., and Roseman, E.F. 2022. Status and Trends of the Lake Huron Prey Fish Community, 1976-2021. U.S. Geological Survey, Ann Arbor, MI.

Pennuto, C.M., Mehler, K., Weidel, B., Lantry, B.F., and Bruestle, E. 2021. Dynamics of the seasonal migration of Round Goby (*Neogobius melanostomus*, Pallas 1814) and implications for the Lake Ontario food web. Ecology of Freshwater Fish **30**(2): 151-161.

Riley, S.C., and Ebener, M.P. 2020. The state of Lake Huron in 2018 [online], Ann Arbor, MI.

Riley, S.C., Roseman, E.F., Nichols, S.J., O'Brien, T.P., Kiley, C.S., and Schaeffer, J.S. 2008. Deepwater demersal fish community collapse in Lake Huron. Trans. Am. Fish. Soc. **137**(6): 1879-1890.

Stige, L.C., Yaragina, N.A., Langangen, O., Bogstad, B., Stenseth, N.C., and Ottersen, G. 2017. Effect of a fish stock's demographic structure on offspring survival and sensitivity to climate. Proc Natl Acad Sci U S A **114**(6): 1347-1352.

Walsh, M.G., Dittman, D.E., and O'Gorman, R. 2007. Occurrence and food habits of the Round Goby in the profundal zone of southwestern Lake Ontario. J. Great Lakes Res. **33**(1): 83-92, 10.

Appendix

Table A1. Mean (±SE) prey fish biomass (g/ha) in the main basin of Lake Huron by species and survey in 2022. Biomass estimates for Alewife, Rainbow Smelt, Bloater, and Cisco are stratified by age class (YOY = young-of-year; YAO = yearling and older).

			Survey	
Common Name	**Scientific Name**	**Age Class**	*Bottom Trawl*	*Acoustics*
Alewife	*Alosa Pseudoharengus*	YOY	574.6 ± 414.4	29.5 ± 17.7
Alewife		YAO	6.2 ± 5.8	5.1 ± 4.6
Bloater	*Coregonus hoyi*	YOY	552.5 ± 173.1	357.7 ± 108.7
Bloater		YAO	7711.1 ± 2515.4	6059.3 ± 2267.5
Cisco	*Coregonus artedi*		—	943 ± 833.9
Deepwater Sculpin	*Myoxocephalus thomsoni*		318.4 ± 40.3	—
Emerald Shiner	*Notropis atherinoides*		—	72.4 ± 39.9
Ninespine Stickleback	*Pungitius pungitius*		111.8 ± 32.8	1.5 ± 1.5
Rainbow Smelt	*Osmerus mordax*	YOY	508.8 ± 147.2	166.8 ± 48.7
Rainbow Smelt		YAO	1101 ± 217.2	1496.1 ± 410.6
Round Goby	*Neogobius melanostomus*		681.6 ± 234.8	—
Slimy Sculpin	*Cottus cognatus*		0.6 ± 0.6	—
Spottail Shiner	*Notropis hudsonius*		0.1 ± 0.1	—
Threespine Stickleback	*Gasterosteus aculeatus*		0.7 ± 0.5	6.8 ± 4.7
Trout-perch	*Percopsis omiscomaycus*		4.4 ± 3.2	—
White Bass	*Morone chrysops*		1.5 ± 1.5	—
White Perch	*Morone americanus*		0.2 ± 0.2	—
Yellow Perch	*Perca flavescens*		133.1 ± 66.3	—

Table A2. Mean (±SE) prey fish density (number/ha) in the main basin of Lake Huron by species and survey in 2022. Density estimates for Alewife, Rainbow Smelt, Bloater, and Cisco are stratified by age class (YOY = young-of-year; YAO = yearling and older).

			Survey	
Common Name	**Scientific Name**	**Age Class**	*Bottom Trawl*	*Acoustics*
Alewife	*Alosa Pseudoharengus*	YOY	149 ± 105	18 ± 12
Alewife		YAO	< 1	1 ± 1
Bloater	*Coregonus hoyi*	YOY	118 ± 40	245 ± 77
Bloater		YAO	469 ± 147	219 ± 61
Cisco	*Coregonus artedi*		—	2 ± 2
Deepwater Sculpin	*Myoxocephalus thomsoni*		62 ± 8	—
Emerald Shiner	*Notropis atherinoides*		—	109 ± 58
Ninespine Stickleback	*Pungitius pungitius*		54 ± 15	1 ± 1
Rainbow Smelt	*Osmerus mordax*	YOY	474 ± 140	184 ± 75
Rainbow Smelt		YAO	128 ± 25	199 ± 51
Round Goby	*Neogobius melanostomus*		99 ± 28	—
Slimy Sculpin	*Cottus cognatus*		< 1	—
Spottail Shiner	*Notropis hudsonius*		< 1	—
Threespine Stickleback	*Gasterosteus aculeatus*		< 1	6 ± 5
Trout-perch	*Percopsis omiscomaycus*		1 ± 0	—
White Bass	*Morone chrysops*		< 1	—
White Perch	*Morone americanus*		< 1	—
Yellow Perch	*Perca flavescens*		33 ± 17	—

Figures

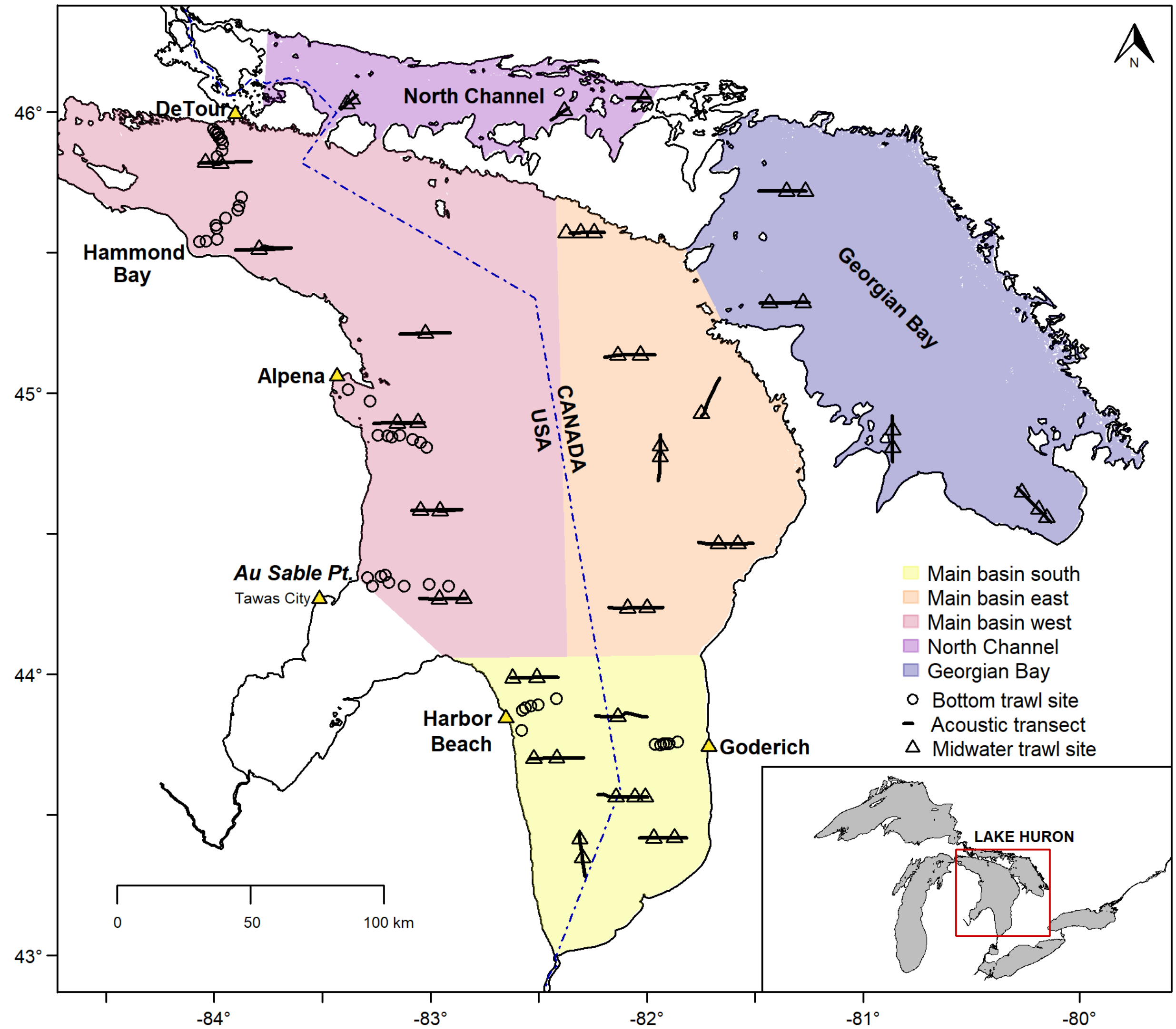

Figure 1. Location of bottom trawls, acoustic transects, and midwater trawls sampled in Lake Huron during 2022. Acoustic sampling strata (shaded areas) correspond to geographic regions: main-basin east, main-basin west, main-basin south, Georgian Bay, and North Channel. Saginaw Bay (unshaded) is not part of the standard acoustic survey area.

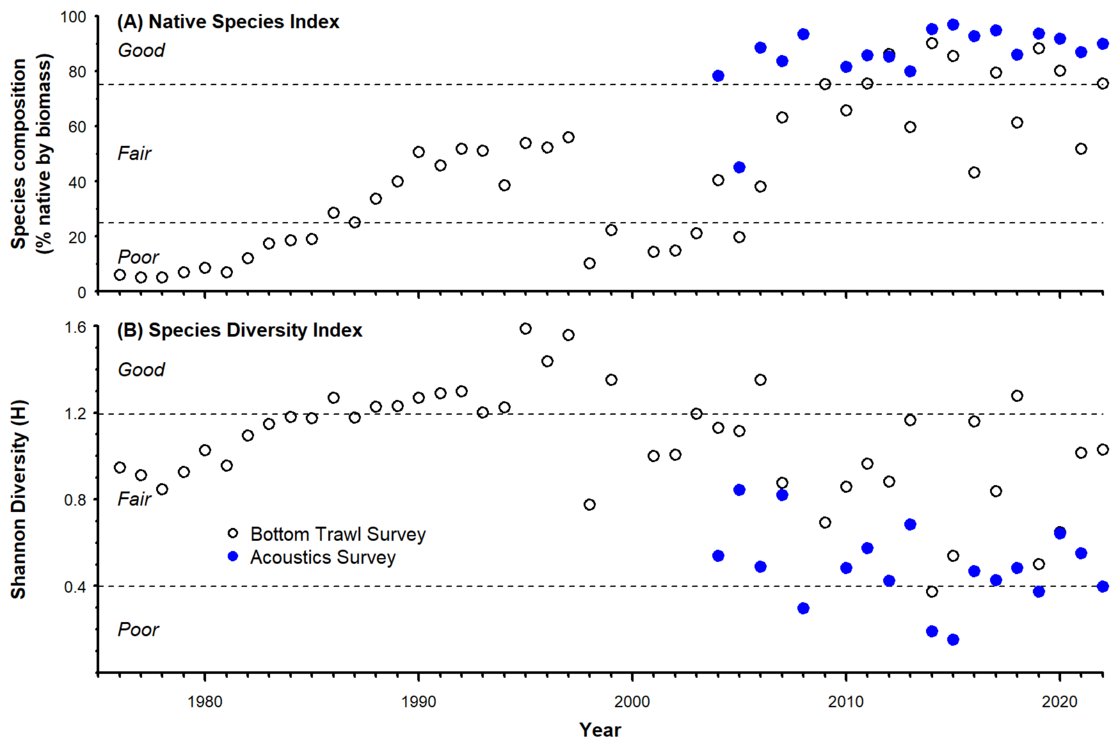

Figure 2. Trends in native species (A) and species diversity (B) indicators for the main basin prey fish community of Lake Huron, 1976-2022. Horizontal lines represent indicator benchmarks for assessing if prey fish community status is 'Good,' 'Fair,' or 'Poor.'

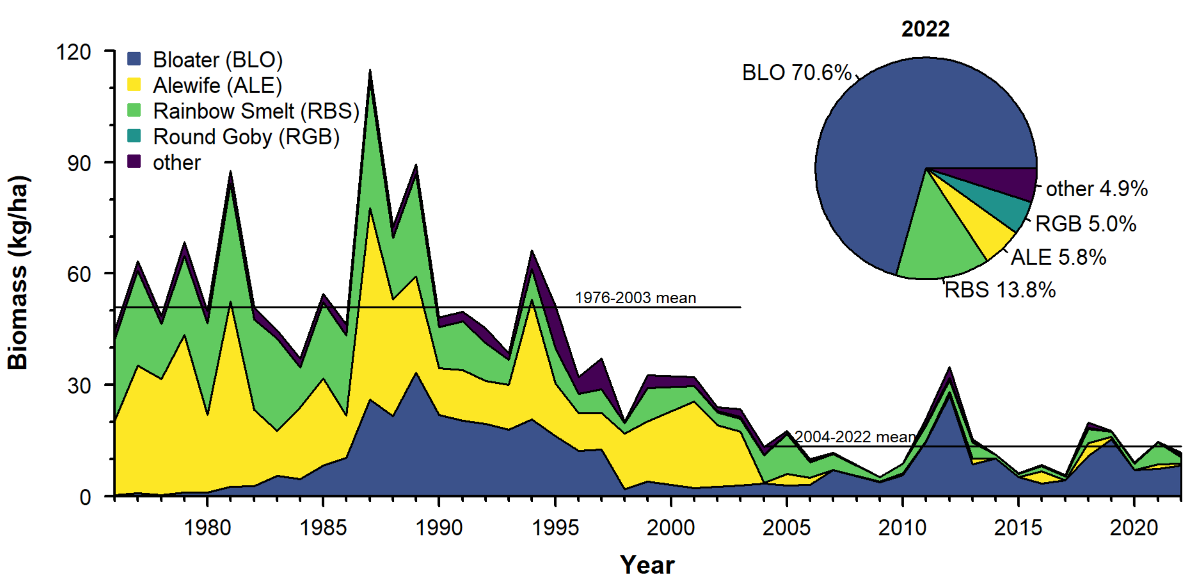

Figure 3. Biomass and species composition of prey fish sampled in bottom trawls in the main basin of Lake Huron, 1976-2022 (pie chart: species composition by biomass in 2022).

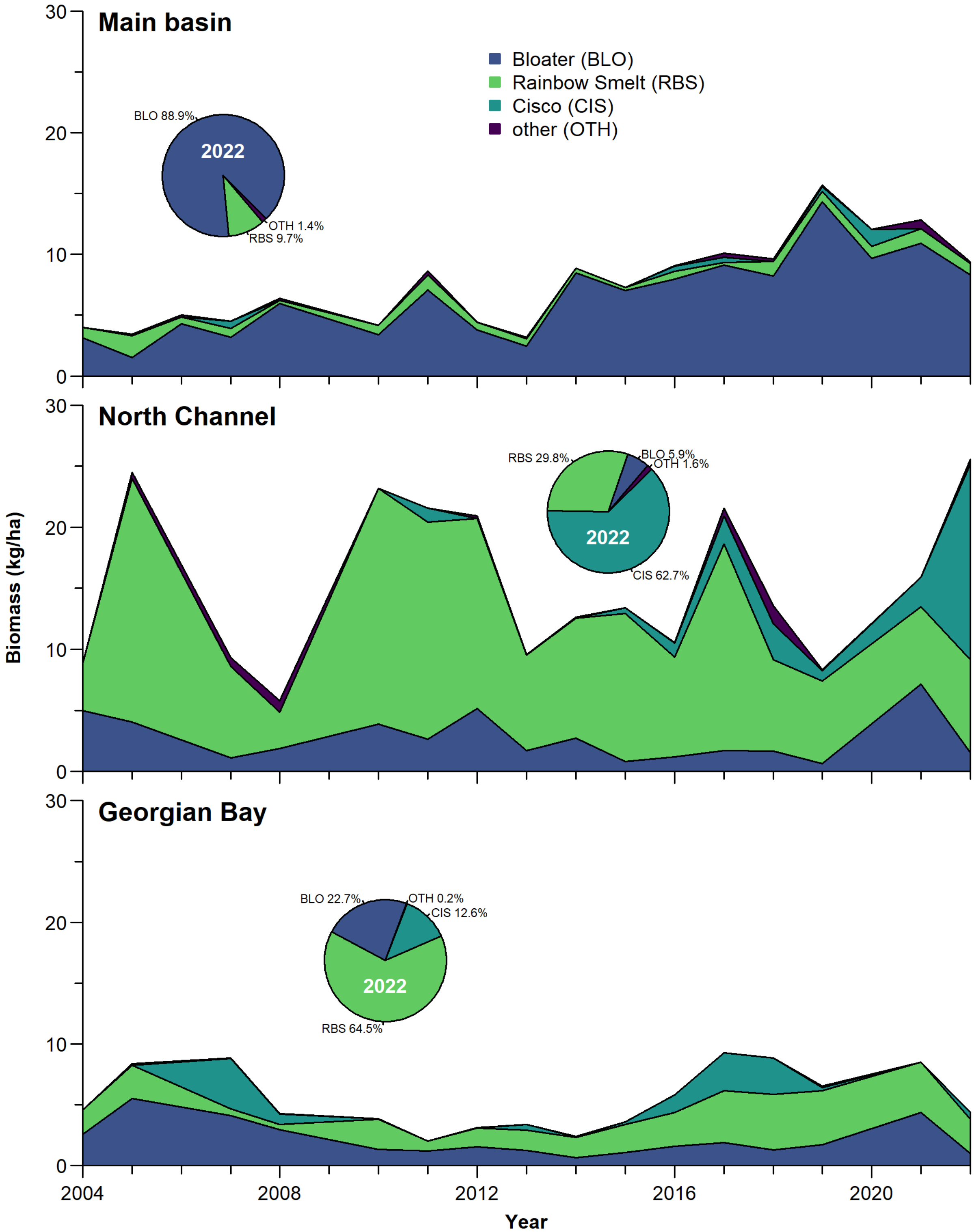

Figure 4. Acoustic prey fish biomass and species composition in Lake Huron by year and lake basin. Pie charts denote species composition by biomass in 2022.

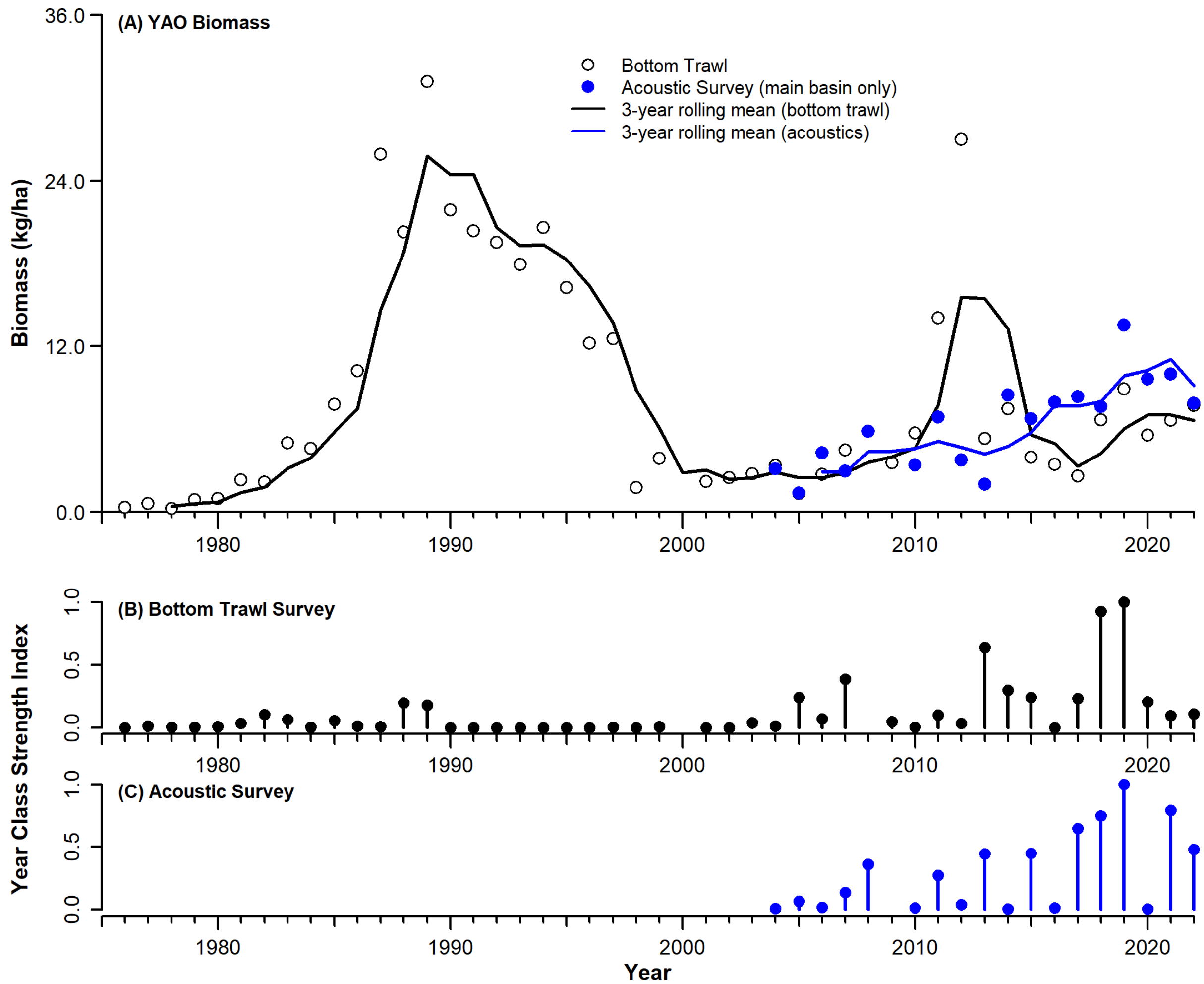

Figure 5. Biomass of yearling-and-older (YAO) Bloater *Coregonus hoyi* (A) and Bloater year-class strength (B, C) as determined from annual USGS bottom trawl (1975-2022) and acoustics (2004-2022) surveys in the main basin of Lake Huron.

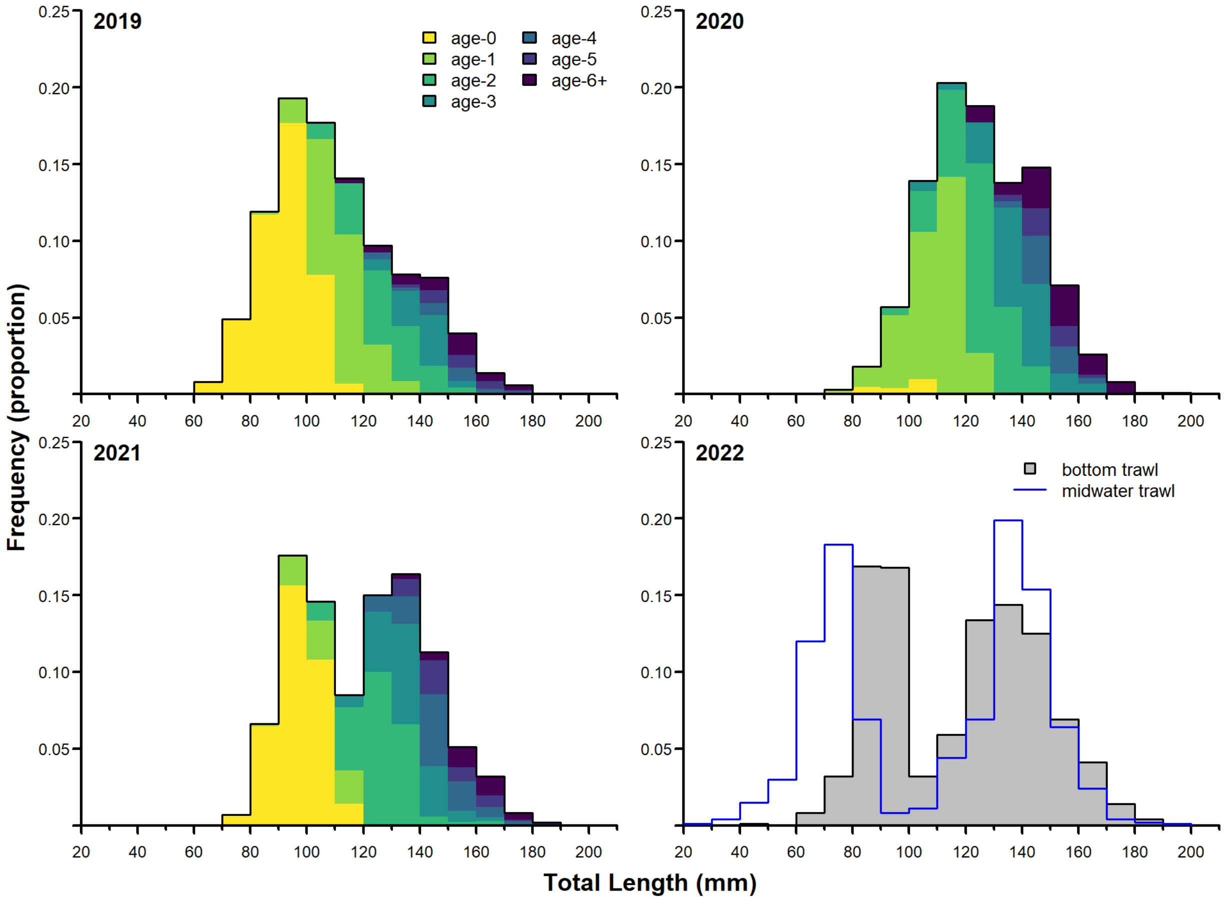

Figure 6. Length-at-age for Bloater *Coregonus hoyi* sampled in the main basin of Lake Huron during 2019-2021 and length frequency distributions of bloater sampled during 2022 prey fish assessments. Otolith ages were estimated from bottom-trawl collected fish in the main basin of Lake Huron during October of each year. Ages were estimated from a subsample of 10 fish/10 mm length bin for each port where Bloater were sampled and expanded to the total length frequency.

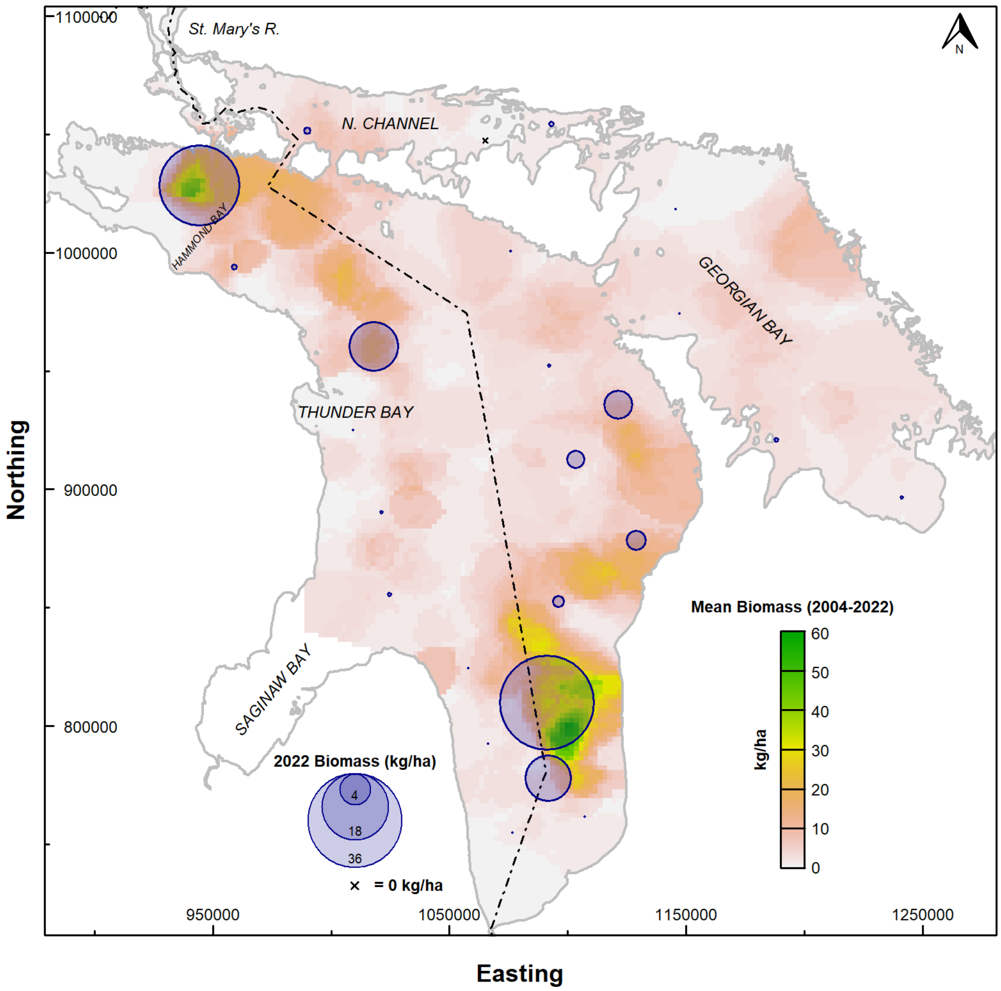

Figure 7. Distribution of Bloater *Coregonus hoyi* in Lake Huron for the most recent survey year, 2022 (bubbles), and mean distribution based on sampling during the period 2004-2022 (heat map). Bloater biomass was estimated solely from the acoustics-midwater trawl survey. Nearest-neighbor interpolation was used to extrapolate fish biomass from acoustic intervals to the lakewide scale.

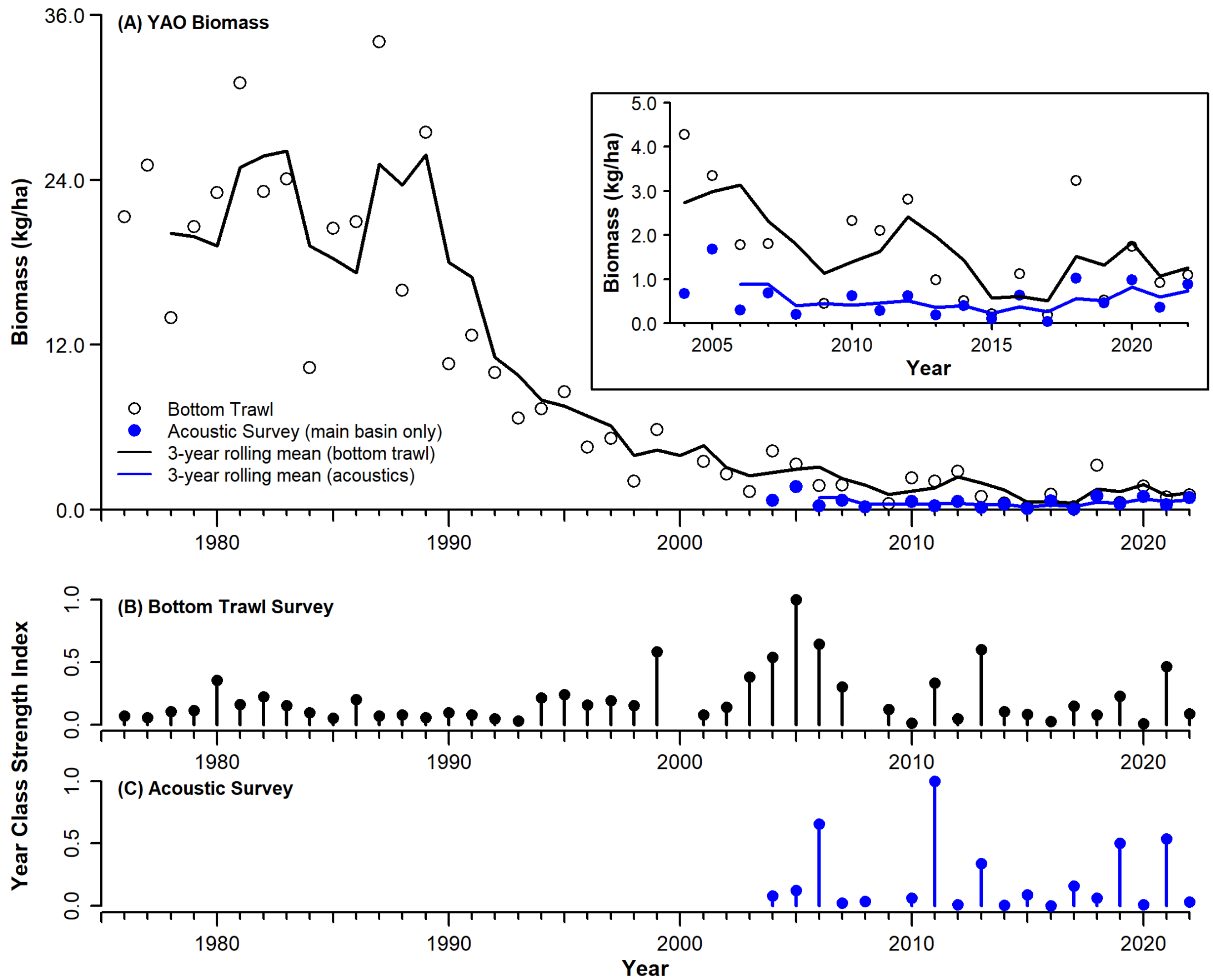

Figure 8. Biomass of yearling-and-older (YAO) Rainbow Smelt *Osmerus mordax* (A) and Rainbow Smelt year-class strength (B, C) as determined from annual USGS bottom trawl (1975-2022) and acoustic (2004-2022) surveys in the main basin of Lake Huron. Inset: Biomass of yearling-and-older (YAO) Rainbow Smelt for the yeas 2004-2022.

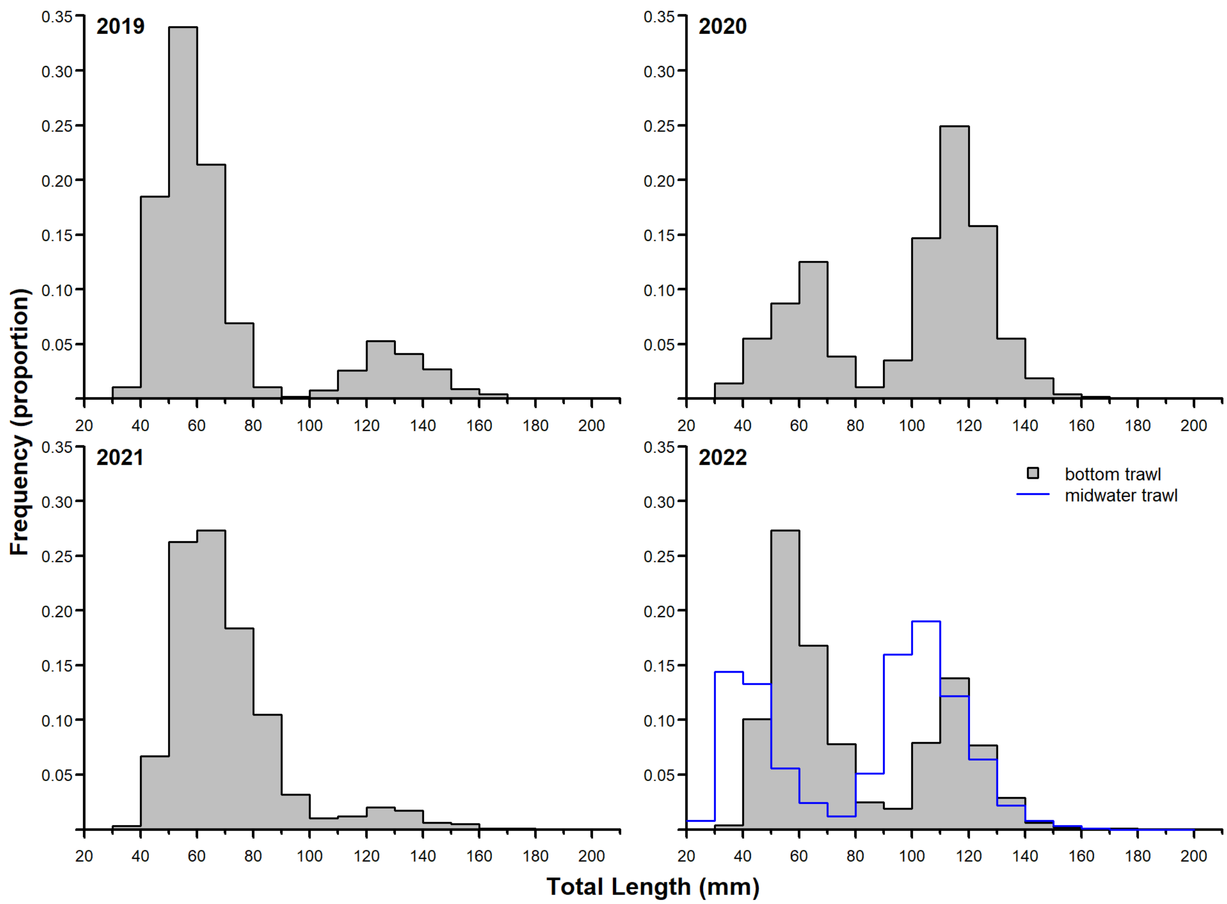

Figure 9. Length-frequency distribution for Rainbow Smelt *Osmerus mordax* sampled in the main basin of Lake Huron during 2019-2022.

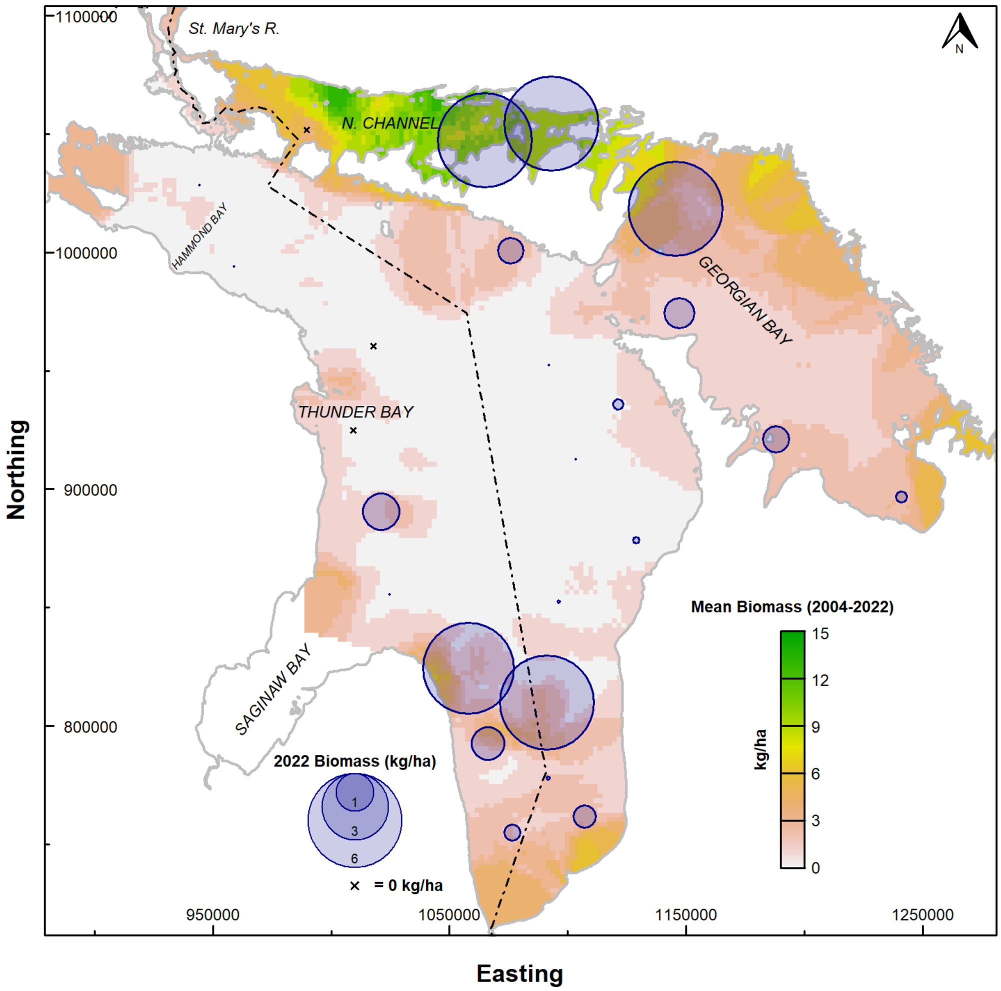

Figure 10. Distribution of Rainbow Smelt *Osmerus mordax* in Lake Huron for the most recent survey year, 2022 (bubbles), and mean distribution based on sampling during the period 2004-2022 (heat map). Rainbow Smelt biomass was estimated solely from the acoustics-midwater trawl survey. Nearest-neighbor interpolation was used to extrapolate fish biomass from acoustic intervals to the lakewide scale.

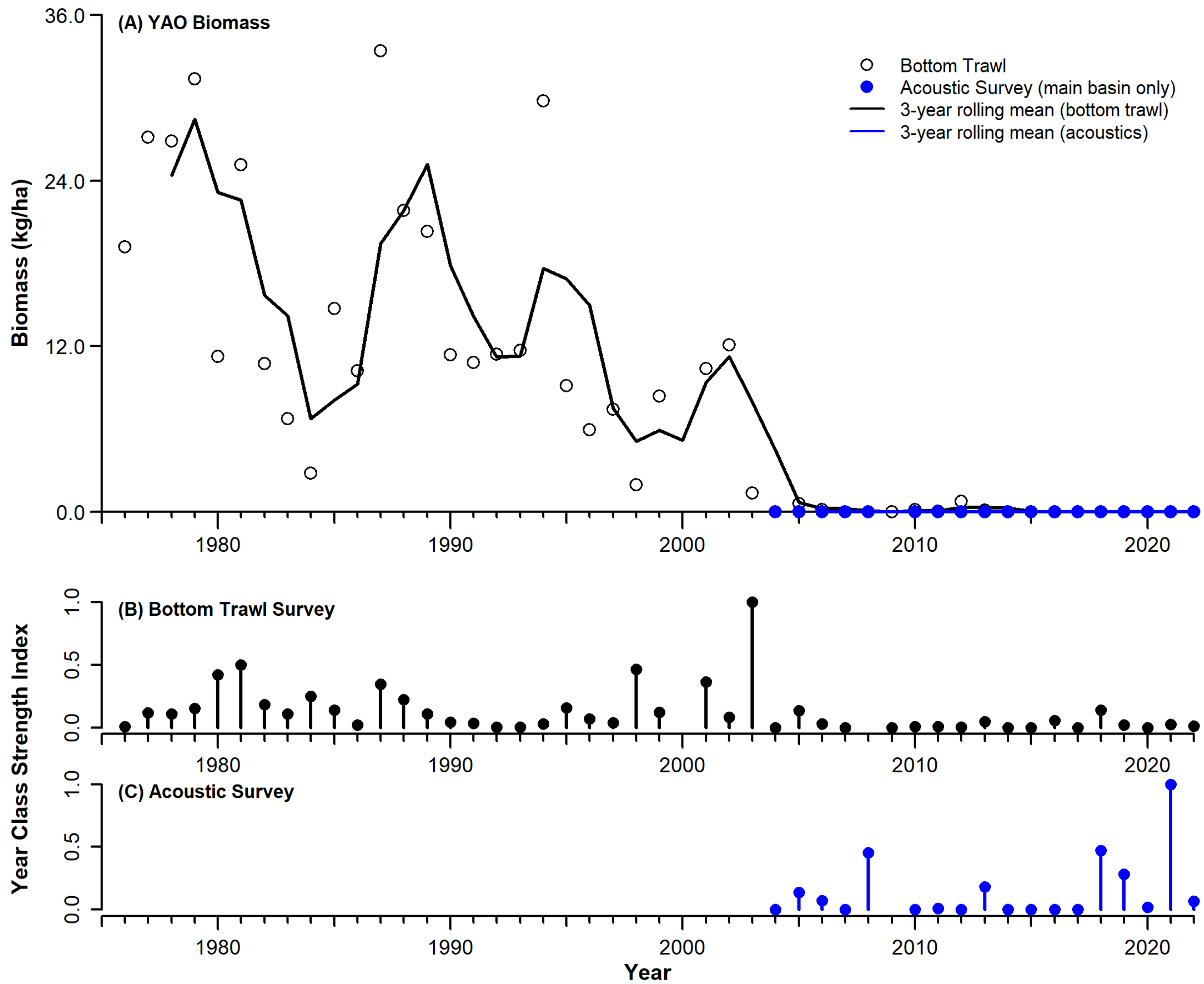

Figure 11. Biomass of yearling-and-older (YAO) Alewife *Alosa pseudoharengus* (A) and Alewife year-class strength (B, C) as determined from annual USGS bottom trawl (1975-2022) and acoustic (2004-2022) surveys in the main basin of Lake Huron.

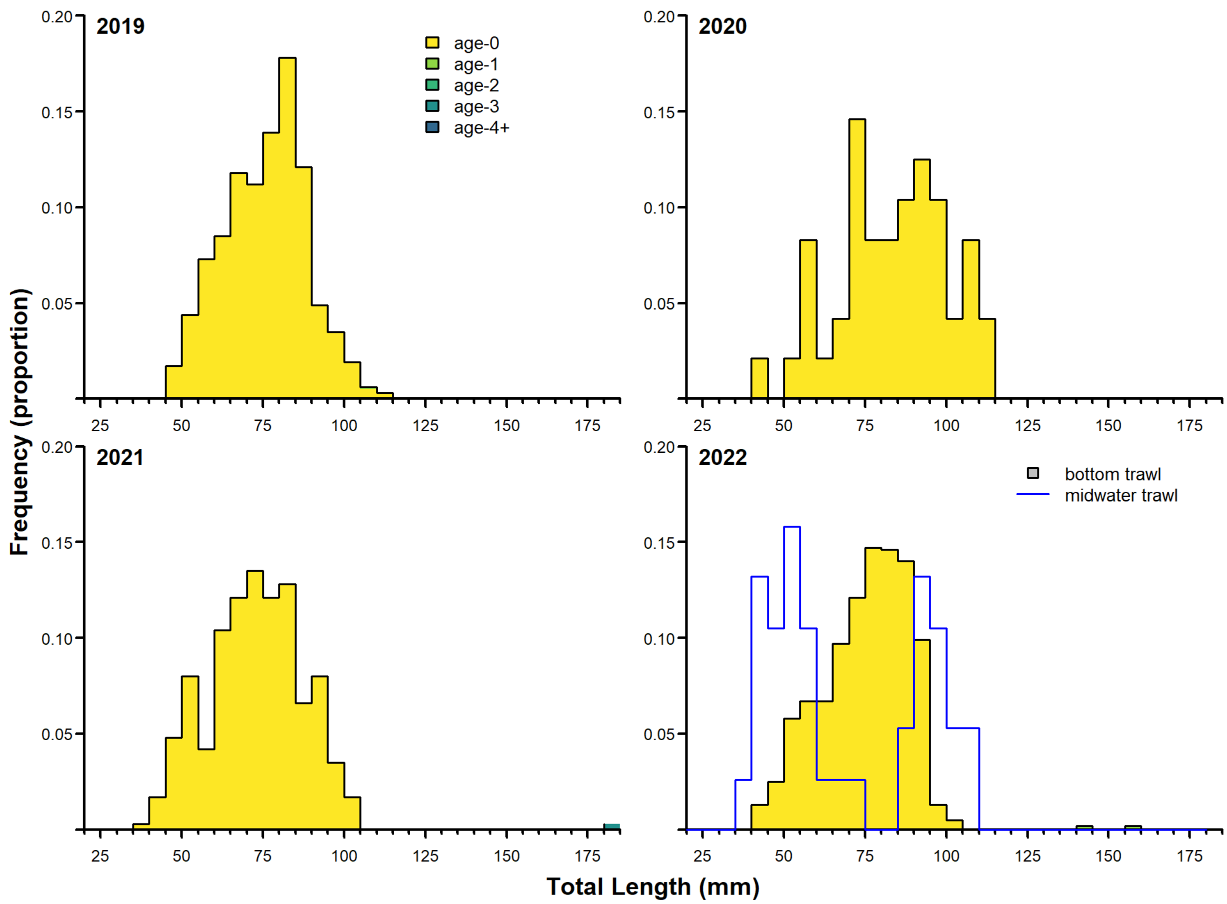

Figure 12. Length-at-age for Alewife *Alosa pseudoharengus* sampled in the main basin of Lake Huron during 2019-2021 and length-frequency distributions for Alewife sampled during 2022 prey fish assessments. Otolith ages were estimated from bottom-trawl collected fish in the main basin of Lake Huron during October of each year. Ages were estimated from a subsample of 10 fish/5 mm length bin for each port where Alewife were sampled and expanded to the total length-frequency.

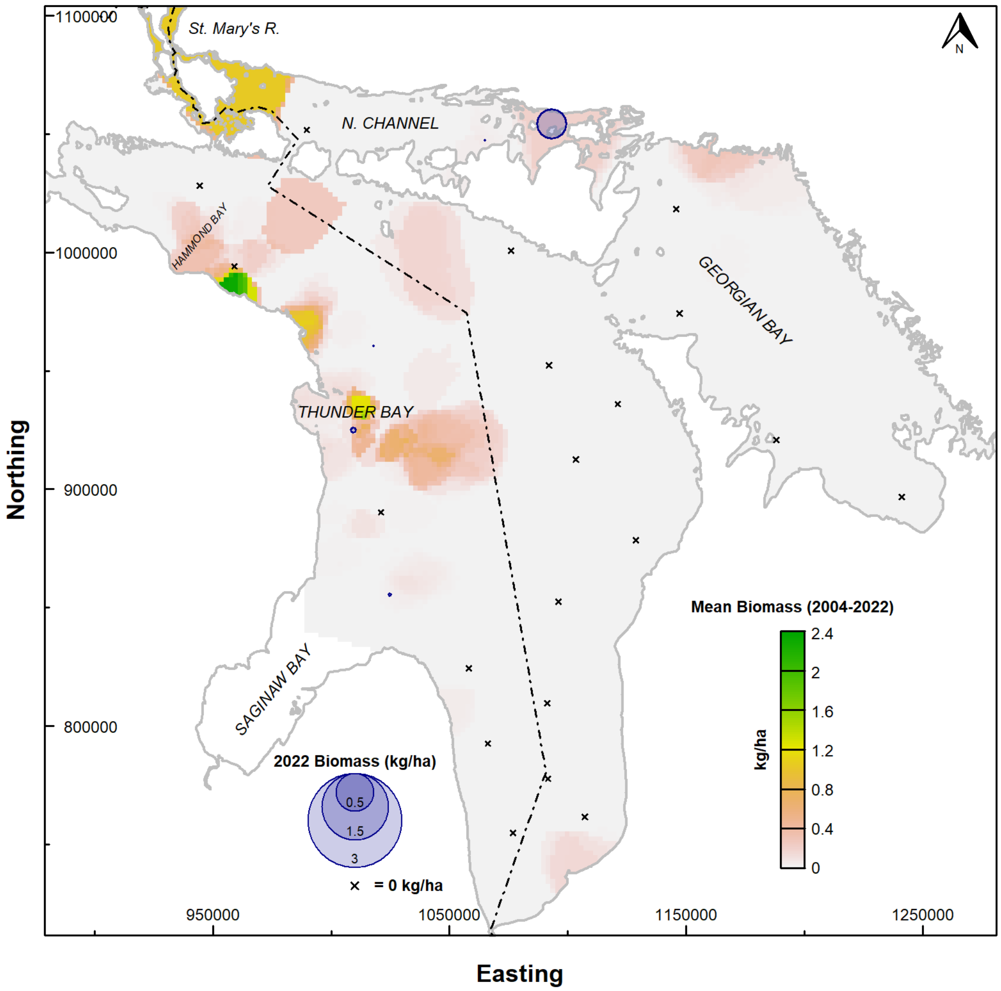

Figure 13. Distribution of Alewife *Alosa pseudoharengus* in Lake Huron for the most recent survey year, 2022 (bubbles), and mean distribution based on sampling during the period 2004-2022 (heat map). Alewife biomass was estimated solely from the acoustics-midwater trawl survey. Nearest-neighbor interpolation was used to extrapolate fish biomass from acoustic intervals to the lakewide scale.

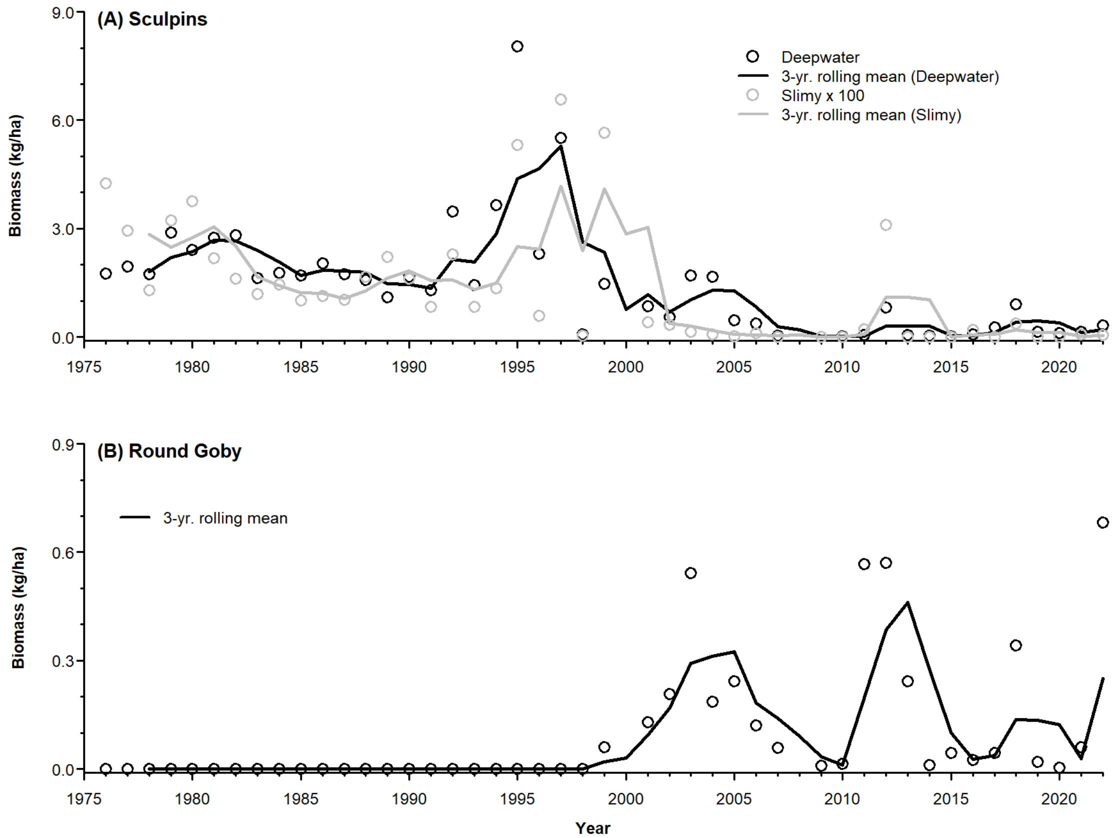

Figure 14. Biomass of sculpins—Slimy Sculpin *Cottus cognatus* and Deepwater Sculpin *Myoxocephalus thompsoni* (A)—and Round Goby *Neogobius melanostomus* (B) as determined from annual U.S. Geological Survey bottom trawl surveys in the main basin of Lake Huron, 1976-2022. Slimy Sculpin biomass was multiplied by 100 to facilitate comparison of abundance trends between sculpin species.

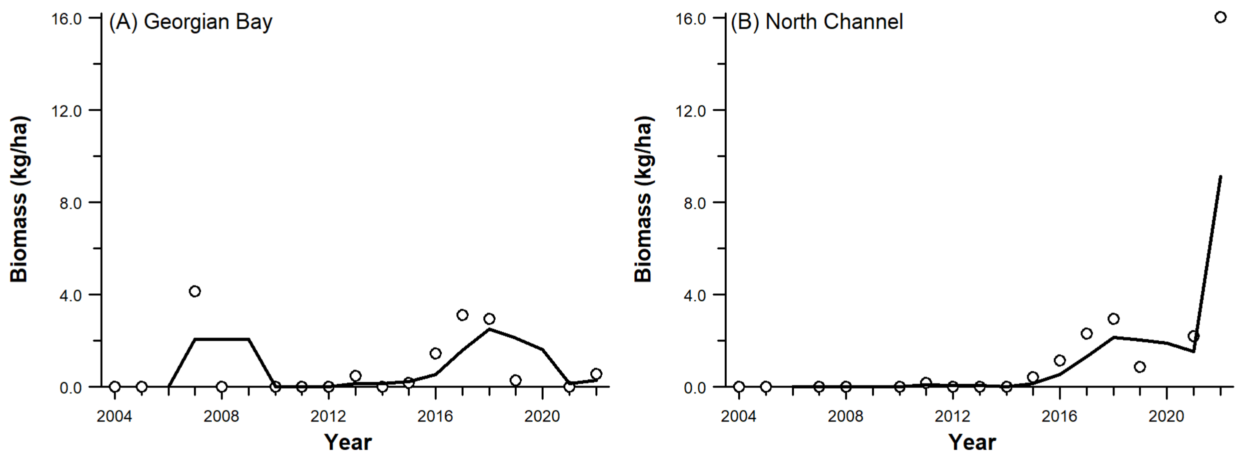

Figure 15. Biomass of Cisco *Coregonus artedi* in Georgian Bay (A) and the North Channel (B) as determined from annual U.S. Geological Survey acoustics surveys in Lake Huron, 2004-2022. Lines represent 3-year rolling means.