Status and Trends of Pelagic and Benthic Prey Fish Populations in Lake Michigan, 2020[1,2]

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As was the case for all Great Lakes fisheries management and research agencies, the impacts of the COVID-19 pandemic on the Center's deepwater science work were significant. The most severe impacts were related to deepwater science cruises scheduled in the spring/early summer, and those requiring extended overnight stays on vessels. In addition, U.S. Geological Survey vessels could not get clearance to cross into Canadian waters as a result of the pandemic, reducing the scope of data normally collected by cruises that were able to get underway. Because of these limitations, reporting for 2020 deepwater science surveys will be limited in scope, and in some cases, limited in the ability to make meaningful comparisons to data from previous years. All USGS personnel involved in deepwater science cruises are looking forward to the return of a more normal sampling schedule in 2021, pandemic conditions permitting.

[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 2020 and make those publicly available. Please direct questions to our Information Technology Specialist, Scott Nelson, at snelson@usgs.gov.

[2] All GLSC sampling and handling of fish during research are carried out in accordance with guidelines for the care and use of fishes by the American Fisheries Society (http://fisheries.org/docs/wp/Guidelines-for-Use-of-Fishes.pdf).

Abstract

Lakewide acoustic (AC) and bottom trawl (BT) surveys are conducted annually to generate indices of pelagic and benthic prey fish densities in Lake Michigan. The BT survey had been conducted each fall from 1973 through 2019 using 12-m trawls at depths ranging from 9 to 110 m and included 70 fixed locations distributed across seven transects. This survey estimates densities of seven prey fish species (i.e., alewife, bloater, rainbow smelt, deepwater sculpin, slimy sculpin, round goby, ninespine stickleback), as well as age-0 yellow perch and large burbot. The AC survey, which serves to estimate densities of three prey fish species (i.e., alewife, bloater, and rainbow smelt), had been conducted each late summer/early fall from 2004-2019. The data generated from these surveys are used to estimate various population parameters that are, in turn, used by state and tribal agencies in managing Lake Michigan fish stocks.

The 2020 COVID-19 pandemic severely limited the Lake Michigan pelagic and benthic prey fish surveys. While the AC survey was not conducted, 32 tows across three of seven standard BT transects (Saugatuck, Waukegan and Port Washington) were completed during an abbreviated survey. Total prey fish biomass density from the abbreviated BT survey was 1.91 kg/ha, continuing a recent trend of historically low estimates below the long-term (i.e., 1973-2020) average of 34.94 kg/ha. Mean biomass of yearling and older (YAO) alewife in 2020 was 0.025 ± 0.017 kg/ha, tied for the lowest ever recorded on the BT survey. No age-0 alewife were captured in the bottom trawl and of the limited number (n=16) of alewife collected, none were older than age four. Bloater (1.39 kg/ha) and deepwater sculpin (0.47 kg/ha) accounted for the greatest proportion of biomass in the BT survey, while biomass density of slimy sculpin, round goby and rainbow smelt were all ≤ 0.01 kg/ha. While caution must be taken when interpreting the results of the abbreviated BT survey, the estimates suggest that prey fish densities remain well below historical values.

Introduction

An annual evaluation of prey fish dynamics is critical for understanding changes to the Lake Michigan food web (e.g., Madenjian et al. 2002, 2015), including continued restructuring due to exotic species, nutrient inputs, climate, and management levers including fishing mortality and fish stocking. Nonindigenous alewife (*Alosa pseudoharengus*) are a key prey fish in the Lake Michigan food web because they serve as the primary prey for Lake Michigan salmonines (Elliott 1993; Warner et al. 2008; Jacobs et al. 2013). Alewife also help structure the food web because they are predators of certain native larval fish like lake trout (*Salvelinus namaycush*) and emerald shiner (*Notropis atherinoides*), which in turn contributes to recruitment bottlenecks (Madenjian et al. 2008). Bloater (*Coregonus hoyi*, commonly known as "chub") is a native coregonine prey fish that dominated the community biomass in the 1980s and 1990s. Nonindigenous rainbow smelt (*Osmerus mordax*) is another abundant planktivorous prey fish, introduced into Lake Michigan in the early 20th century. Alewife, bloater, and rainbow smelt supported commercial fisheries in the 1980s, but these fisheries have either been closed or now have limited participation owing to low fish densities in recent decades. Key native benthic species include deepwater and slimy sculpin (*Myoxocephalus thompsonii* and *Cottus cognatus*, respectively). Since 2004, nonindigenous benthic round goby (*Neogobius melanostomus*) has become abundant in Lake Michigan and another key player in the food web given their importance as prey for lake trout, brown trout (*Salmo trutta*), and smallmouth bass (*Micropterus dolomieu*), but also for their ability to consume nonindigenous dreissenid mussels and "return" that energy back into the food web. At the same time, round goby have the potential to negatively affect native fishes by consuming their eggs (e.g., Chotkowski and Marsden 1999; Steinhart et al. 2004).

Invasive dreissenid mussels in the Great Lakes basin include zebra mussels (*Dreissena polymorpha*) and quagga mussels (*Dreissena rostriformis bugensis*), both introduced to the basin in the late 1980s. Both species are believed to have been introduced via ballast water from foreign ships (Ricciardi and MacIsaac 2000). In the years following the discovery, dreissenid mussels quickly expanded throughout the Great Lakes, with quagga mussels now dominating in Lake Michigan (Nalepa et al. 2020). After a rapid expansion into deeper Lake Michigan waters that began in 2004, quagga mussels have been linked with extensive, multi-seasonal, changes to the food web (Nalepa et al. 2009; Vanderploeg et al. 2010; 2012; Rowe et al. 2015). Large colonies of quagga mussels reduce phytoplankton density in the water column via their filter-feeding. Understanding the effects of dreissenid mussels on higher trophic levels is an area of active research and several summaries for Lake Michigan exist (see Madenjian et al. 2015; Bunnell et al. 2018).

Lakewide monitoring of prey fish began in 1973 with a bottom trawl (BT) survey that samples the bottom ~1.5 m of water over soft or sandy substrates during the daytime. Although many adult prey fishes occupy the bottom of the lake during the day, presumably to avoid predation, scientists always recognized that the survey provided a relative (not absolute) density index because some proportion of adult alewife, bloater, and rainbow smelt remain pelagic during the day. In addition, age-0 alewife are mostly above the thermocline, rather than below, during the day (Brandt 1980). To provide a complementary relative index of prey fish abundance, Lake Michigan scientists began conducting nighttime lakewide acoustic (AC) surveys in the early 1990s (Argyle 1992), and an interagency annual survey was solidified in 2004. Together, these two annual surveys have enabled the development of a stock assessment model for alewife (Tsehaye et al. 2014) that is used to inform annual agency stocking decisions of Chinook salmon, lake trout, steelhead (*Oncorhynchus mykiss*), brown trout, and coho salmon (*Oncorhynchus kisutch*) in Lake Michigan. Furthermore, each survey provides unique and complementary data. The BT survey provides abundance indices for benthic species such as deepwater sculpin, slimy sculpin, round goby, ninespine stickleback, and even age-0 yellow perch (*Perca flavescens*). The BT survey has also traditionally indexed burbot (*Lota lota*) and weights of dreissenid mussels are also recorded. In turn, the AC survey indexes three prey fish species (i.e., alewife, bloater, and rainbow smelt) and provides abundance indices for age-0 alewife, which is an early indicator of alewife year-class strength (Warner et al. 2008). Given that ciscoes (*Coregonus artedi*) are also becoming more common in Lake Michigan (Claramunt et al. 2019), it is conceivable—based on Lake Superior sampling—that the BT survey could index yearling ciscoes (see Yule et al. 2008) and the AC survey could index adults (see Stockwell et al. 2006).

The COVID-19 pandemic dramatically altered the ability of U.S. Geological Survey (USGS) researchers to complete the 2020 BT and AC surveys. The AC survey, normally conducted in late summer, was cancelled because an approved process for keeping vessel crew members safe from COVID-19 infection had not yet been established. However, through a stepwise approach of increasing mission complexity while instituting and testing safety protocols, it was determined that an abbreviated BT survey (3 of 7 standard ports) could be carried out safely. Despite the limitations of the 2020 field season, this report is structured to capture (when applicable) the rationale, methodology, and results of the BT and AC surveys throughout their time series. For further methodological details for each survey, we invite readers to consult the previous separate survey reports published in 2019 and earlier (see Bunnell et al. 2019; Warner et al. 2019).

Methods

To accommodate the need for an abbreviated BT survey, USGS research scientists collaborated with the Lake Michigan Committee and the Planktivore Working Group of the Lake Michigan Technical Committee to select a set of ports that would be most representative of the full 7-port survey and that had the greatest likelihood of completion during the shortened time frame. Percent change in overall biomass was examined for a series of 3-port surveys relative to the 7-port biomass estimates over the last decade. Saugatuck, Waukegan, and Port Washington were determined to be the best 3-port alternative to the full survey (Fig. 1). However, analyses of historical data predicted biases with respect to deepwater sculpin (this survey would overestimate, relative a to full survey) and slimy sculpin (this survey would underestimate, relative to a full survey). Given the limited spatial coverage of the survey and the predicted biases with these two species, we recommend that readers interpret the 2020 BT survey results with caution.

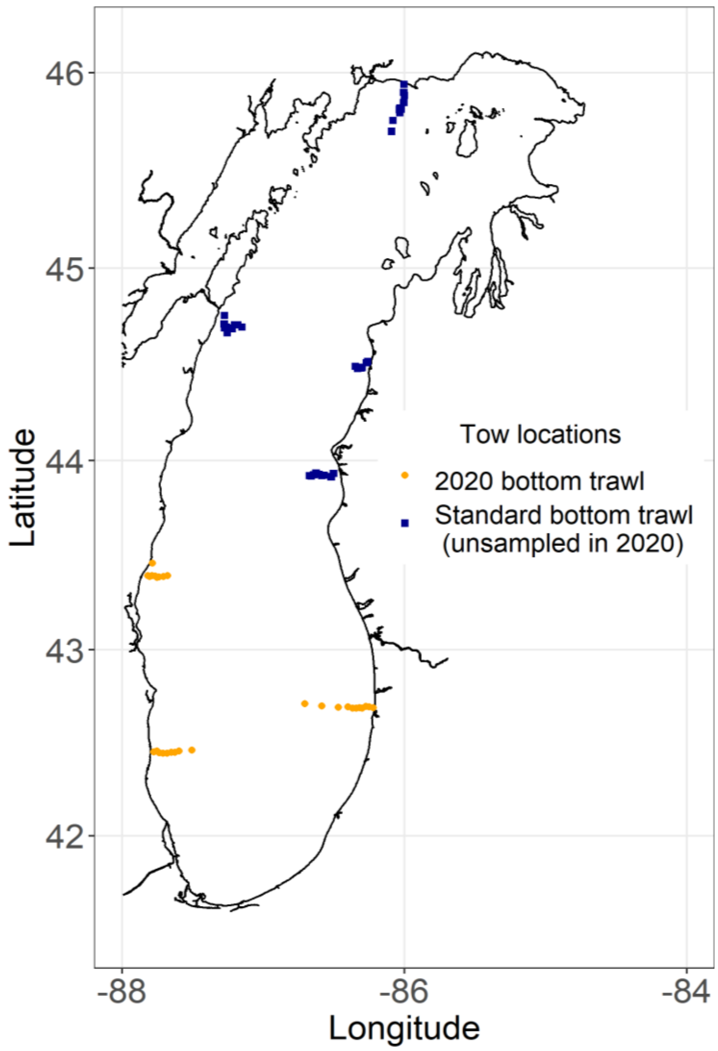

Figure 1: Sampling locations for the Lake Michigan bottom trawl conducted in September 2020 and unsampled standard tows.

Prior to the 2020 BT survey, updates were made to the R/V Arcticus to reduce airborne noise, which has the potential to lower radiated noise that may be a contributing factor to recent low bottom trawl catchability (Bunnell et al. 2019). Improvements ranged from alterations to the engine room to the installation of sound-dampening and vibration-reducing material in other areas of the vessel. Airborne noise was reduced by 10-15 decibels, negating the need for ear protection during operation (Occupational Safety and Health Administration (OSHA), 29 CFR 1910.95).

The basic unit of sampling in the BT survey is a 10-min tow using a “Yankee” trawl (12-m headrope, 25- to 45-mm bar mesh in net body, 6.4-mm bar mesh in cod end) dragged along depth contours at 9 m (5 fathom) depth increments at 2.1 mph. Towing depths in 2020 ranged from 9 m to 110 m. Depths shallower than 9 m cannot be sampled at most sites because the draft of the research vessel (i.e., vertical distance between the waterline and the bottom of the hull) prevents safe navigation while trawling. Since 2016, we have begun directly estimating time on bottom for each tow with a head-rope depth sensor that provides a more accurate estimate of area (ha) swept. We estimate both numeric (fish per hectare [ha]) and biomass (kg/ha) density. A weighted mean density over the entire range of depths sampled (within the 5 m to 110 m depth contours) is estimated by first calculating mean density for each depth zone, and then weighting mean density for each depth zone by the proportion of lake surface area assigned to that depth zone. Standard error (SE) of mean density was estimated by weighting the variances of fish density in each of the depth zones by the appropriate weight (squared proportion of surface area in the depth zone), averaging the weighted variances over all depth zones, and taking the square root of the result.

Given the importance of the alewife age distribution for the stock assessment model, sagittal otoliths were removed from individuals. Otoliths were mounted and the number of annual rings was read independently two times by two readers. If consensus could not be reached, the otolith age was determined to be unknown. In 2020, ages from all alewife caught (n=16, age ≤ 4) were successfully estimated with full agreement between readers. However, due to the low number of alewife captured in 2020, an age-length key was not generated for the BT survey.

By convention, we classified alewife, bloater, rainbow smelt, and yellow perch as either age-0 or yearling and older (YAO) based on total length (TL) cutoffs (where YAO includes the noted size): alewife = 100 mm, bloater = 120 mm, rainbow smelt = 90 mm, yellow perch = 100 mm.

Results

Alewife

Biomass density of YAO alewife in 2020 was estimated to be 0.025 ± 0.017 kg/ha (mean ± SE) in the BT survey (Fig. 2a). No age-0 alewife were captured in the 2020 survey. This continues the overall trend of record low alewife biomass densities captured since 2014, with 2020 tying 2017 as lowest ever recorded in the BT survey. YAO alewife attained the highest densities in the Port Washington transect and were caught in a total of four tows (Fig. 3).

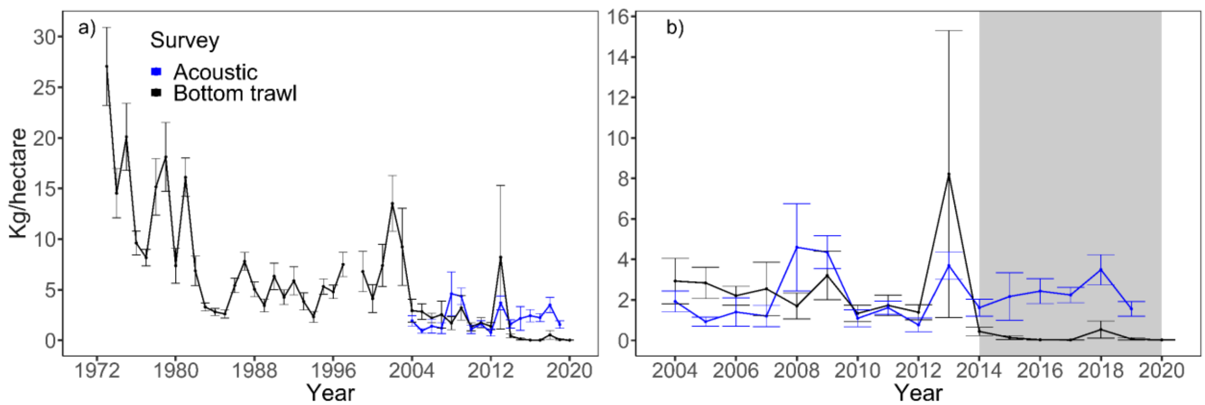

Figure 2. Yearling and older (YAO) alewife as biomass density in Lake Michigan over the entire time series (1973-2020, a) and since the solidification of the lakewide acoustic survey (2004-2020, b). Error bars are +/- standard error (SE). The shaded area in (b) indicates a recent period of consistent and substantial (>1 SE) differences in annual YAO alewife biomass density estimates between the two surveys.

Overall, results of the 2020 BT survey do not support the hypothesis that high radiated noise associated with the R/V Arcticus increased trawl avoidance by alewife, in turn contributing to lower catchability in the bottom trawl survey beginning in 2014 (Fig. 2b). Future research is needed to determine why catchability for the BT survey apparently declined around 2014.

Lower levels of alewife biomass in the 2000s relative to the 1990s and earlier are attributable primarily to high levels of consumption by salmonines (Madenjian et al. 2002, 2005a; Tsehaye et al. 2014), despite declines in Chinook salmon stocking in 2006, 2013, and 2017-2018. Factors that have maintained high predation pressure include a relatively high abundance (i.e., at least 50%) of wild Chinook salmon in Lake Michigan (Williams 2012; Tsehaye et al. 2014), increased migration of Chinook salmon from Lake Huron in search of alewife (Clark et al. 2017), increased importance of alewife in the diet of Chinook salmon in Lake Michigan (Jacobs et al. 2013;

Leonhardt et al. 2020), a decrease in the energy density of adult alewife between 1979 and 2004 (Madenjian et al. 2006), and increases in consumption by lake trout owing to their increased abundance due to increased rates of stocking and natural reproduction (USFWS/GLFC 2017; Lake Michigan LTWG 2019). Evidence for reduced growth rates of larval alewife in Lake Michigan has recently emerged (Bunnell et al. 2018; Eppehimer et al. 2019), but more research is needed to relate these findings to changes in alewife population biomass in Lake Michigan.

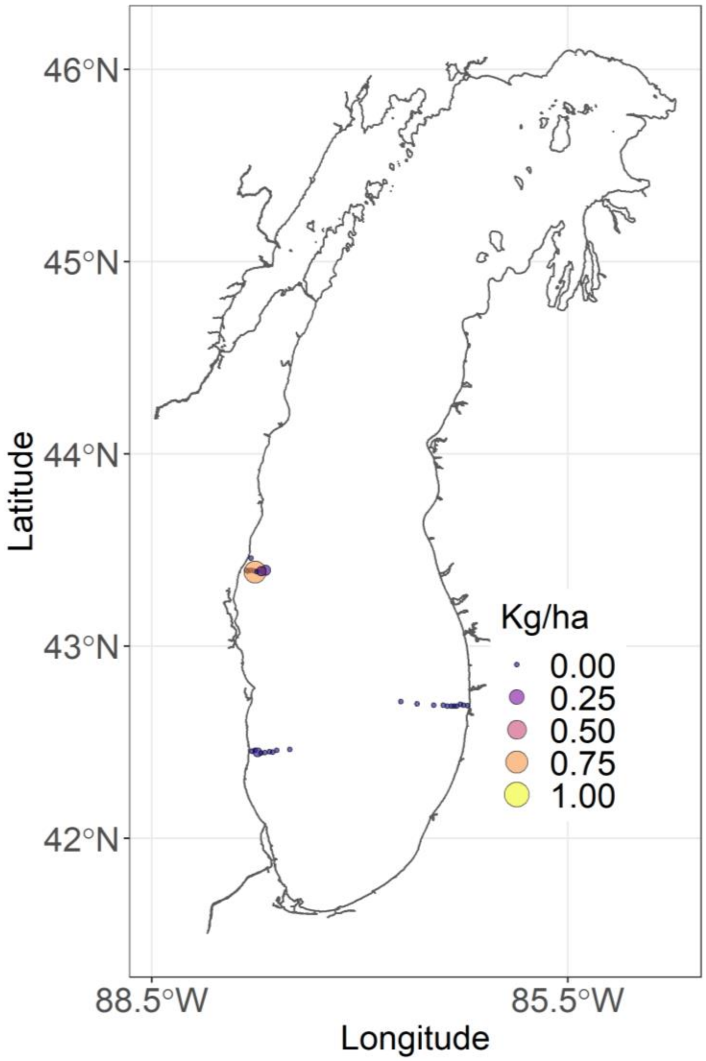

Figure 3. Map of biomass density of alewife ≥ age-1 observed during the Lake Michigan bottom trawl survey, 2020.

Bloater

Biomass density of YAO bloater in 2020 was estimated as 1.39 ± 0.61 kg/ha in the BT survey (Fig. 4a), while a single age-0 bloater was caught during the abbreviated survey (Fig. 4b). Like 2019 (0.78 ± 0.48 kg/ha), 2020 estimates of YAO bloater biomass density remain well below historical highs recorded from 1981 to 1997. Yearling and older bloater density estimates were relatively uniform across the 3 ports sampled in 2020 (Fig. 5).

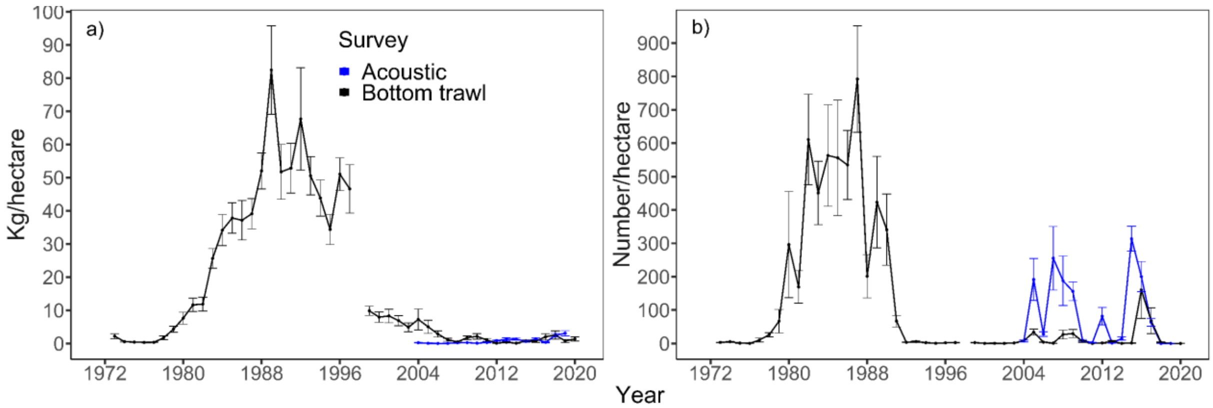

Figure 4. Density of yearling and older (YAO) bloater as biomass density (a) and of age-0 bloater as numeric density (b) in Lake Michigan, 1973-2020. Error bars in both panels are +/- standard error.

The buildup of adult biomass during the 1980s and 1990s was due to 11 consecutive years of age-0 bloater density > 100/ha from 1980-1990. Following 13 years of weak production (i.e., <10/ha) from 1992-2004, six year-classes with more than 100 age-0 bloater/ha were detected by at least one of the surveys between 2005 and 2016. However, 2018-2020 represents three consecutive year-classes with near record lows of age-0 bloater production. Similarly, acoustic density estimates for age-0 bloater were very low in 2018 and 2019.

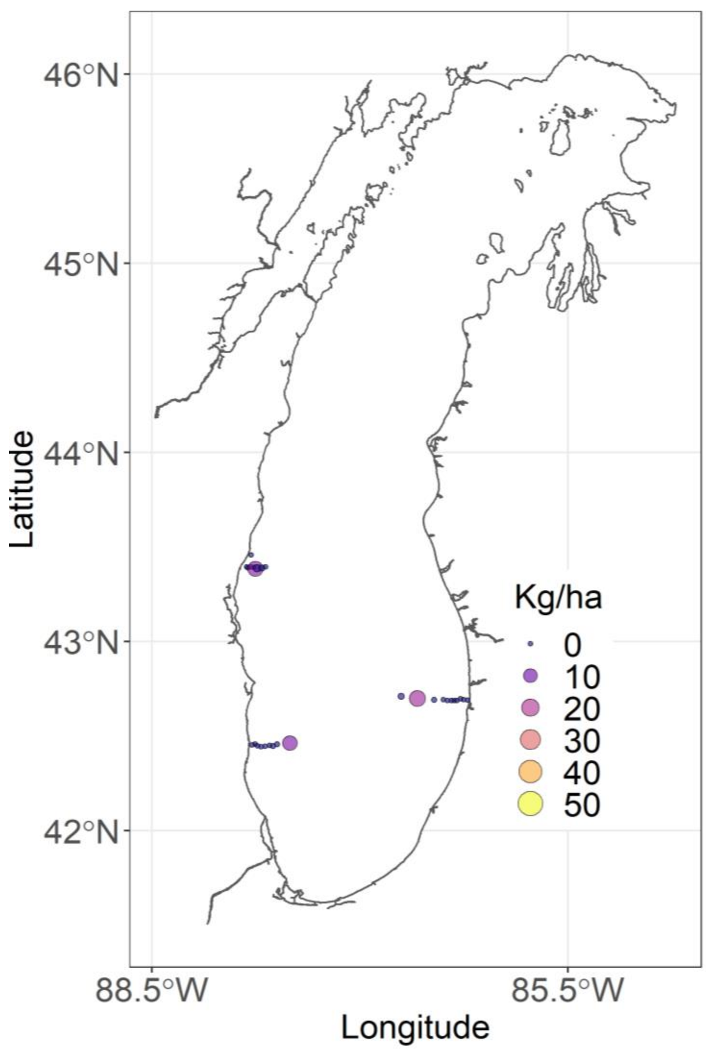

Figure 5. Map of biomass density of bloater ≥ age-1 observed during the Lake Michigan bottom trawl survey, 2020.

The exact mechanisms underlying the apparently poor bloater recruitment from the 1992-2004 and 2018-2020 periods remain unknown. Of the mechanisms that have been recently evaluated, reductions in bloater fecundity associated with poorer body condition (Bunnell et al. 2009) and egg predation by slimy and deepwater sculpins (Bunnell et al. 2014) may be contributing to the reduced bloater recruitment, but neither one is the primary regulating factor.

Rainbow smelt

No YAO rainbow smelt were captured in 2020 for the first time in the recorded BT survey (Fig. 6a). Biomass density of rainbow smelt has been <2 kg/ha since 1994, following the 1973-1993 era when rainbow smelt density averaged 3.71 kg/ha. Numeric density of age-0 rainbow smelt was also the lowest on record in the BT survey data series (0.19 ± 0.19/ha; Fig. 6b), indicating the second consecutive year of weak year-classes in Lake Michigan. Age-0 rainbow smelt were only caught during the shallowest tow (9 m) along the Saugatuck transect.

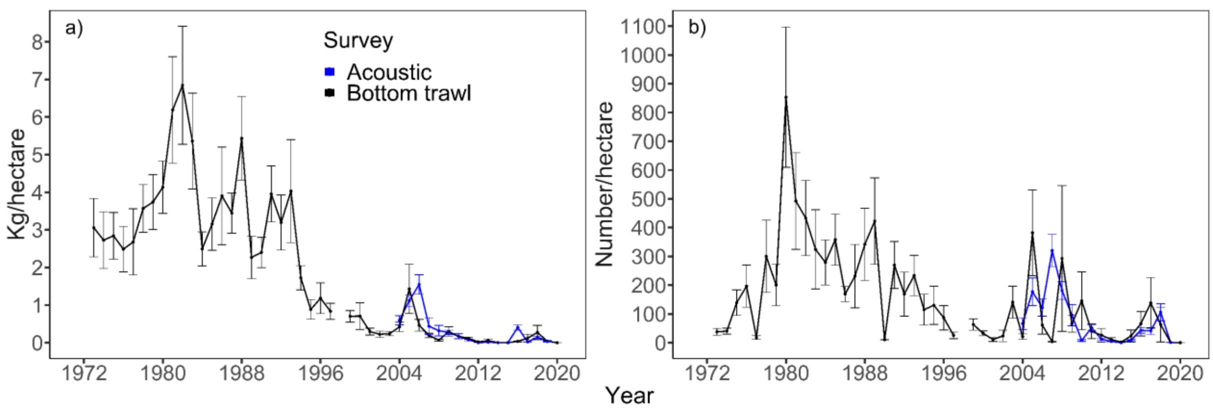

Figure 6. Density of yearling and older (YAO) rainbow smelt as biomass density (a) and of age-0 rainbow smelt as numeric density (b) in Lake Michigan, 1973-2020. Error bars in both panels are +/- standard error.

Causes for the long-term decline in rainbow smelt biomass since 1993 remain unclear. Consumption of rainbow smelt by salmonines was higher in the mid-1980s than during the 1990s (Madenjian et al. 2002), yet rainbow smelt abundance remained high. Results from a more recent analysis suggested that predation by salmonines was not the primary driver of long-term temporal trends in Lake Michigan rainbow smelt abundance (Tsehaye et al. 2014). Furthermore, a time series analysis through 2012 suggested that the production of age-0 fish relative to the number of spawners had actually increased since 2000 (relative to 1982-1999), yet those age-0 fish do not appear to be surviving as well to the adult population (Feiner et al. 2015).

Slimy sculpin

Biomass density of slimy sculpin measured by the BT in 2020 was 0.01 ± 0.006 kg/ha, the lowest density on record (Fig.7a) but not completely surprising given that transects with higher slimy sculpin densities were not sampled in 2020. In 2013, slimy sculpin biomass density declined below 0.25 kg/ha and has not rebounded. Previous analyses have revealed that slimy sculpin abundance is regulated, at least in part, by predation from juvenile lake trout (Madenjian et al. 2005b). In fact, slimy sculpin biomass began declining in 2010, which coincides with a substantial increase in the rate of stocking juvenile lake trout into Lake Michigan and an increase in natural reproduction by lake trout (USFWS/GLFC 2017; Lake Michigan LTWG 2019). When the 128-m tows are analyzed, slimy sculpin still occur in about 50% of them, but their densities are nearly an order of magnitude lower than what is estimated at 73, 82, 91, and 110 m sites. Hence, unlike deepwater sculpin, we do not believe the decline in slimy sculpins is an artifact of only sampling out to 110 m for our standard tows.

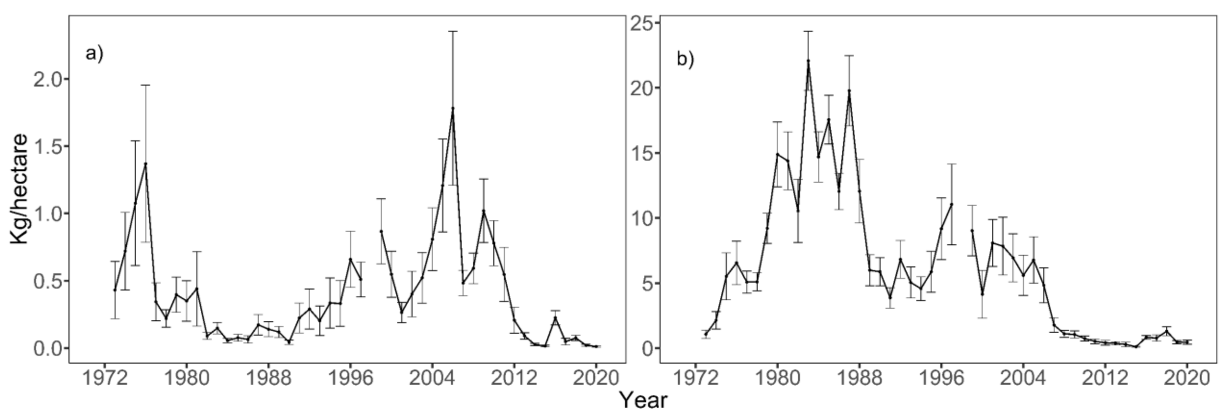

Figure 7. Biomass density of slimy sculpin (a) and deepwater sculpin (b) in Lake Michigan, 1973-2020, as measured by the bottom trawl survey. Error bars in both panels are +/- standard error.

Deepwater Sculpin

Biomass density of deepwater sculpin in 2020 estimated by the BT survey was 0.47 ± 0.17 kg/ha, mirroring the 2019 BT biomass density estimate and continuing a decade long trend of values <1 kg/ha (Fig. 7b). Deepwater sculpin have remained at relatively low levels since 2007 (mean = 0.73 kg/ha). Previous analysis of the time series indicated deepwater sculpin density is negatively influenced by alewife (predation on sculpin larvae) and burbot (predation on juvenile and adult sculpin, Madenjian et al. 2005b). As neither of these species have increased since 2007, these mechanisms likely do not underlie the recent downward trend. A more likely explanation is that some proportion of the deepwater sculpin population has shifted to waters deeper than 110 m (the deepest depth for the standard trawling sites). In support of this, Madenjian and Bunnell (2008) found that deepwater sculpins have been captured at increasingly greater depths since the 1980s. The data collected from the 128 m sites since 2013 also clearly demonstrate increasing biomass density with depth. Future research should sample at even greater depths to determine the depth at which deepwater sculpin biomass peaks.

Ninespine stickleback

No sticklebacks were caught in the 2020 abbreviated BT survey (Fig.8a). Two stickleback species occur in Lake Michigan. Ninespine stickleback (*Pungitius pungitius*) is native, whereas threespine stickleback (*Gasterosteus aculeatus*) is non-native and was first collected in the BT survey during 1984 (Stedman and Bowen 1985) but has been extremely rare in recent years. Biomass density of ninespine stickleback has also been extremely low (i.e., <0.5 kg/ha) since 2007.

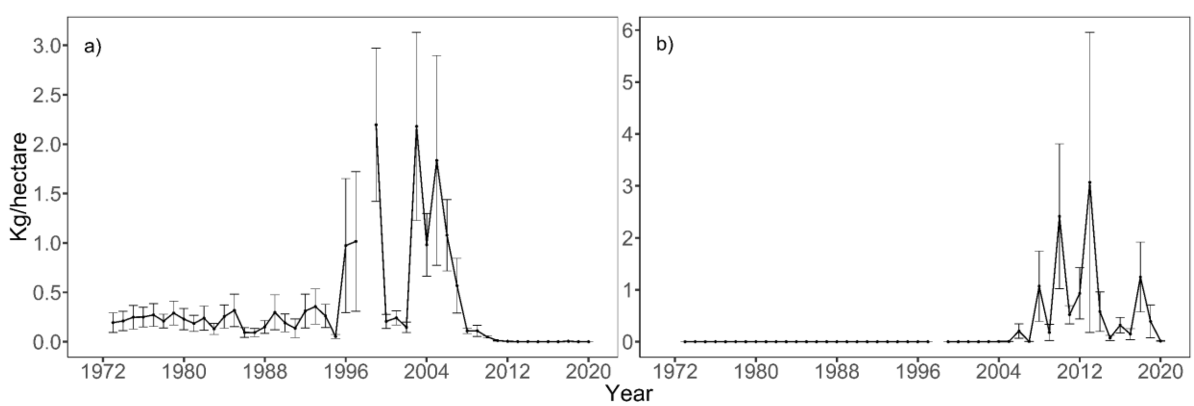

Figure 8. Biomass density of ninespine stickleback (a) and round goby (b) in Lake Michigan, 1973-2020, as measured by the bottom trawl survey. Error bars in both panels are +/- standard error.

Biomass of ninespine stickleback was low from 1973-1995 and then increased dramatically through 2007, perhaps attributable to dreissenid mussels enhancing ninespine stickleback spawning and nursery habitat through proliferation of *Cladophora* (Madenjian et al. 2010). One plausible explanation for the low ninespine stickleback abundance since 2011 is that piscivores began to incorporate ninespine sticklebacks into their diets as the abundance of alewife declined to a lower level. For example, Jacobs et al. (2013) found ninespine sticklebacks in large Chinook salmon diets (i.e., 2% occurrence) during 2009-2010 after 0% occurrence in 1994-1996.

Round goby

Nonindigenous round gobies were first detected in bays and harbors of Lake Michigan in 1993 (Clapp et al. 2001) but were not widespread enough to be sampled in our BT survey until 2003. Because our survey samples on soft substrates at depths 9 m and deeper, our estimate is biased low because we are not sampling their preferred habitat in September which is rocky substrate and shallow (< 9 m) depths.

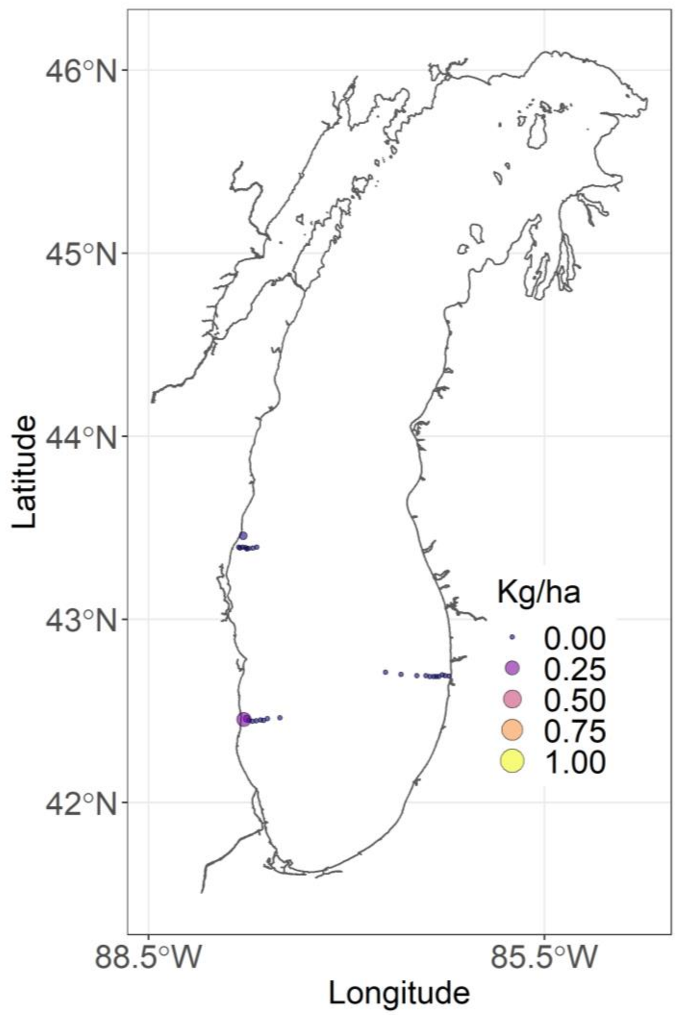

Figure 9. Map of biomass density of round goby observed during the bottom trawl survey, 2020.

Round goby biomass density equaled 0.01 ± 0.012 kg/ha in 2020 (Fig. 8b), the lowest on record since 2005. Round gobies were captured in 3 of 32 tows, all on the western shoreline (Fig. 9). One potential explanation for higher densities on the western side of the lake is rockier habitat relative to the eastern side of the lake (Janssen et al. 2005). We hypothesize that round goby abundance in Lake Michigan is controlled by predation, given that annual mortality rates range from 79-84% (Huo et al. 2014), comparable to estimates from adult alewife (Tsehaye et al. 2014).

Prey fish community trends

The prey fish community sampled by the BT survey included alewife, bloater, rainbow smelt, deepwater sculpin, slimy sculpin, ninespine stickleback, and round goby. In 2020, this survey estimated a total biomass density of prey fish equal to 1.91 kg/ha (Fig. 10), well below the long-term (i.e., 1973-2020) average total biomass of 34.94 kg/ha. Total biomass density first dropped below 10 kg/ha in 2007 and has largely remained below that level. For the sixth straight year, the composition of the 2020 prey fish community was dominated by bloater (73%).

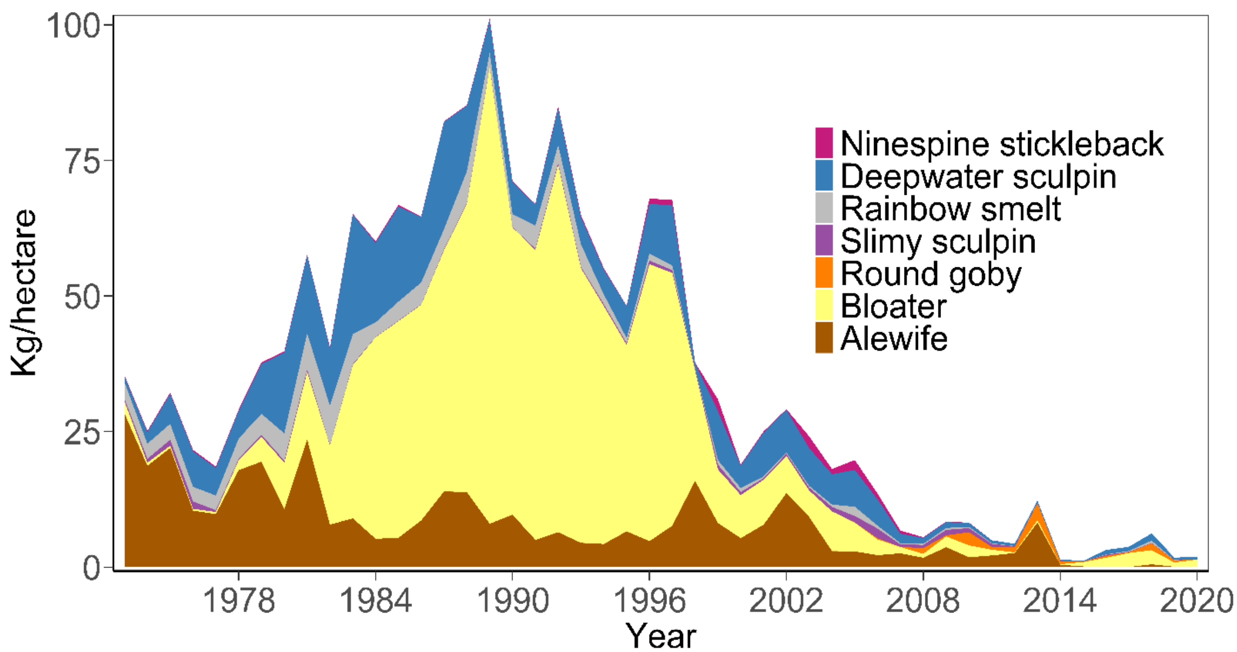

Figure 10. Estimated biomass of prey fishes sampled in the bottom trawl survey, 1973-2020.

Other species of interest

<u>Burbot</u> – Burbot and lake trout represent the native top predators in Lake Michigan. The recovery of burbot during the 1980s was attributable to reduction in sea lamprey (Wells and McLain 1973) and perhaps even alewife (Eshenroder and Burnham-Curtis 1999; Madenjian et al. 2008). Burbot collected in the BT survey are typically large individuals (>350 mm TL); juvenile burbot apparently do not inhabit areas sampled by the BT survey. A single burbot (782 mm) was captured

in the abbreviated BT survey. Burbot biomass density is well below historic highs of the series in the late 1980's and early 1990's (Fig. 11a). It is unclear why burbot catches in the BT survey have remained low in the face of relatively low densities of sea lamprey and alewife.

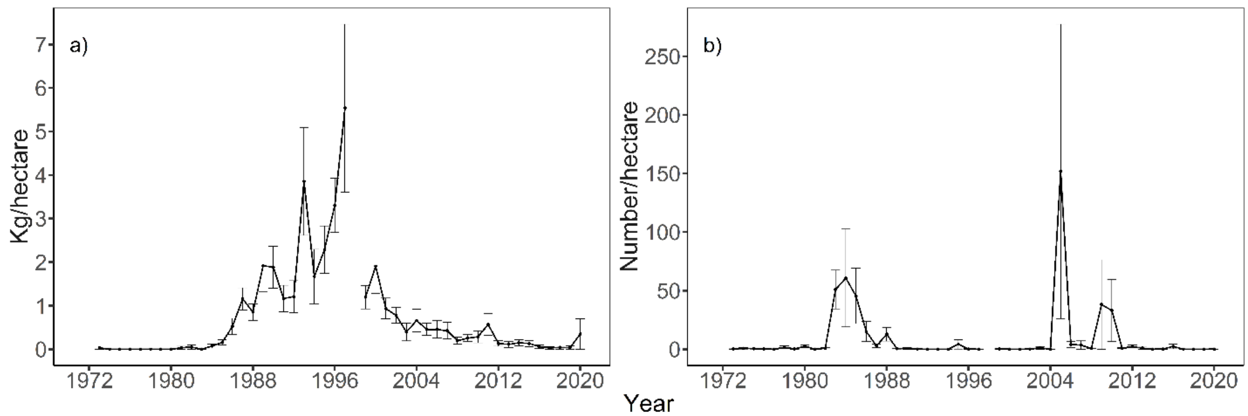

Figure 11. Biomass density of burbot (a) and numeric density of age-0 yellow perch (b) in Lake Michigan, 1973-2020, as measured by the bottom trawl survey. Error bars in both panels are +/- standard error.

<u>Age-0 yellow perch</u> – The yellow perch population in Lake Michigan has supported valuable recreational and commercial fisheries (Wells 1977). The BT survey provides an index of age-0 yellow perch numeric density, which serves as an indication of yellow perch recruitment success. The 2005 year-class of yellow perch was the largest ever recorded (Fig. 11b) and the 2009 and 2010 year-classes also were higher than average. In 2020, the first age-0 perch were caught in the bottom trawl since 2016 (0.09 ± 0.093/ha), still indicative of a near-decade long trend in weak year-classes.

Conclusions

Trends in prey fish sampling in 2020 were similar to what was observed in 2019: poor recruitment for bloater, rainbow smelt, and yellow perch and near historic lows for yearling and older alewife, bloater, and rainbow smelt and all size classes of native sculpin species. Ensuring that both the full AC and BT survey will resume in 2021 is critical to understanding long-term trends in prey fish biomass density and updating assessment models that inform stocking decisions for salmonines. One additional important finding from the 2020 BT survey is the persistence of low biomass density estimates despite improvements to the R/V Arcticus airborne, and presumably radiated, noise levels. This suggests that further research needs to be implemented to fully understand the mechanisms driving the disparity between the estimates of YAO alewife between the BT and AC surveys. Future research is also needed to tease apart the impacts of invasive dreissenid mussels on Lake Michigan prey fish trends; most notably, impacts on recruitment, growth, and survival of prey fish species.

Acknowledgments

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