Status and Trends of the Lake Huron Prey Fish Community, 1976-2019[1,2]

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Abstract

The U.S. Geological Survey Great Lakes Science Center has assessed annual changes in the offshore prey fish community of Lake Huron since 1973. Assessments are based on a bottom trawl survey conducted in October of each year and an acoustics-midwater trawl survey, which began in 2004 and is conducted in September-October. Both surveys were completed in their entirety in 2019. Prey fish biomass in Lake Huron in 2019 was dominated by two species, Bloater (*Coregonus hoyi*) and Rainbow Smelt (*Osmerus mordax*). In the main basin, prey fish biomass remained below levels observed prior to community-wide declines that began in the early to mid 1990s. Bloater was the most abundant prey fish species in the main basin, whereas Rainbow Smelt was the most abundant prey species in the North Channel and in Georgian Bay. Both surveys suggested that Bloater biomass is increasing in the main basin. Low biomass of invasive species like Alewife (*Alosa pseudoharengus*) and Rainbow Smelt is consistent with fish community objectives focused on restoration of native fish communities. Abundance of invasive Round Goby (*Neogobius melanostomus*) in 2019 was low relative to 2018. Biomass of the native Cisco (*Coregonus artedi*) continued to increase in the North Channel and Georgian Bay. Biomass of Slimy Sculpin (*Cottus cognatus*) and Deepwater Sculpin (*Myoxocephalus thompsoni*) in 2019 was down from 2018 but within the range observed over the past decade. Reduced lake productivity, predation by a recovering piscivore community, and shifts in food web dynamics that favor fish production in nearshore environments may prevent prey fish biomass in offshore areas from returning to levels observed prior to the early 1990s. However, increased biomass of Bloater and Cisco suggests that lake conditions may favor recovery of native corgonines.

[1] The data associated with this report have not received final approval by the U.S. Geological Survey (USGS) and are currently under review. The Great Lakes Science Center is committed to complying with the Office of Management and Budget data release requirements and providing the public with high quality scientific data. We plan to release all USGS research vessel data collected between 1958 and 2019 and make those publicly available. Please direct questions to our Information Technology Specialist, Scott Nelson, at snelson@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

Lake Huron historically supported a diverse and abundant prey fish community that provided food for native piscivores and fishing opportunities for anglers (Berst and Spangler 1972). The endemic prey fish community in deep, offshore waters included several species of deepwater Cisco (*Coregonus hoyi*, *C. johannae*, *C. kiyi*, *C. nigrippinis*, *C. zenithicus*, *C. reighardi*, *C. alpenae*) and at least two species of sculpin (Cottidae). Deepwater ciscoes and Sculpin were the primary prey of Lake Trout (*Salvelinus namaycush*), which sustained a large commercial fishery. Cisco (*C. artedi*) likely roamed the entire lake but mainly inhabited depths above the thermocline. Native prey fish in nearshore areas included Yellow Perch (*Perca flavescens*) and Emerald Shiner (*Notropis atherinoides*).

Overfishing, introduction of exotic species, and habitat degradation precipitated major shifts in the abundance and species composition of the Lake Huron prey fish community beginning in the late nineteenth century. Unsustainable harvest resulted in the extirpation of deepwater ciscoes except for Bloater (*C. hoyi*) and main basin populations of Cisco (*C. artedi*) by the early 1900s. Pollution and eutrophication of spawning habitats also may have contributed to Cisco declines (Berst and Spangler 1972). Losses of native prey species and commensurate declines in native piscivores such as Lake Trout and Burbot (*Lota lota*) created vacant niche space that was exploited by exotic Rainbow Smelt (*Osmerus mordax*) and Alewife (*Alosa pseudoharengus*), which were first detected in Lake Huron in 1925 and 1951, respectively. By the late 1950s or early 1960s, the Lake Huron prey fish community consisted mainly of Rainbow Smelt, Alewife, and Bloater (Berst and Spangler 1972). Starting in 1968, Pacific salmon (*Oncorhynchus* spp.) were stocked into Lake Huron to create a sport fishery and to control populations of Alewife and Rainbow Smelt (Johnson et al. 2010). Stocking of Lake Trout commenced in 1970 in an effort to rehabilitate native predator populations (Eshenroder et al. 1995).

Quantitative assessment of the Lake Huron prey fish community was soon a critical need of fishery managers who were concerned that stocking rates of Pacific salmon and Lake Trout might exceed levels that could be supported by the available prey base. Assessment of the Lake Huron prey fish community also was considered necessary to address potential negative impacts of exotic prey fish (e.g., Alewife) on native fish populations and food web dynamics (Crowder 1980, Evans and Loftus 1987, Madenjian et al. 2008, Smith 1970). To address the need for prey fish assessment, the USGS Great Lakes Science Center (GLSC) began annual bottom trawl surveys on Lake Huron in 1973 and added an integrated acoustic-midwater trawl survey starting in 2004. Addition of the acoustic survey was a response to concerns that bottom trawls were undersampling pelagic fish (Fabrizio et al. 1997, Stockwell et al. 2006, Yule et al. 2008). Both surveys were designed to assess prey fish communities in "offshore" waters (i.e., depth ≥ 9 m).

Numerous ecosystem changes have occurred during the time periods covered by the trawl and acoustic surveys that have the potential to influence the Lake Huron prey fish community. These include the initiation of nutrient controls mandated by the Great Lakes Water Quality Agreement of 1972; control of Sea Lamprey (*Petromyzon marinus*); introduction of Dreissenid mussels and drastic declines in the abundance of the benthic amphipod *Diporeia* spp. (McNickle et al. 2006, Nalepa et al. 2005, Nalepa et al. 2007); significant changes in the abundance and species composition of phytoplankton and zooplankton (Barbiero et al. 2009, Barbiero et al. 2018, Burlakova et al. 2018); reduced Chinook Salmon (*O. tshawytscha*) abundance (Bence and He 2015, Dettmers et al. 2012); the invasion of the Round Goby (*Neogobius melanostomus*); and increased natural reproduction of Lake Trout and Walleye (*Sander vitreus*) (Fielder et al. 2007, Riley et al. 2007).

The goal of this report is to describe and explain changes in the Lake Huron prey fish community from 1976 (the first year of a complete bottom trawl survey) through the most recent year of data collection (2019). In contrast to prior years, results from the 2019 bottom trawl and acoustic surveys are presented jointly rather than in separate reports. This change was implemented to provide a more cohesive picture of status and trends in the Lake Huron prey fish community. Report objectives are to 1) describe temporal and spatial trends in species composition of the Lake Huron prey fish community; 2) describe temporal change in the abundance of dominant species (Alewife, Bloater, and Rainbow Smelt) and determine if trends are consistent between surveys; 3) describe the spatial distribution and size structure of dominant species in 2019; and 4) describe abundance trends and population characteristics for other prey fish species of interest to fishery managers.

Methods

Bottom Trawl Survey—The GLSC has monitored prey fish abundance annually from 1973-2019 using 12-m headrope (1973-1991) and 21-m headrope (1992-2019) bottom trawls at fixed transects at up to eleven depths (9, 18, 27, 36, 46, 55, 64, 73, 82, 92, 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). Sampling has been conducted at Goderich (Ontario) since 1998 using the same trawling protocols that are used at U.S. ports. The bottom trawl survey was conducted

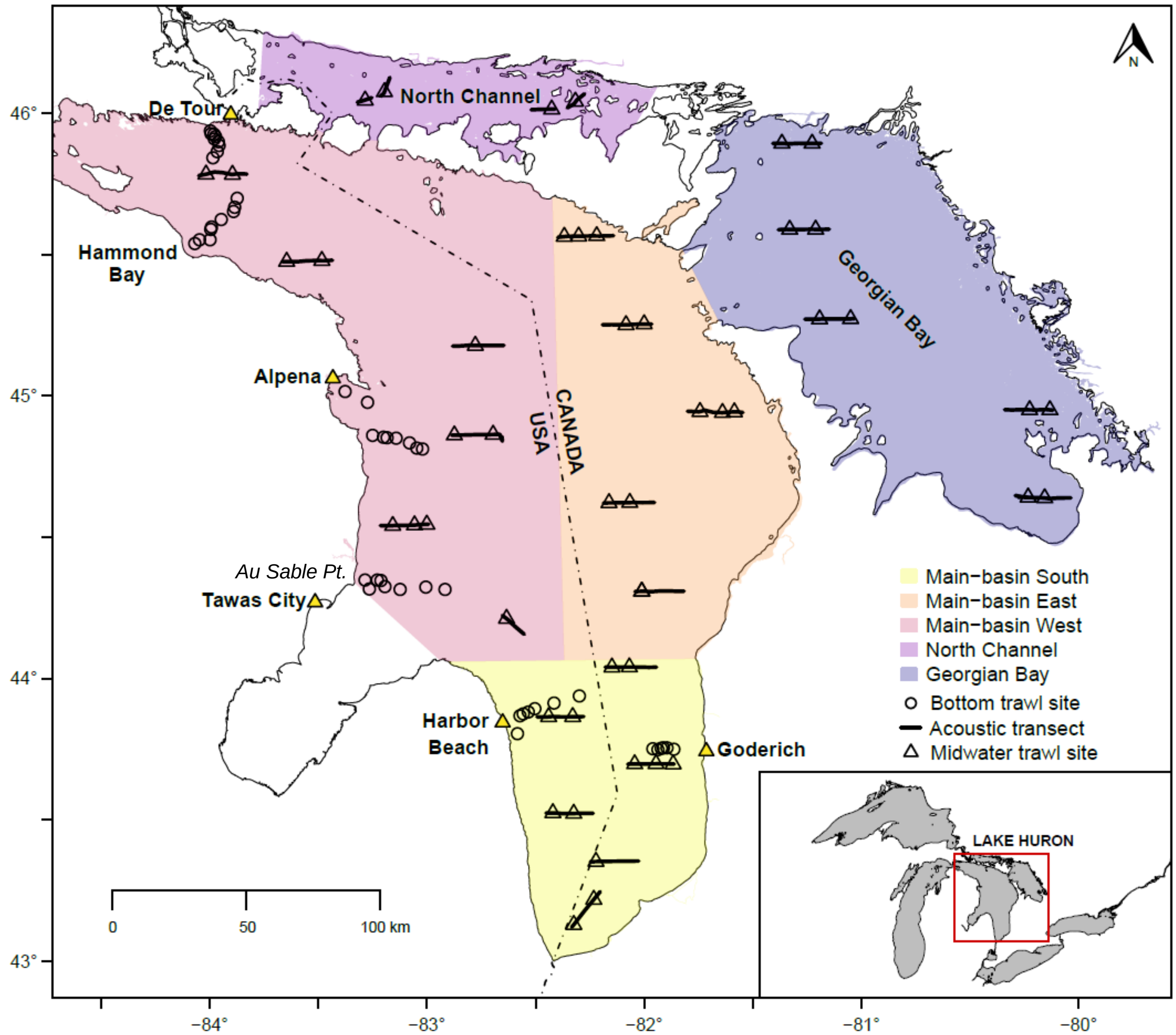


Figure 1. Location of bottom trawls, acoustic transects, and mid-water trawls sampled in Lake Huron during 2019. Acoustic sampling strata (shaded areas) correspond to geographic regions: main-basin east, main-basin west, main-basin south, Georgian Bay, and North Channel.

between mid-October and early November most years. Single 10-min bottom trawl tows were conducted during daylight at each transect each year. Trawl catches were sorted by species and each species was counted and weighed in aggregate. For Alewife, Rainbow Smelt, and Bloater, length cut-offs (Table 1) were determined from length-frequency data and 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). Mean catch weighted by the area of the main basin occurring

Table 1. Length thresholds (total length, in mm) used to assign Bloater, Alewife, and Rainbow Smelt to age groups representing young-of-the-year (YOY) and yearling-and-older (YAO) individuals. Fish with total length < threshold length were classified as YOY.

	Survey	
Species	**Bottom Trawl**	**Acoustic**
Alewife	110	100
Rainbow Smelt	80	90
Bloater	110	100

within 10-m depth strata was used to generate a main-basin estimate of prey fish abundance expressed in density (number/ha) or biomass (kg/ha). Data from surveys prior to 1976, and in 1992, 1993, 1998, 2000, and 2008 were excluded from analyses because surveys were conducted in a non-standard manner (1973-1975, 1992, 1993, 1998) or were not completed (2000, 2008). Additional details concerning survey design and data analysis are provided in the appendix.

Acoustic survey— The GLSC has monitored pelagic prey fish abundance annually from 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 from the first within the constraints of region boundaries. 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 species composition of acoustic targets. Acoustic density of Alewife, Rainbow Smelt, and Bloater was apportioned by age group (YOY vs. YAO) using fixed length cut-offs determined from age-length relationships (see Table 1). Lake-wide fish abundance expressed in density (number/ha) or biomass (kg/ha) was estimated as the weighted average of acoustic fish density, with region area as the weighting variable. Additional details concerning survey design and data analysis are provided in the appendix.

Data analysis—Data from both surveys were used to assess shifts in prey fish community biomass and species composition over time (Objective 1); describe trends in the abundance of individual species (Objectives 2, 4); determine if abundance trends for dominant species (Alewife, Bloater, and Rainbow Smelt) differed between surveys (Objective 2); and describe population size (length) structure (Objective 3). Non-parametric correlation (Spearman Rank Sum Test) was used to test for temporal correlation between fish abundance (biomass) estimated from the bottom trawl and acoustic surveys. Data from the acoustics survey alone were used to describe prey fish abundance and species composition by lake basin (Objective 1) and spatial distributions of dominant species in 2019 (Objective 3). Abundance was expressed in density (numbers/ha) for YOY Alewife, Rainbow Smelt, and Bloater, whereas abundance was expressed as biomass (kg/ha) for YAO Alewife, Rainbow Smelt, and Bloater and all species that were not subdivided by age group.

Results and Discussion

Survey overview—The Lake Huron acoustics and bottom trawl surveys were completed during 5 September - 10 October 2019 and 10-28 October 2019, respectfully. 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-six acoustic transects were sampled, and 49 midwater trawl tows were conducted in conjunction with acoustic data collection (Figure 1). The bottom trawl survey was conducted aboard the R/V *Arcticus*, and all standard ports and transects were sampled (48 total trawl tows).

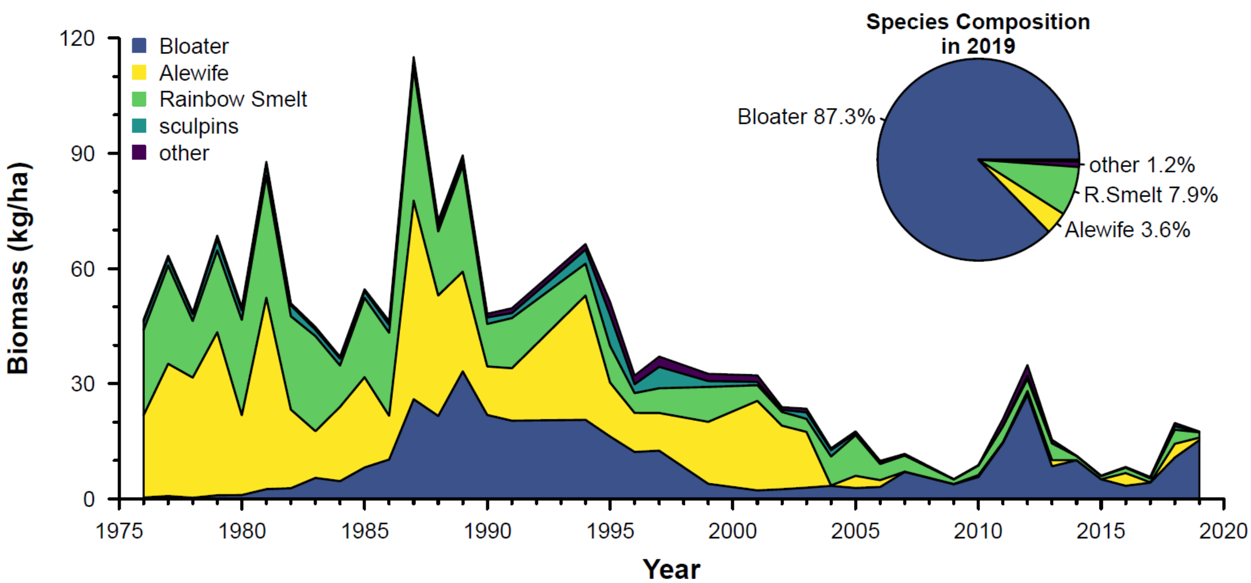


Figure 2. Prey fish biomass and species composition in the region sampled by the bottom trawl (i.e., 9-110 m depth) in Lake Huron, 1976-2019, and in 2019 (pie chart).

Community biomass and species composition— Prey fish biomass in the region sampled by the bottom trawl (9-110 m) in 2019 averaged 17.5 kg/ha, which was well below levels observed prior to basin-wide declines in prey fish biomass that occurred during the early 2000s (Figure 2). Prey fish biomass measured from the acoustic survey in 2019 varied regionally (Figure 3), with the highest biomass occurring in the main basin (15.7 kg/ha) and lower biomass in the North

Channel (8.3 kg/ha) and Georgian Bay (6.5 kg/ha). Prey fish biomass in the North Channel

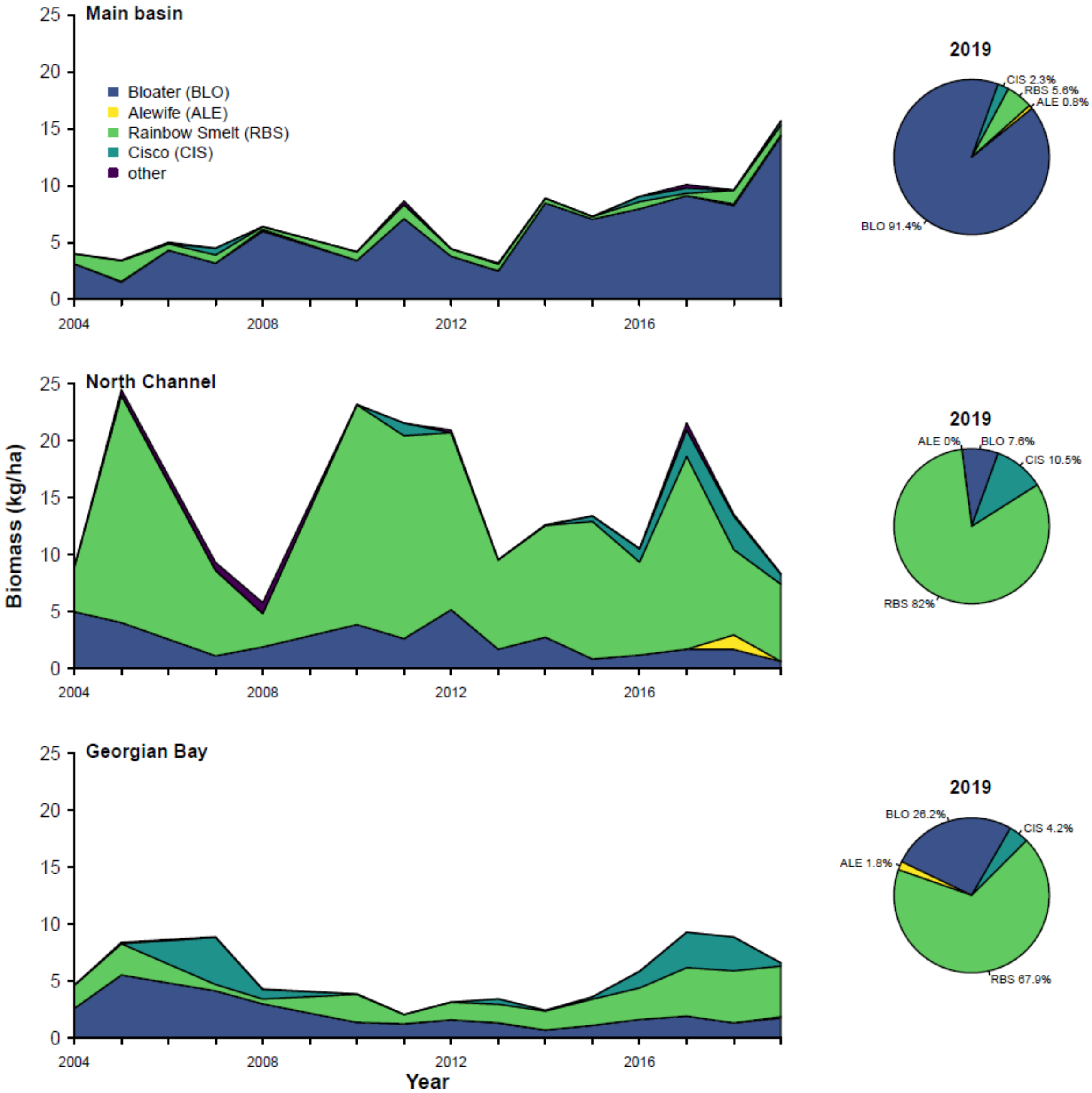


Figure 3. Acoustic prey fish biomass and species composition by year and region. Pie charts to the right of each area plot denote species composition (% biomass) in 2019.

during 2019 was the lowest observed since 2008 (Figure 3). The prey fish community in 2019 was dominated by Bloater and Rainbow Smelt, which together accounted for 85 % (acoustic) to 92% (bottom trawl) of estimated prey fish biomass (Figures 2, 3). Bloater and Rainbow Smelt have been the most abundant species in USGS bottom trawl surveys since the collapse of

Alewife in 2004 (Figure 2). Alewife has remained the third-most abundant species in bottom trawl catches despite the scarcity of YAO individuals. Results of the acoustic survey suggested that Bloater were the dominant prey fish species in the main basin while Rainbow Smelt were dominant in the North Channel and Georgian Bay (Figure 3). In the North Channel and Georgian Bay, non-smelt biomass was mainly comprised of Cisco and Bloater (Figure 3). All other prey fish species combined accounted for less than 1.5 % (by weight) of prey species sampled in both surveys.

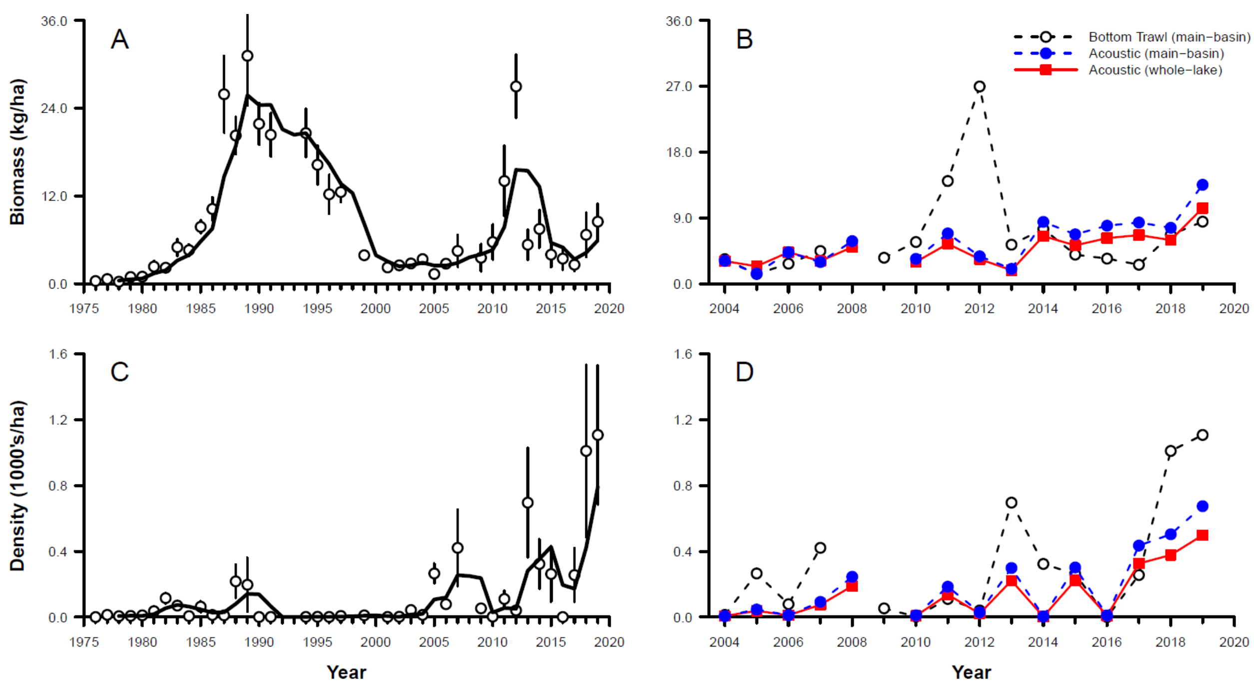


Figure 4. Bloater abundance in Lake Huron by age group (yearling-and-older, young-of-year), period (1976-2019, 2004-2019), and survey (bottom trawl, acoustic). A-B: Estimated biomass of yearling-and-older bloater from bottom trawls and acoustics during 1976-2019 (A) and 2004-2019 (B). C-D: Estimated density of young-of-year bloater from bottom trawls and acoustics during 1976-2019 (C) and 2004-2019 (D). Lines in panels A and C represent the 3-year running mean. Error bars in panels A and C represent ±1 standard error. Colored lines in panels B and D represent mean acoustic biomass (B) or density (D) for all three basins combined (red) and for the main basin only (blue).

Bloater—Bloater have been the most abundant prey fish in the main basin of Lake Huron over the past decade and accounted for 87% of prey fish biomass in bottom trawl catches during 2019. Biomass of YAO Bloater estimated from bottom trawls increased from historical lows in the late

1970s to peak levels from 1987-1994 (Figure 4A). Biomass declined rapidly from 1995 to 2001 and remained relatively low through the 2000s before peaking again in 2011-12. Both surveys indicate an increasing trend in YAO biomass from 2018 to 2019. Biomass of YAO Bloater estimated from the 2019 bottom trawl survey (8.5 kg/ha) was the highest observed since the 2012 peak, and the 2019 main-basin and lake-wide estimates from the acoustic survey were the highest observed in the time series (Figure 4B). Trends in YAO Bloater biomass since 2004 were poorly correlated between the bottom trawl and acoustics time series (Spearman Rank-sum test; $\rho = 0.31$, $P = 0.27$) mainly due to the spike in trawl biomass that occurred in 2012 that was not observed in the acoustics time series (Figure 4B). Bloater are a minor component of piscivore diets (Happel et al. 2017, Roseman et al. 2014), so predation is not likely driving variability in YAO abundance.

Densities of YOY Bloater in 2019 were the highest observed in both the bottom trawl and acoustic time series (Figures 4C, 4D). Large Bloater year classes (e.g., in 2007, 2013, and 2018) have occurred more frequently since the crash of Alewife in 2004, which is consistent with the hypothesized negative effect of Alewife on Bloater recruitment (Collingsworth et al. 2014). Time series of YOY Bloater abundance from the bottom trawl and acoustic surveys track each other closely (Spearman Rank-sum test; $\rho = 0.66$, $P = 0.01$) and suggest that YOY density has been increasing since 2016 (Figures 4C, 4D).

Bloater in 2019 were most abundant in the eastern half of the main basin and near St. Mary's River outflow (Figure 5). Size distribution of Bloater from midwater trawl catches in September 2019 was bi-modal with the peak at 60-79 mm total length representing YOY-sized individuals (Figure 5). Bottom trawl catches in October 2019 consisted mainly of individuals with total length between 80 and 150 mm (Figure 5).

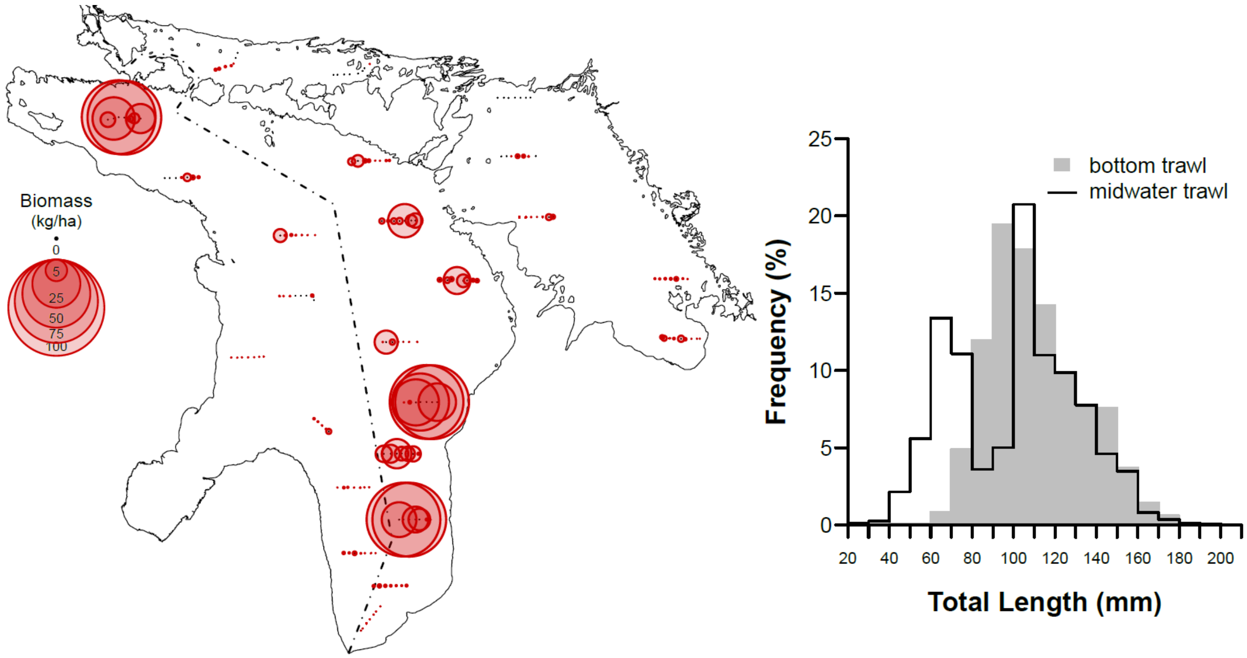


Figure 5. Bloater biomass distribution (left) and size structure (right) in Lake Huron in 2019. Biomass distribution was estimated from the acoustic survey and includes all age groups.

Rainbow Smelt—Rainbow Smelt have been important prey for Chinook salmon, Lake Trout, and Walleye since their introduction into Lake Huron (Diana 1990, Roseman et al. 2014), but current biomass of YAO Rainbow Smelt is low relative to historical levels (Figure 6A). Biomass of YAO smelt decreased steadily between 1990 and 2003 and has remained at all-time lows ever since (Figure 6A). Biomass since 2004 has fluctuated with no distinct trend at both the main-basin and lake-wide scales (Figure 6B). Main-basin biomass of YAO rainbow smelt was significantly correlated between surveys (Spearman Rank-sum test; $\rho = 0.77$, $P < 0.01$). Acoustic biomass for YAO Rainbow Smelt is higher at lake-wide than main-basin scales due to large concentrations of Rainbow Smelt in the North Channel and Georgian Bay. Declines in YAO Rainbow Smelt abundance in Lake Huron preceded the crash of adult Alewife in 2004, so predators switching from Alewife to Rainbow Smelt cannot entirely explain declines in YAO abundance.

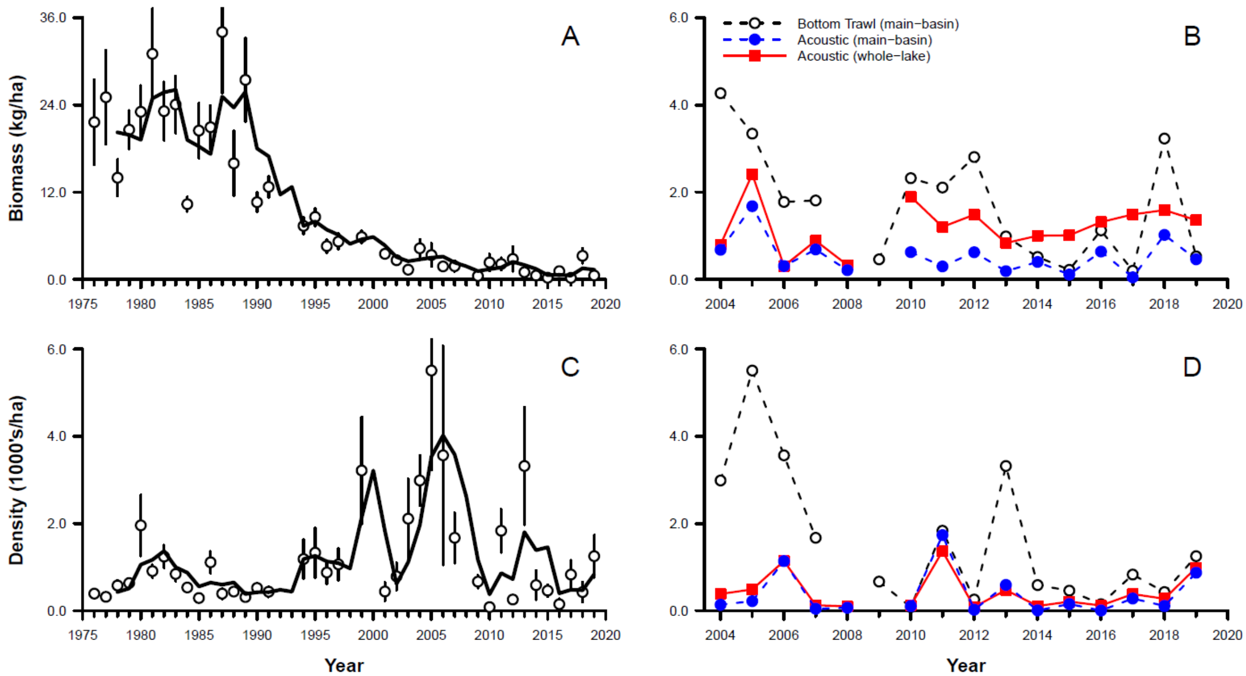
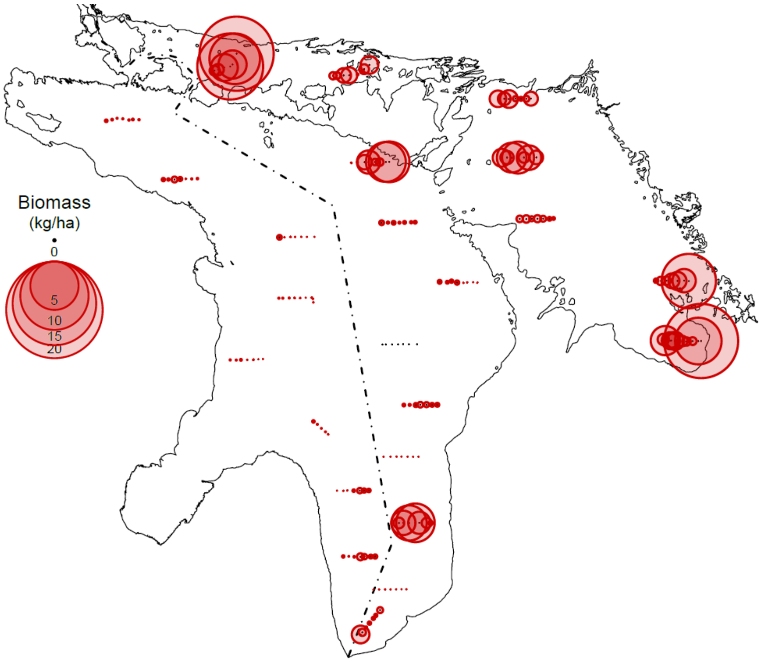


Figure 6. Rainbow Smelt abundance in Lake Huron by age group (yearling-and-older, young-of-year), period (1976-2019, 2004-2019), and survey (bottom trawl, acoustic). A-B: Estimated biomass of yearling-and-older Rainbow Smelt from bottom trawls and acoustics during 1976-2019 (A) and 2004-2019 (B). C-D: Estimated density of young-of-year Rainbow Smelt from bottom trawls and acoustics during 1976-2019 (C) and 2004-2019 (D). Lines in panels A and C represent the 3-year running mean. Error bars in panels A and C represent ±1 standard error. Colored lines in panels B and D represent mean acoustic biomass (B) or density (D) for all three basins combined (red) and for the main basin only (blue).

Abundance of YOY Rainbow Smelt has fluctuated with few distinct trends throughout the time series (Figures 6C, 6D). Large spikes in YOY density since 1999 may have been the result of declines in YAO Rainbow Smelt, which are known to cannibalize smaller individuals (Henderson and Nepszy 1989). However, these strong reproductive events did not kindle a recovery in the YAO population, which suggests the existence of a recruitment bottleneck. Estimated density of YOY Rainbow Smelt from bottom trawls and acoustics exhibited similar trends (Spearman Rank-sum test; r = 0.66, P = 0.01) and both indicated that abundance of YOY Rainbow Smelt increased from 2018 to 2019 (Figures 6C, 6D).



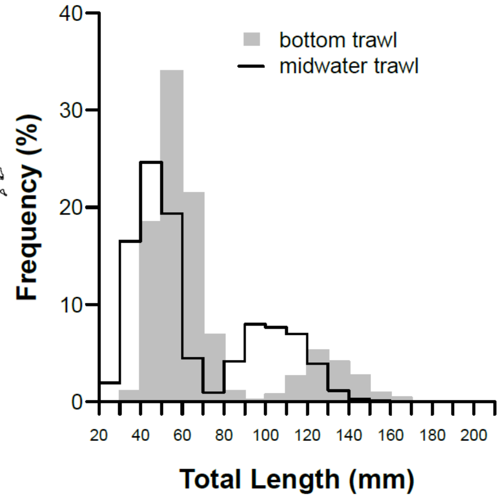


Figure 7. Rainbow Smelt biomass distribution (left) and size structure (right) in Lake Huron in 2019. Biomass distribution was estimated from the acoustic survey and includes all age groups.

Rainbow Smelt were widely distributed in Lake Huron in 2019 but were most abundant in Canadian waters (Figure 7). Rainbow Smelt were collected in all 48 bottom trawls and all but two midwater trawls in 2019 and were particularly abundant in the North Channel and Georgian Bay (Figure 7). Size distributions of Rainbow Smelt 2019 were bimodal with the peaks at 30-59 mm (midwater trawl) and 40-69 mm (bottom trawl) representing the 2019-year class (Figure 7). The shift towards larger Rainbow Smelt in the bottom trawl survey in 2019 suggests that juvenile Rainbow Smelt grew rapidly during the period between surveys (Figure 7).

Alewife—Alewife are the preferred prey of Lake Trout and salmon in Lake Huron (Diana 1990, Happel et al. 2017, Roseman et al. 2014) and were the first- or second-most abundant prey species in Lake Huron until 2004 when YAO individuals disappeared from trawl catches (Figures 8A, 8B). Alewife abundance in Lake Huron has been driven by sporadic catches of

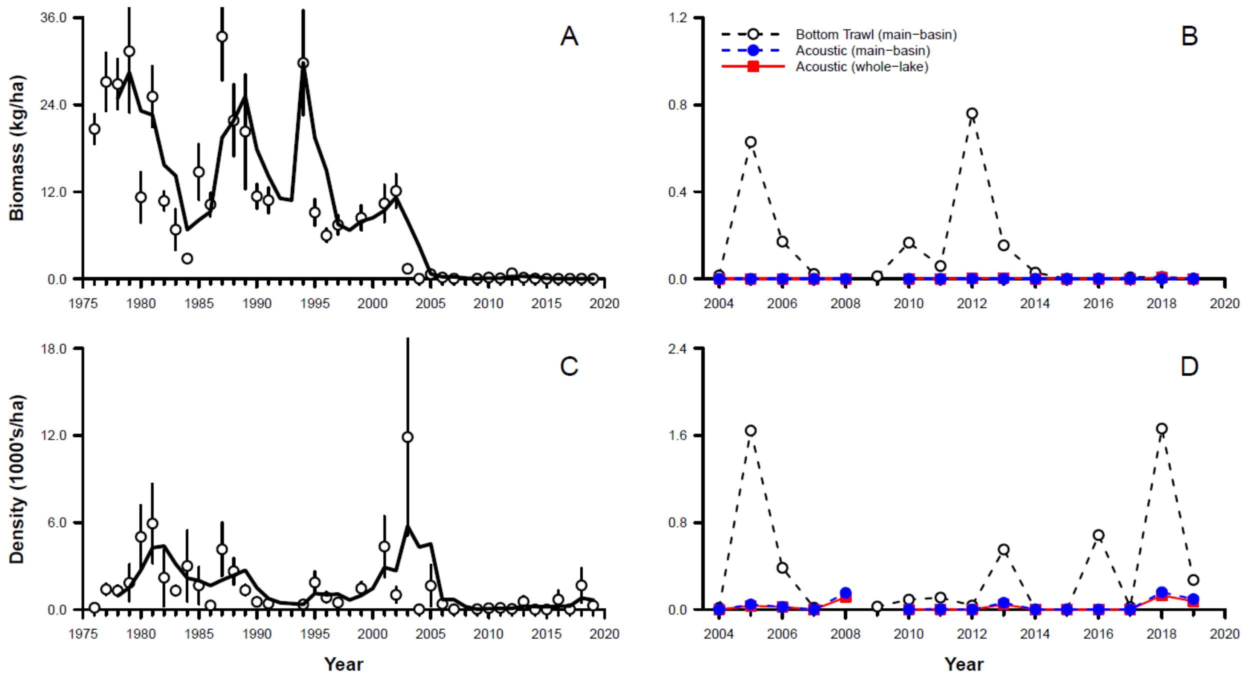


Figure 8. Alewife abundance in Lake Huron by age group (yearling-and-older, young-of-year), period (1976-2019, 2004-2019), and survey (bottom trawl, acoustic). A-B: Estimated biomass of yearling-and-older Alewife from bottom trawls and acoustics during 1976-2019 (A) and 2004-2019 (B). C-D: Estimated density of young-of-year Alewife from bottom trawls and acoustics during 1976-2019 (C) and 2004-2019 (D). Lines in panels A and C represent the 3-year running mean. Error bars in panels A and C represent ±1 standard error. Colored lines in panels B and D represent mean acoustic biomass (B) or density (D) for all three basins combined (red) and for the main basin only (blue).

young-of-year fish since the collapse of the adult population. Time series of YOY Alewife density from the two surveys have agreed since 2004 ($\rho = 0.72$, $P < 0.01$), and both suggested that YOY Alewife density in 2019 was lower than in 2018 (Figures 8C, 8D). All but one individual collected in 2019 surveys was age-0, which suggests that few individuals from the relatively large 2018 year-class survived to the end of 2019. The largest concentrations of YOY alewife occurred in the western main basin north of Saginaw Bay and offshore of the French River in Georgian Bay (Figure 9). Alewife sampled in bottom trawls in October were larger than conspecifics sampled in midwater trawls during September-October (Figure 9).

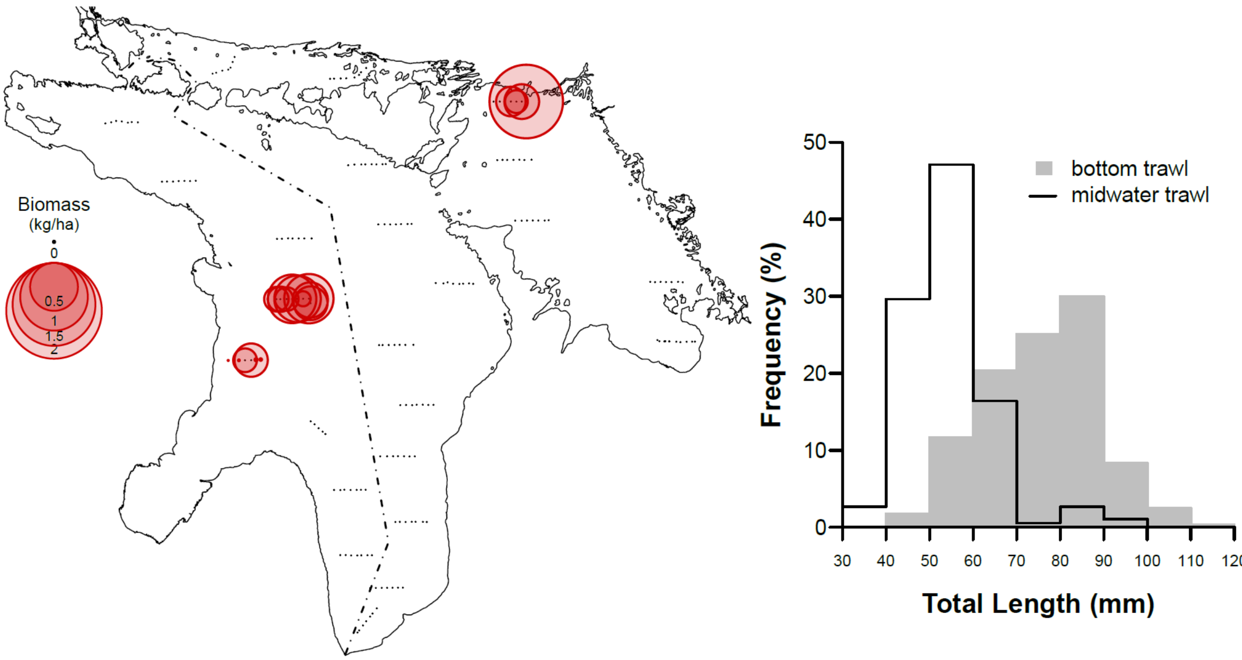


Figure 9. Alewife biomass distribution (left) and size structure (right) in Lake Huron in 2019. Biomass distribution was estimated from the acoustic survey and includes all age groups.

Causes of the Alewife decline in Lake Huron have been debated and include unsustainable levels of predation by salmon and Lake Trout (He et al. 2015), a severe winter mortality event in 2003 (Dunlop and Riley 2013), bottom-up forces related to nutrient reduction (Kao et al. 2016), mussel-induced disruption of inshore-offshore energy exchange (Barbiero et al. 2018), and declines in the abundance of the benthic amphipod *Diporeia* spp., an important Alewife prey (Nalepa et al. 2007). We hypothesize that the severe winter of 2002-03 reduced the adult Alewife population to historically low levels, but that recovery of the adult population presently is restricted both by bottom-up and top-down forces. Alewife abundance and population dynamics are more influenced by nutrients and primary production in Lake Huron than in Lake Michigan (Bunnell et al. 2014, Collingsworth et al. 2014), so we concur with Kao et al. (2016) that reductions in phosphorous inputs to Lake Huron and the sequestration of nutrients in mussel biomass has likely reduced Alewife carrying capacity below historical levels. Predation by a recovering lake trout population may keep alewife biomass below current carrying capacity if they and other predators are able to use alternate prey (e.g., Round Goby) when Alewife are unavailable (He et al. 2015, Madenjian et al. 2013).

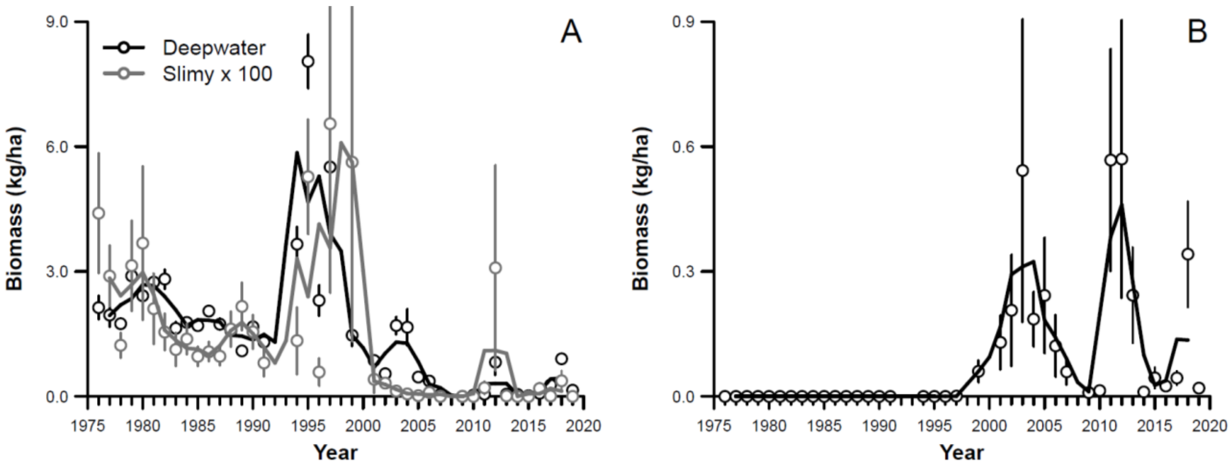


Figure 10. Estimated biomass of sculpins (A) and Round Goby (B) from bottom trawls during 1976-2019. Lines represent the 3-year running mean. Error bars represent ±1 standard error. Slimy Sculpin abundance was multiplied by 100 to facilitate comparison of abundance trends between sculpin species.

Sculpin——Historically, Slimy and Deepwater Sculpin were important prey of the native piscivore community in offshore waters of Lake Huron (Van Oosten and Deason 1938). Juvenile and adult sculpins are confined to the lake bottom, so they are sampled only during the bottom trawl survey. Sculpin populations in Lake Huron declined gradually between 1976 and 1992, experienced a brief resurgence in the middle to late 1990s, and then declined rapidly in the early to mid 2000s (Figure 10A). Slimy Sculpin have become rare over the past decade (2010-2019), with surveys failing to collect a single individual in 2010, 2014, 2015, and 2019. The current low abundance of sculpin in Lake Huron coincides with the expansion and proliferation of a potential competitor, Round Goby, as well as the decline of an important prey, *Diporeia* spp.

Round Goby—Round Goby have become a significant part of Lake Trout diets in some areas of the Great Lakes (Dietrich et al. 2006), including Lake Huron (Roseman et al. 2014). Round Goby were first captured in the Lake Huron bottom trawl survey in 1997, reached a peak in abundance in 2003, and declined in abundance until increasing again in 2011-2012 and 2018 (Figure 10B). Our results suggest that they were at relatively low abundance in the offshore waters of Lake Huron in 2019 (Figure 10B). However, the bottom trawl may not provide a

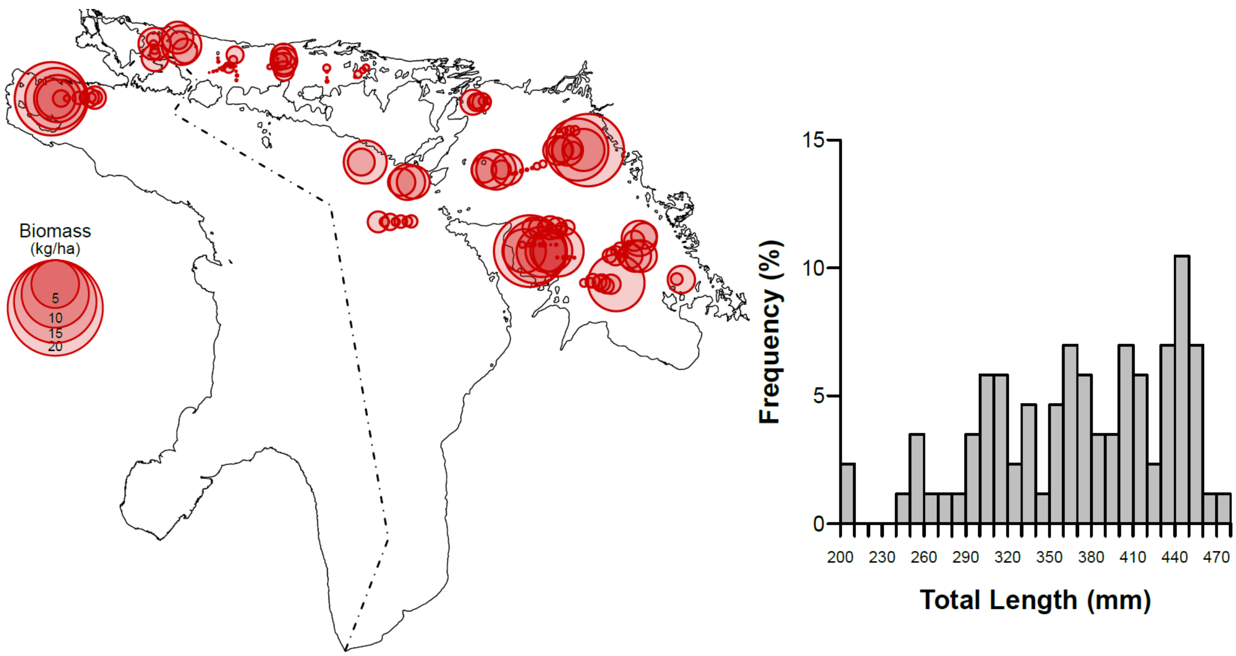


Figure 11. Cisco biomass distribution (left) and size structure (right) in Lake Huron during 2007-2019. Biomass distribution was determined from the acoustic survey and includes all age-length classes. Only non-zero densities are shown.

robust estimate of Round Goby abundance because gobies are thought to be concentrated in nearshore (depth < 9 -m) and/or rocky (i.e., untrawlable) habitat(s) not sampled in GLSC bottom trawl surveys. Goby also 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.

Cisco—Cisco is a native planktivore that was once common in offshore areas throughout Lake Huron. They were overfished to historically low abundance, and most spawning populations in the main basin were extirpated by the early 1900s (Berst and Spangler 1972). Cisco exhibit diel, vertical feeding migrations and during the fall-early winter move into shallow water to spawn (Hrabik et al. 2006, Stockwell et al. 2009), so their movements were important to the transfer of energy and nutrients between benthic and pelagic habitats and between nearshore and offshore areas. Cisco are only sampled in the acoustics survey and have only been collected in the North Channel, Georgian Bay, and adjacent waters of the main basin since 2007 (Figure 11). Catches of Cisco in midwater trawls consisted mainly of large, adult-sized fish with total length > 300 mm (Figure 11). Cisco numbers in Georgian Bay and the North Channel have increased since 2015 (Figure 12), which suggests current lake conditions may favor Cisco recovery.

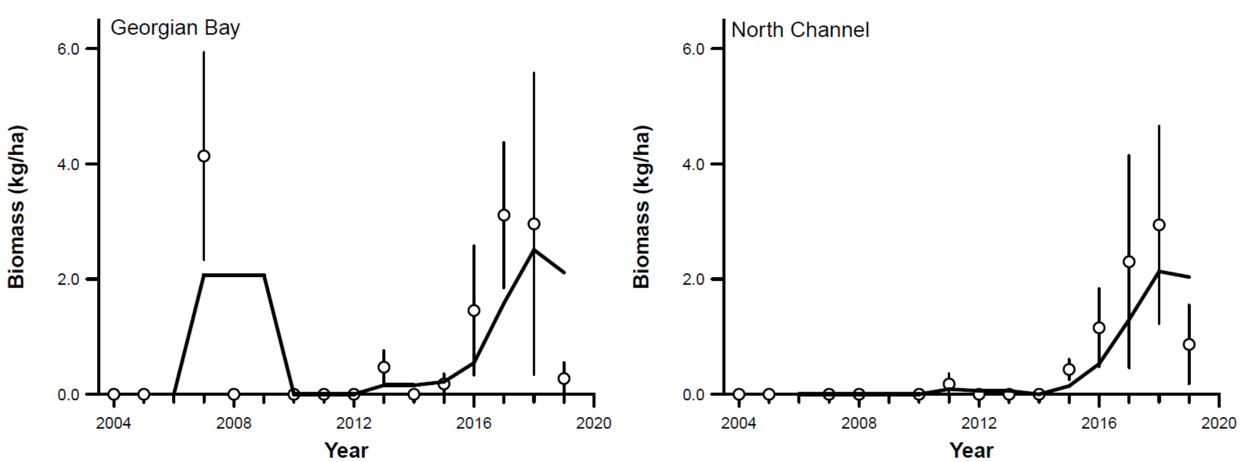


Figure 12. Estimated biomass of Cisco from acoustic surveys in Georgian Bay (left) and the North Channel (right), Lake Huron, during 2004-2019. Lines represent 3-year running means. Error bars represent ±1 standard error.

Minor species—Gizzard Shad, Threespine Stickleback, Ninespine Stickleback, Trout-perch, Emerald Shiner, and Yellow Perch were the only other prey fish species sampled in bottom trawl and acoustic surveys in Lake Huron in 2019. Collectively, these species comprised than 0.3 % of prey fish community biomass in 2019 (Table 2). Ninespine Stickleback and Yellow Perch were the most abundant minor species in bottom trawls, while Emerald Shiner was the most abundant minor species sampled in the acoustic survey (Table 3).

Table 2. Biomass (kg/ha) of minor prey fish species sampled in bottom trawl and acoustic surveys in 2019.

		Survey	
Common Name	**Scientific Name**	**Bottom Trawl**[1]	**Acoustic**[2]
Gizzard Shad	*Dorosoma cepedianum*	0.01 ± 0.01	NS[3]
Threespine Stickleback	*Gasterosteus aculeatus*	< 0.01	0.01 ± 0.01
Ninespine Stickleback	*Pungitius pungitius*	0.01 ± 0.01	< 0.01
Trout-perch	*Percopsis omiscomaycus*	< 0.01	NS
Emerald Shiner	*Notropis atherinoides*	NS	0.01 ± 0.01
Yellow Perch	*Perca flavescens*	0.02 ± 0.01	NS

[1]main basin average

[2]whole-lake average

[3]not sampled in survey

Table 3. Density (number/ha) of minor prey fish species sampled in bottom trawl and acoustic surveys in 2019.

		Survey	
Common Name	**Scientific Name**	**Bottom Trawl**[1]	**Acoustic**[2]
Gizzard Shad	*Dorosoma cepedianum*	1.0 ± 0.9	NS[3]
Threespine Stickleback	*Gasterosteus aculeatus*	0.2 ± 0.2	5.0 ± 18.0
Ninespine Stickleback	*Pungitius pungitius*	5.1 ± 3.4	0.1 ± 0.1
Trout-perch	*Percopsis omiscomaycus*	0.1 ± 0.1	NS
Emerald Shiner	*Notropis atherinoides*	NS	64.2 ± 2448.0
Yellow Perch	*Perca flavescens*	6.8 ± 5.7	NS

[1]main basin average

[2]whole-lake average

[3]not sampled in survey

Summary and Conclusions

1. Prey fish biomass in the main basin of Lake Huron remains low relative to levels observed prior to 1995. Return to historical levels of prey fish biomass in offshore waters is unlikely due to reduced nutrient inputs, high predation levels by recovering piscivore populations (e.g., Lake Trout, Walleye), and changes in food web dynamics that potentially favor nearshore benthic species such as Round Goby.

2. Persistent low abundance of Alewife and Rainbow Smelt in the main basin of Lake Huron means an uncertain future for recreational fisheries focused on Pacific Salmon, but is consistent with fish community objectives focused on restoration of native fish communities (Dettmers et al. 2012). Current efforts to reestablish Cisco into the main basin also may benefit from low abundance of YAO Alewife and Rainbow Smelt.

3. Offshore prey fish communities in Lake Huron, particularly in the main basin, are characterized by extremely low species diversity. At present, a single species, Bloater, accounts for ~90% of prey fish biomass in the main basin. Theory suggests that community resiliency is positively related to species diversity (Mellin et al. 2014), so offshore prey fish abundance and species composition in Lake Huron could change quickly in response to climate change and other ecosystem-scale disturbances.

4. Trends in main-basin abundance of major species were similar between surveys, so inferences about prey fish population dynamics in areas sampled by both surveys are robust to the use of different sampling gears and survey designs. However, use of complementary surveys (bottom trawl, acoustics) remains important for characterizing change in offshore prey fish communities in Lake Huron. This is particularly true for species that show strong spatial gradients in abundance (e.g., Rainbow Smelt and Cisco).

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Literature Cited

Adams, J. 2008. EchoNet2Fish: Estimate fish abundance from acoustic echoes and net catch. R package 0.3.1.9000. Available from https://github.com/JVAdams/EchoNet2Fish.

Adams, J.V., Argyle, R.L., Fleischer, G.W., Curtis, G.L., and Stickel, R.G. 2006. Improving the design of acoustic and midwater trawl surveys through stratification, with an application to Lake Michigan prey fishes. N. Amer. J. Fish. Mgmt. **26**(3): 612-621.

Adams, J.V., Riley, S.C., and Adlerstein, S.A. 2009. Development of fishing power corrections for 12-m yankee and 21-m wing bottom trawls used in Lake Huron Great Lakes Fishery Commission Technical Report 68

Barbiero, R.P., Balcer, M., Rockwell, D.C., and Tuchman, M.L. 2009. Recent shifts in the crustacean zooplankton community of Lake Huron. Can. J. Fish. Sci. **66**(5): 816-828.

Barbiero, R.P., Lesht, B.M., Warren, G.J., Rudstam, L.G., Watkins, J.M., Reavie, E.D., Kovalenko, K.E., and Karatayev, A.Y. 2018. A Comparative Examination of Recent Changes in Nutrients and Lower Food Web Structure in Lake Michigan and Lake Huron. J Great Lakes Res **44**(4): 573-589.

Bence, J.R., and He, J.X. 2015. Update to the Brenden et al. (2012) Statistical Catch-at-age Assessment for Chinook salmon in the Main Basin of Lake Huron QFC Technical Report T2015-01 Michigan State University Quantitative Fisheries Center.

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.

Burlakova, L.E., Barbiero, R.P., Karatayev, A.Y., Daniel, S.E., Hinchey, E.K., and Warren, G.J. 2018. The benthic community of the Laurentian Great Lakes: Analysis of spatial gradients and temporal trends from 1998 to 2014. J. Great Lakes Res. **44**(4): 600-617.

Collingsworth, P.D., Bunnell, D.B., Madenjian, C.P., and Riley, S.C. 2014. Comparative Recruitment Dynamics of Alewife and Bloater in Lakes Michigan and Huron. Trans. Am. Fish. Soc. **143**(1): 294-309.

Crowder, L.B. 1980. Alewife, rainbow smelt and native fishes in Lake Michigan: competition or predation? Env. Biol. Fish. **5**(3): 225-233.

Dettmers, J.M., Goddard, C.I., and Smith, K.D. 2012. Management of Alewife using Pacific salmon in the Great Lakes: Whether to manage for economics or the ecosystem? Fisheries **37**(11): 495-501.

Diana, J.S. 1990. Food habits of angler-caught salmonines in western Lake Huron. J. Great Lakes Res. **16**(2): 271-278.

Dietrich, J.P., Morrison, B.J., and Hoyle, J.A. 2006. Alternative ecological pathways in the eastern Lake Ontario food web: Round goby in the diet of lake trout. J. Great Lakes Res. **32**: 395-400.

Dryer, W.R. 1966. Bathymetric distribution of fish in the Apostle Islands region, Lake Superior. Trans. Am. Fish. Soc. **95**(3): 248-259.

Dunlop, E.S., and Riley, S.C. 2013. The contribution of cold winter temperatures to the 2003 alewife population collapse in Lake Huron. J. Great Lakes Res. **39**(4): 682-689.

Eshenroder, R.L., Robert Payne, N., Johnson, J.E., Bowen, C., and Ebener, M.P. 1995. Lake Trout Rehabilitation in Lake Huron. J. Great Lakes Res. **21**: 108-127.

Evans, D.O., and Loftus, D.H. 1987. Colonization of inland lakes in the Great Lakes region by rainbow smelt, *Osmerus mordax*: Their freshwater niche and effects on indigenous fishes. Can. J. Fish. Sci. **44**(S2): s249-s266.

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.

Fielder, D.G., Schaeffer, J.S., and Thomas, M.V. 2007. Environmental and ecological conditions surrounding the production of large year classes of Walleye (*Sander vitreus*) in Saginaw Bay, Lake Huron. J. Great Lakes Res. **33**: 118-132.

Happel, A., Jonas, J.L., McKenna, P.R., Rinchard, J., He, J.X., and Czesny, S.J. 2017. Spatial variability of lake trout diets in Lakes Huron and Michigan revealed by stomach content and fatty acid profiles. Can. J. Fish. Sci. **75**(1): 95-105.

He, J.X., Bence, J.R., Madenjian, C.P., Pothoven, S.A., Dobiesz, N.E., Fielder, D.G., Johnson, J.E., Ebener, M.P., Cottrill, R.A., Mohr, L.C., and Koproski, S.R. 2015. Coupling age-structured stock assessment and fish bioenergetics models: a system of time-varying models for quantifying piscivory patterns during the rapid trophic shift in the main basin of Lake Huron. Can. J. Fish. Sci. **72**(1): 7-23.

Henderson, B.A., and Nepszy, S.J. 1989. Factors affecting recruitment and mortality rates of Rainbow Smelt (*Osmerus mordax*) in Lake Erie, 1963–85. J. Great Lakes Res. **15**(2): 357-366.

Hrabik, T.R., Jensen, O.P., Martell, S.J.D., Walters, C.J., and Kitchell, J.F. 2006. Diel vertical migration in the Lake Superior pelagic community. I.Changes in vertical migration of coregonids in response to varying predation risk. Can. J. Fish. Sci. **63**(10): 2286-2295.

Johnson, J.E., DeWitt, S.P., and Gonder, D.J.A. 2010. Mass-Marking Reveals Emerging Self Regulation of the Chinook Salmon Population in Lake Huron. N. Amer. J. Fish. Mgmt. **30**(2): 518-529.

Kao, Y.-C., Adlerstein, S.A., and Rutherford, E.S. 2016. Assessment of Top-Down and Bottom-Up Controls on the Collapse of Alewives (Alosa pseudoharengus) in Lake Huron. Ecosystems **19**(5): 803-831.

Madenjian, C.P., O'Gorman, R., Bunnell, D.B., Argyle, R.L., Roseman, E.F., Warner, D.M., Stockwell, J.D., and Stapanian, M.A. 2008. Adverse effects of alewives on Laurentian Great Lakes fish communities. N. Amer. J. Fish. Mgmt. **28**(1): 263-282.

Madenjian, C.P., Rutherford, E.S., Stow, C.A., Roseman, E.F., and He, J.X. 2013. Trophic shift, not collapse. Environ Sci Technol **47**(21): 11915-11916.

McNickle, G.G., Rennie, M.D., and Gary Sprules, W. 2006. Changes in benthic invertebrate communities of South Bay, Lake Huron following invasion by Zebra Mussels (*Dreissena polymorpha*), and potential effects on Lake Whitefish (*Coregonus clupeaformis*) diet and growth. J. Great Lakes Res. **32**(1): 180-193.

Mellin, C., Bradshaw, C.J., Fordham, D.A., and Caley, M.J. 2014. Strong but opposing beta-diversity-stability relationships in coral reef fish communities. Proc Biol Sci **281**(1777): 20131993.

Nalepa, T.F., Fanslow, D.L., and Messick, G. 2005. Characteristics and potential causes of declining Diporeia spp. populations in southern Lake Michigan and Saginaw Bay, Lake Huron. Proceedings of a workshop on the dynamics of Lake Whitefish (*Coregonus clupeaformis*) and the amphipod *Diporeia* spp. in the Great lakes 66. Great Lakes Fishery Commission.

Nalepa, T.F., Fanslow, D.L., Pothoven, S.A., Foley, A.J., and Lang, G.A. 2007. Long-term Trends in Benthic Macroinvertebrate Populations in Lake Huron over the Past Four Decades. J. Great Lakes Res. **33**(2): 421-436.

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., He, J.X., Johnson, J.E., O'Brien, T.P., and Schaeffer, J.S. 2007. Evidence of Widespread Natural Reproduction by Lake Trout Salvelinus namaycush in the Michigan Waters of Lake Huron. J. Great Lakes Res. **33**(4): 917-921.

Roseman, E.F., Schaeffer, J.S., Bright, E., and Fielder, D.G. 2014. Angler-caught piscivore diets reflect fish community changes in Lake Huron. Trans. Am. Fish. Soc. **143**(6): 1419-1433.

Smith, S.H. 1970. Species Interactions of the Alewife in the Great Lakes. Trans. Am. Fish. Soc. **99**(4): 754-765.

Stockwell, J.D., Ebener, M.P., Black, J.A., Gorman, O.T., Hrabik, T.R., Kinnunen, R.E., Mattes, W.P., Oyadomari, J.K., Schram, S.T., Schreiner, D.R., Seider, M.J., Sitar, S.P., and Yule, D.L. 2009. A synthesis of cisco recovery in Lake Superior: implications for native fish rehabilitation in the Laurentian Great Lakes. N. Amer. J. Fish. Mgmt. **29**(3): 626-652.

Stockwell, J.D., Yule, D.L., Gorman, O.T., Isaac, E.J., and Moore, S.A. 2006. Evaluation of bottom trawls as compared to acoustics to assess adult lake herring (*Coregonus artedi*) abundance in Lake Superior. J. Great Lakes Res. **32**(2): 280-292.

Van Oosten, J., and Deason, H.J.T.f.o.t.l.t.C.n.a.o.t.l.L.m.o.L.M.T.A.F.S. 1938. The food of the lake trout (*Cristovomer namaycush*) and of the lawyer (*Lota maculosa*) of Lake Michigan. Trans. Am. Fish. Soc. **67**: 155-177.

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.

Warner, D.M., Schaeffer, J.S., and O'Brien, T.P. 2009. The Lake Huron pelagic fish community: persistent spatial pattern along biomass and species composition gradients. Can. J. Fish. Sci. **66**(8): 1199-1215.

Wells, L. 1968. Seasonal depth distribution of fish in southeastern Lake Michigan. Fishery Bulletin **67**(1): 1-15.

Yule, D.L., Adams, J.V., Hrabik, T.R., Vinson, M.R., Woiak, Z., and Ahrenstorff, T.D. 2013. Use of classification trees to apportion single echo detections to species: Application to the pelagic fish community of Lake Superior. Fisheries Research **140**: 123-132.

Yule, D.L., Adams, J.V., Stockwell, J.D., and Gorman, O.T. 2008. Factors affecting bottom trawl catches: Implications for monitoring the fishes of Lake Superior. N. Amer. J. Fish. Mgmt. **28**(1): 109-122.

Appendix

Bottom trawl survey design and methods

The GLSC has monitored fish abundance annually from 1973-2018 using 12-m headrope (1973-1991) and 21-m headrope (1992-2019) bottom trawls (4.76 mm square mesh cod end) at fixed transects at up to eleven depths (9, 18, 27, 36, 46, 55, 64, 73, 82, 92, and 110 m) at five ports (Detour, Hammond Bay, Alpena, Au Sable Point, and Harbor Beach) in the Michigan waters of Lake Huron. These transects were sampled by the USGS R/V *Kaho* during 1973-1977, the USGS R/V *Grayling* during 1978-2014, and the USGS R/V *Arcticus* in 2015-2019; in addition, some transects were fished from the USGS R/V *Cisco* in 1990. Sampling began at Goderich (Ontario) in 1998 using the same trawling protocols used at U.S. ports.

A single 10-min bottom trawl tow was conducted during daylight at each transect each year. Tow duration was occasionally less than 10 min due to large catches or obstacles in the tow path; catches for these tows were corrected to be equivalent to 10-min tows (see below). Occasionally, presence of trap nets over trawl stations necessitated skipping entire transects, but these instances have been infrequent, and every effort is made to tow part of, or adjacent to, the transect. Trawl catches were sorted by species and each species was counted and weighed in aggregate. Large catches (> ca. 20 kg) were subsampled; a random sample was sorted, counted, and weighed, and the remainder of the catch was weighed for extrapolation of the sample.

actual time on bottom for each trawl increased with depth (Fabrizio et al. 1997), so trawl catch rates were adjusted for trawl fishing time according to the following equation:

$$C_t = \frac{10N}{K_t T},$$

where C_t is the catch per 10 min (CPE) on bottom for trawl type t, N is the catch, T is tow time, and K_t is a correction factor that varies with fishing depth (D in m) and trawl type such that K_{12} =

0.00400D + 0.8861 for the 12-m trawl and K_{21} = 0.00385D + 0.9149 for the 21-m trawl. Catches were expressed in terms of density or biomass (number/ha and kg/ha) by dividing the CPE by the area swept by the trawl. The area swept was estimated as the product of the distance towed (speed multiplied by tow time) and the trawl width. Trawl width estimates were depth-specific and were based on trawl mensuration data collected from the R/V *Grayling* in 1991, 1998, and 2005. Catches of Alewife, Rainbow Smelt, and Bloater were partitioned into length-based age classes for analysis. Year-specific length cutoffs were determined from length-frequency data and then used to apportion the catches into age-0 fish (young-of-the-year, or YOY) and those age-1 or older (yearling and older, or YAO). Lastly, fish catches were weighted by the area of the main basin of Lake Huron that occurred in each depth range.

To make density estimates from the 12-m headrope (1973-1991) and 21-m headrope (1992-2019) trawls comparable, we multiplied density estimates from the 12-m trawl (1976-1991) by species-specific fishing power corrections (FPCs) developed from a comparative trawl experiment (Adams et al. 2009). We applied FPCs greater than 1.0 to the density and biomass of Alewife, Rainbow Smelt (YAO only), Bloater, and FPCs less than 1.0 to the density and biomass of Deepwater Sculpin. Catches of Trout-perch were not significantly different between the two trawls. Insufficient data were available to estimate FPCs for Ninespine Stickleback and YOY Rainbow Smelt, so density estimates were not corrected for these species.

Trawl surveys on Lake Huron are typically conducted between early October and mid-November. In 1992 and 1993, however, trawl surveys occurred in early- to mid-September, and these data were not used in this report because the distribution of many offshore species in the Great Lakes is seasonally variable (Dryer 1966, Wells 1968) and data collected in September may not be comparable to the rest of the time series. In 1998, sampling was conducted in a non-standard manner, and these data were also excluded. The fall survey was not conducted in 2000 and was not completed in 2008. We did not use data prior to 1976 because all ports and depths in Lake Huron were not consistently sampled until 1976.

Acoustic-midwater trawl survey design and methods—The pelagic prey fish survey in Lake Huron is based on a stratified-random design with acoustic transects in five geographic strata: main-basin east, main-basin west, main-basin south, Georgian Bay, and the North Channel. Within each stratum, the first transect is selected randomly each year based on latitude and longitude; subsequent transects are spaced equidistant from the first within the constraints of the stratum boundary. Effort (transects per stratum) is reallocated each year based on stratum area and variability of total biomass in each stratum from previous surveys (Adams et al. 2006). For the purposes of this report, acoustic strata are hereafter referred to as "regions." For analyses, each transect was divided into 3,000 m horizontal units and 10 m depth layers. These divisions comprise the elementary sampling units (ESUs) within which fish density is summarized along transects.

During 2004-2005 and 2007-2008 acoustic data were collected during September through early October with a BioSonics split-beam 120 kHz echosounder deployed from the Research Vessel (R/V) *Sturgeon*. During 2006, acoustic data were collected during August with a 70 kHz echosounder and a transducer deployed via towfish from the R/V *Grayling*. During 2009, the survey was performed with a 38 kHz echosounder because the 120 kHz transducer failed field calibration tests. Because the 38 kHz echosounder results in higher fish density estimates than the 120 kHz, we chose to exclude 2009 data from this report until appropriate corrections can be applied to the 38 kHz data from that survey. In 2010-2019, we used both a 38 and 120 kHz echosounder to facilitate frequency comparisons, but only 120 kHz data are presented in this report. During 2011-2012 and 2014-2019, the survey was carried out jointly between USGS-GLSC and the United States Fish and Wildlife Service (USFWS) to increase spatial coverage. USFWS used 70 kHz and 120 kHz split-beam echosounders (Simrad EK60) to sample transects located in the MW region. In all years, sampling was initiated one hour after sunset and ended no later than one hour before sunrise. A threshold equivalent to uncompensated target strength (TS) of - 66 decibels (dB) was applied to S_v data.

Fish were collected using a 16.5-m headrope mid-water trawl with 76, 38, 25, and 6.35 mm stretch meshes (USGS) and a 19.8-m headrope mid-water trawl with 200, 150, 100, 75, 50, and 38 mm stretch mesh with a cod-end liner having 3.175 mm stretch mesh (USFWS). Mid-water trawl locations and depths were chosen to target fish aggregations. Multiple tows per transect were conducted when fish were present at multiple depths so that trawl data within a region were available from each scattering layer formed by fish. At a minimum, a single mid-water trawl was conducted on each transect except in rare instances when very few fish targets were detected. Trawl fishing depth was monitored using Netmind™ (2004-2015) and Marport M3 (2016-2019) systems (USGS) and a Simrad PI44 catch monitoring system (USFWS). In 2019, mid-water trawling depths ranged from 2 to 72 m (mean = 26 m, mode = 17 m). Most mid-water trawl tows were of 20-minute duration, with tow times extended up to 25 or 30 minutes when few fish were present. All fishes captured in the mid-water trawl tows were identified, counted, and weighed in aggregate by species. Total length in millimeters was measured on a random subsample (100-200 fish) per species per tow. Individual fishes were assigned to two size categories based on the following length cutoffs: alewife =100 mm; rainbow smelt *Osmerus mordax* = 90 mm; bloater *Coregonus hoyi* = 100 mm, and cisco *Coregonus artedi* = 200 mm.

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

Acoustic estimates of fish density presented in this report from 2004-2019 were derived using the NearD method (Yule et al. 2013). Previous analyses of the acoustic and mid-water trawl data from USGS surveys of Lake Huron have relied on the Hierarchical Averaging Method (Warner et al. 2009). Both methods rely on the composition of midwater trawl catch (for acoustic data < 50 m below the surface) or target strength (for acoustic data ≥ 50 m below the surface) to apportion density to species. However, one notable difference between hierarchical averaging and NearD is that only trawls from the same geographic stratum can be used for a given acoustic sample with NearD. This approach more accurately reflects spatial patterns in fish density and biomass for evaluation of long-term trends in the fish community. Numeric fish density estimates and biomass density were generated using the *estimateLake()* function in the EchoNet2Fish R package (Adams 2008). This function calculates numeric fish density estimates and apportions them to user-defined fish groups using catch data.