Status of Pelagic Prey Fishes in Lake Michigan, 2018[1]

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Abstract

Acoustic surveys were conducted in late summer/early fall during the years 2004-2018 to estimate pelagic prey fish biomass in Lake Michigan. Midwater trawling during the surveys and acoustic target strength provided a measure of species and size composition of the fish community for use in scaling acoustic data and providing species-specific abundance estimates. The 2018 survey consisted of 33 acoustic transects [648 km total (403 miles)] and 52 midwater trawl tows. Bottom depth at sampling sites ranged from 5 to 245 m (16-804 ft). Mean prey fish biomass density was 7 kg/ha, which was 2.2 times higher than in 2017 and 1.7 times the long-term (15 years) mean. The numeric density of the 2018 alewife year-class was 52% of the time series average and 2.2 times the 2017 density. The 2018 cohort was 12% of total alewife biomass (4 kg/ha). In 2018 alewife comprised 57% of total prey fish biomass, while rainbow smelt and bloater were 6% and 35% of total biomass, respectively. Small bloater were extremely rare in 2018 and were only caught near Ludington, Michigan. Their density (<1 fish/ha) in 2018 was the lowest observed in the 2004-2018 period. Cisco are infrequently caught in this survey. In 2018 three adult fish were caught (>400 mm), with two in Grand Traverse Bay and one south of Manistique, Michigan. These results indicate that cisco density is very low at the lake level.

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Introduction

Annual evaluation of long-term data on prey fish dynamics is critical considering changes to the Lake Michigan food web during the last 40 years (Madenjian et al. 2002) and continued restructuring due to exotic species, pollution, fishing, and fish stocking. Alewives (*Alosa pseudoharengus*) are the primary prey in Lake Michigan and of especial importance to stocked salmonines in the Great Lakes (Elliott 1993; Rybicki and Clapp 1996; Warner et al. 2008; Jacobs et al. 2013), however they are also predators of larval fish and are tied to thiamine deficiencies that contribute to recruitment bottlenecks in native fishes including lake trout (*Salvelinus namaycush*). As such, alewives constitute an important component of the food web. The traditional U.S. Geological Survey (USGS) Great Lakes Science Center (GLSC) prey fish monitoring method (bottom trawl) is inadequate for fish located off bottom (Fabrizio et al. 1997). Though bottom trawls are quite effective for benthic fish, they provide particularly biased estimates for age-0 alewives based on catchability estimates from stock assessment modeling (Tsehaye et al. 2014). Much of the alewife biomass will not be recruited to bottom trawls until age-3 (Madenjian et al. 2005), but significant predation by salmonines may occur on alewives ≤ age-2 (Warner et al. 2008). Alewife abundance patterns are largely driven by the age-classes that are not effectively sampled by bottom trawls; total alewife density is highly correlated with the density of alewife ≤ age-2 (Warner et al. 2008). Because of the ability of acoustic surveys to count organisms far above bottom, this type of sampling is ideal for highly pelagic fish like age-0 alewives, rainbow smelt (*Osmerus mordax*), bloater (*Coregonus hoyi*), and cisco (*C. artedi*) and is a valuable complement to bottom trawl sampling. Further, these two long-term surveys have enabled the development of a stock assessment model for alewife (Tsehaye et al. 2014).

Methods

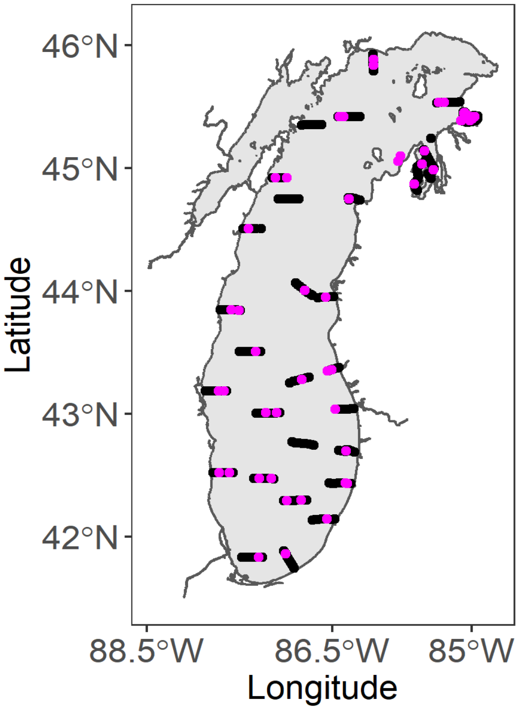
The initial annual Lake Michigan acoustic survey adopted by the Lake Michigan Technical Committee (Fleischer et al. 2001) was a stratified quasi-random design with three strata (north, south-central, and west) and unequal effort allocated among strata. The location of strata and number of transects within each stratum was determined from a study of geographic distribution of species and the variability of fish abundance within strata (Adams et al. 2006). A modified design was developed in 2004 (Warner et al. 2005), which included two additional strata (north and south offshore) because of the use of offshore waters by young alewife. The initial three strata were retained, but their size was modified based on data collected in 2003 as well as NOAA Coast Watch Great Lakes node maps of sea surface temperature from 2001-2003. In 2007-2018, the number of transects in each stratum was optimized based on stratum area and standard deviation of biomass using methods in Adams et al. (2006). While the sampling design has changed some in terms of the strata and number of transects, both acoustic and trawl sampling is conducted at night as originally intended.

Multiple agencies contribute effort to this survey. Split beam transducers with a nominal frequency of 120 kHz (range 120-129) were used in all years except 2004, when Michigan Department of Natural Resources used a dual beam system. Each survey vessel collected acoustic data along transects. These data are used to estimate numeric fish density. While sampling those transects, midwater trawls are used to collect fish, which enabled the determination of species, size, and (in the case of alewife), age composition. Acoustic estimates reported here were derived using what is known as the NearD method (described below, Yule et al. 2013). In prior years, the Hierarchical Averaging Method (HAM, Yule et al. 2013) was used (Warner et al. 2008; Warner et al. 2009). The latter method was described in detail by Warner et al (2008, 2009) and Yule et al. (2013). Numeric fish density estimates were generated using the function estimateLake() layers in The EchoNet2Fish package for R (Adams 2018) with geographic strata and two depth layers. This function calculates numeric fish density estimates and apportions them to user-defined fish groups using catch data.

Annual age-length keys were created for alewife from fish collected in the acoustic survey in 2018 and from the acoustic survey and bottom trawl survey in prior years. Age was estimated from sagittal otoliths. The age-length key was used to estimate the age composition of the catch for each midwater tow based on the length composition of all alewife.

Warner et al. (2012) found that the pelagic fish community composition of Lakes Michigan and Huron varied with depth below the water surface, with a dividing depth of 40 m. They found that the community in the upper layer was composed of alewife, rainbow smelt, and small bloater (<120 mm) while the lower layer was consistently composed of larger bloater. Because of this information, and because biomass estimation methods that take advantage of vertical variation in community composition are more accurate (Yule et al. 2013), acoustic and trawl data were divided into two depth layers (<40 m and ≥40 m). Fish density in the upper layer was apportioned into fish categories (age or size groups within species) using the catch composition from the nearest trawl (Euclidean distance) within this layer and geographic stratum. Numeric density (fish/ha) for each category was the product of acoustic density and the proportion of the catch composed of different fish groups in the nearest midwater trawl sample. Biomass density (kg/ha) was the product of numeric density and the wet weight of the different species groups predicted from length.

Consistent with prior analyses, acoustic target strength (TS) and prior information about the composition of midwater trawl catch in the lower depth zone (Adams et al. 2006; Warner et al. 2012) was used to assign species the layer ≥40 m below the surface. Warner et al. (2012) found that over a 30+ year period in lakes Michigan and Huron, regardless of season, the probability that a fish captured 40-60 m below the surface was a bloater ≥120 mm was 0.73. This probability was >0.9 for depths ≥60 m below the surface. Therefore, any acoustic cell with mean TS ≥-45 dB was assumed to be bloater ≥120 mm. We arrived at this TS using the equation $\text{Length}_{(\text{mm})} = 10 * 10^{(3.2+0.047*TS(dB))}$. This equation was derived from 92 paired midwater trawl/acoustic TS samples from lakes



Michigan and Huron where at least 90% of the fish caught were bloater. The correlation between length and TS was high (r^2 = 0.93). Any cell in this depth range that had a mean TS <-45 dB was assigned a density of zero. For cells meeting or exceeding the TS value, numeric density was apportioned to large bloater. Biomass density was the product of numeric density and the mean wet weight of fish predicted from TS using the equation $\text{Weight}_{(g)} = 10^{(7.449+0.141*TS(dB))}$. This equation was derived from the same samples as the prior equation.

Results

Survey Characteristics

The 2018 Lake Michigan acoustic survey was conducted by the USGS, the Michigan Department of Natural Resources (MDNR), the United States Fish and Wildlife Service (USFWS), and the Little Traverse Band of Odawa Indians (LTB). The survey consisted of 52 midwater trawl tows and 33 transects for a total transect distance of 648 km (403 mi). The bottom range over which acoustic data were collected was 5-245 m (16-804 ft). Survey locations are shown in Figure 1.

Figure 1. Map of the sampling locations in the Lake Michigan acoustic survey, August 2018. Black symbols represent acoustic samples and magenta symbols represent midwater trawl samples.

Alewife

Ages were estimated for 262 alewife ranging from 70-190 mm and from 0-5 years old (Figure 2). The smallest age-1 alewife was 91 mm, therefore, we assumed any alewife <90 mm were age-0. Fish age-2 + made up 48% of the catch, which was much higher than in 2016 (5%) and 2017 (17%), indicating it is likely that more of the population was of reproductive age in 2018. However, age-5 fish made up only <1% of all fish caught.

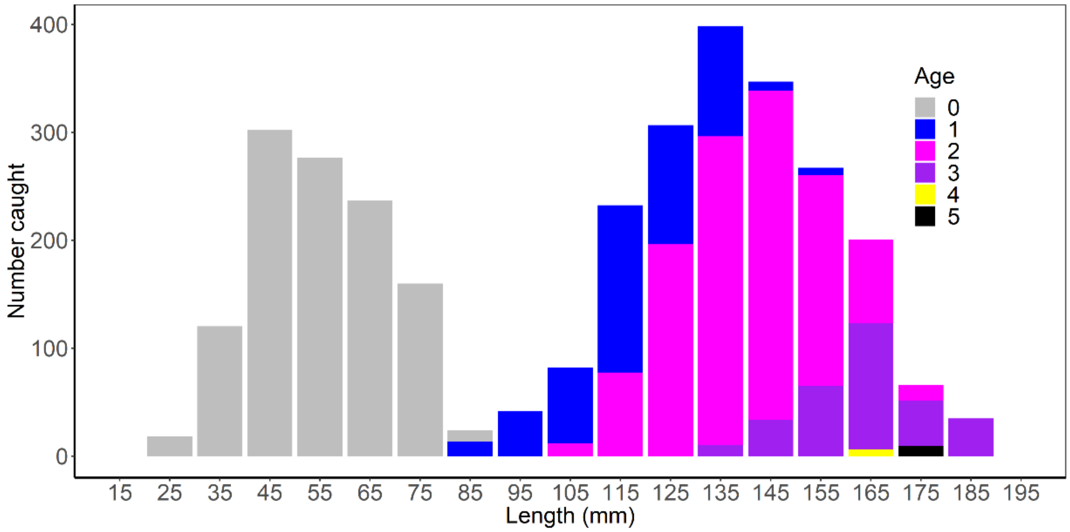


Figure 2. Predicted age composition at length for alewife captured during the Lake Michigan acoustic survey, August 2018.

The numeric density of the 2018 alewife year class in 2018 was 403 fish/ha (Figure 3), which was 2 times the density of age-0 alewife in 2017 and was 52% of the long-term mean. The biomass density of age-1 or older alewife was 3.5 kg/ha, which was 1.7 times the long-term mean and 1.5 times higher than in 2017. The biomass of alewife ≥age-1 was made up mostly of the 2015, 2016, 2017 year classes (23%, 63%, and 12%, respectively) with the remainder being the 2013 and 2014 year classes. This suggests that the increase in biomass of alewife ≥age-1 was the result of survival of the 2016- and 2015-year classes combined with their growth. For example, alewife ≥age-1 were more than 7 g heavier in 2018 than in 2017. The acoustic estimate of alewife biomass density was approximately 10 times that from the bottom trawl survey (Bunnell et al. 2019). The density of alewife in Lake Michigan is still much higher than the density of alewife in Lake Huron (O’Brien et al. 2018).

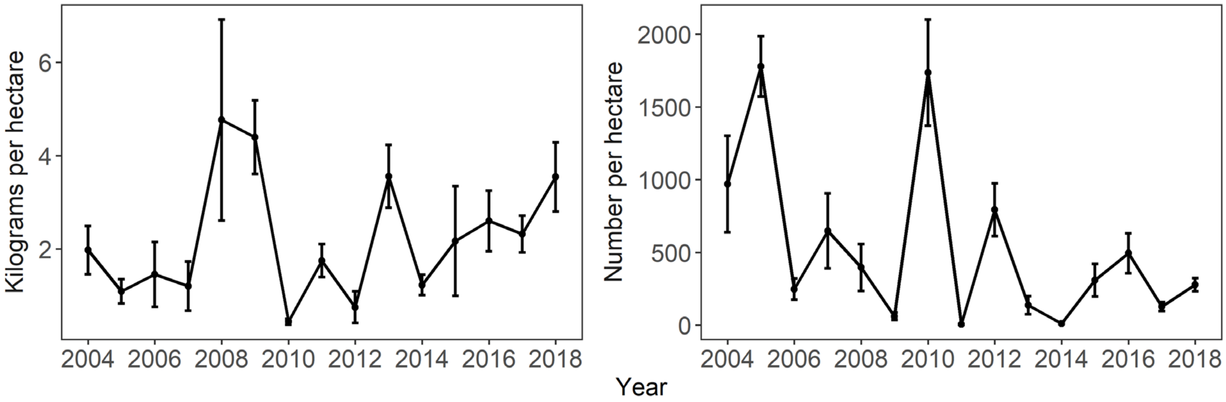


Figure 3. Biomass density of age-1 or older alewife (left panel) and numeric density of age-0 alewife (right panel) observed during the Lake Michigan acoustic survey during 2004-2018. Error bars show one standard error.

Spatial patterns in age-0 and alewife ≥age-1 indicate that these fish have a patchy distribution (Figure 4). Highest numeric densities of age-0 alewife were observed in the southeastern and south-central areas of the lake with these fish absent from much of the rest of the lake. Densities of alewife ≥age-1 were more evenly distributed compared to age-0 alewife, but there were areas of higher density (mostly in the eastern half of the lake).

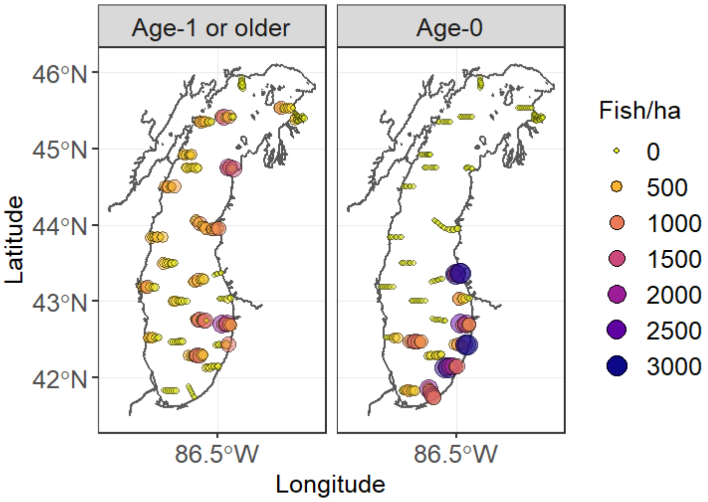


Figure 4. Map of numeric density of alewife ≥age-1 (left map) and age-0 alewife (right map) observed during the Lake Michigan acoustic survey, August 2018.

Rainbow smelt

At 86 fish/ha, numeric density of small rainbow smelt (<90 mm) in 2018 (Figure 5) was slightly lower than that observed 2017. This density was almost 62% of the time series mean of 139 fish/ha. Similarly, at 0.1 kg/ha, biomass density of large rainbow smelt (≥90 mm) was similar to that observed in 2017. Even though acoustic biomass density estimates of large smelt have generally exceeded bottom trawl estimates, both surveys show there was an order of magnitude decrease from the 1990s to 2001-2014 (Bunnell et al. 2019). Recent low biomass is in stark contrast to observations from the late 1980s (Argyle 1992) and changes in community composition are consistent with the findings of Warner et al. (2012), who reported a shift in the pelagic fish community away from rainbow smelt in dominance in the mid-1990s to a community dominated by alewife and bloater.

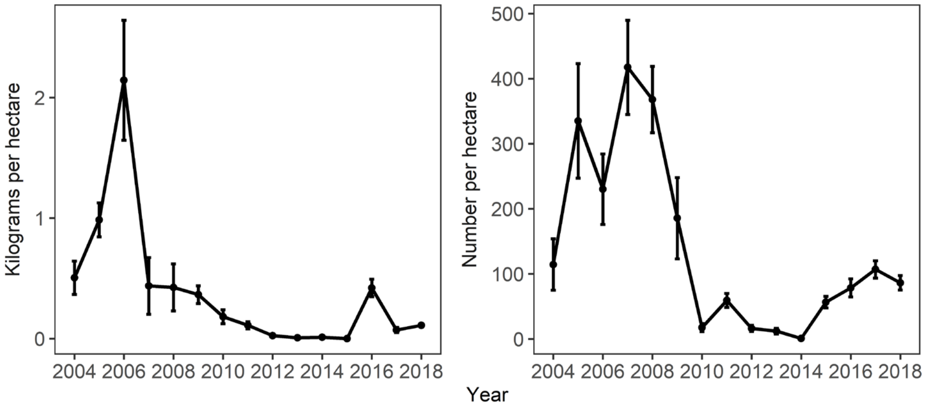


Figure 5. Biomass density of large rainbow smelt (≥90 mm, left panel) and numeric density of small rainbow smelt (<90 mm, right panel) observed during the Lake Michigan acoustic survey during 2004-2018. Error bars show one standard error.

Spatial patterns in rainbow smelt density differed from alewife. Small rainbow smelt were observed only in the northern portion of the lake with the highest density observed in Little Traverse Bay (Figure 6). Large rainbow smelt were somewhat more widely distributed in the northern half of the lake but were not observed in the southern half.

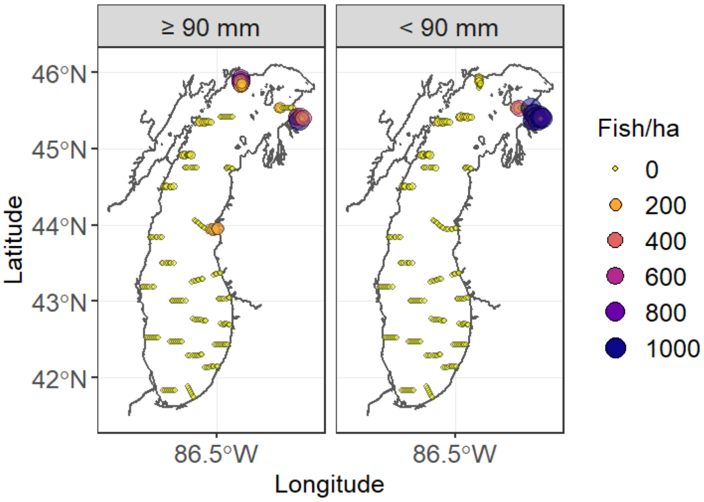


Figure 6. Map of numeric density of large rainbow smelt (>90 mm total length, left map) and small rainbow smelt (right map) observed during the Lake Michigan acoustic survey, August 2018.

Bloater

Densities of both small and large bloater have been variable in 2004-2018. Mean numeric density of small bloater in 2018 was less than 1 fish/ha and was the lowest observed in 2004-2018 (Figure 7). Biomass density of large bloater in 2018 was 3.1 kg/ha, which was 11% above the time series mean but much lower than levels from the 1980s/1990s reported by the bottom trawl survey (Bunell et al. 2019). In 2018, the estimates were similar for the acoustic survey and for the bottom trawl survey (2.6 kg/ha, Bunnell et al. 2019).

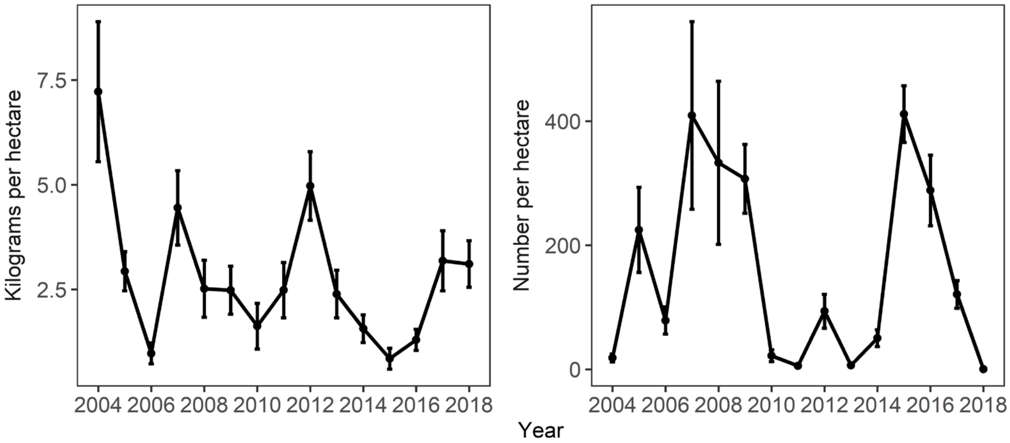


Figure 7. Biomass density of large bloater (≥120 mm, left panel) and numeric density of small bloater (<120 mm, right panel) observed during the Lake Michigan acoustic survey during 2004-2018. Error bars show one standard error.

Spatial patterns in bloater indicated different distributions for small and large bloater (Figure 8). Small bloater were only observed near Ludington, MI. Large bloater were more widespread in distribution and locations with density of 20-50 fish/ha were common.

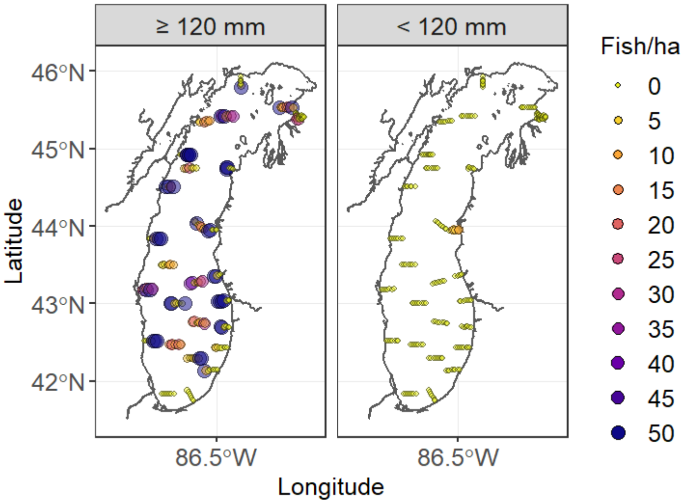


Figure 8. Map of numeric density of large bloater (≥120 mm total length, left map) and small bloater (right map) during the Lake Michigan acoustic survey, August 2018.

Cisco

Cisco have generally been absent from the midwater trawl catch in most years of this survey. However, small numbers have been caught in Grand Traverse Bay, near the Beaver Archipelago, and Manistique, Michigan. Efforts are underway to identify the best method of estimating density for a fish rarely caught in midwater tows. In 2018, three Cisco were caught, with two from Grand Traverse Bay and one from the Manistique, Michigan area. All three were >400 mm.

Assumptions

As with any survey, it is important to note that any estimates of fish density are potentially biased and, when possible, we should describe the effects of any bias when interpreting results. With acoustic sampling, areas near the surface (upper blind zone 0-4 m) or near the bottom (bottom dead zone, bottom 0.3-1 m) are not sampled well or at all. The density of fish in these areas therefore is unknown. Recent technological advances allow for acoustic sampling of the upper blind zone over large spatial areas, but the cost of this technology has been prohibitive. While our highest alewife and rainbow smelt catches and catch-per-unit-effort with midwater tows generally occur near the thermocline in Lake Michigan (Warner et al. 2008; Warner et al. 2012), it is possible that some are in the top 4 m and can't be captured with trawls because the ship displaces this water and the fish.

We are less concerned with bias in alewife and rainbow smelt densities attributable to ineffective acoustic sampling off the bottom because of their pelagic distribution at night when our sampling occurs. In Lake Michigan, day-night bottom trawling was conducted at numerous locations and depths in 1987 (Argyle 1992), with day and night tows occurring on the same day. These data indicate that night bottom trawl estimates of alewife density in August/September 1987 were only 6% of day estimates. Similarly, night bottom trawl estimates of rainbow smelt density were ≈ 6% of day estimates. Disparities between day and night bottom trawl data demonstrate that alewife and rainbow smelt make an upward diel vertical migration at night in Lake Michigan which facilitates accurate sampling using acoustics and midwater trawling. However, bloaters tend to be more demersal; in Lake Superior, night acoustic/midwater trawl sampling may detect only 60% of bloater present (Yule et al. 2007). The day-night bottom trawl data from Lake Michigan in 1987 suggested that the availability of bloater to acoustic sampling at night was somewhat higher (mean=76%). We assume that slimy sculpins (*Cottus cognatus*) and deepwater sculpins (*Myoxocephalus thompsonii*) are not sampled acoustically and we must rely on bottom trawl estimates for these species (Yule et al. 2008). We also assumed that our midwater trawling provided accurate estimates of species and size composition. Based on the relationship between trawling effort and uncertainty in species proportions observed by Warner et al. (2012), this assumption was likely reasonable.

We made additional assumptions about acoustic data not described above. For example, we assumed that all targets below 40 m in analysis cells with mean target strength (TS) ≥-45 dB were bloater. Given information about rainbow smelt from Warner et al. (2012), it is possible that this resulted in a slight underestimation of rainbow smelt density. We also assumed that conditions were suitable for use of in situ TS to estimate fish density, which could also lead to biased results if conditions are not suitable for measuring TS (Rudstam et al. 2009; Sawada et al. 1993). However, we used the Nv index of Sawada et al. (1993) to identify areas where TS bias was likely (Nv ≥0.1) and replaced the data in these cells with values from adjacent cells with lower Nv. We assumed that noise levels did not contribute significantly to echo integration data and did not preclude detection of key organisms. Detection limits were such that the smallest fish were detectable well below the depths they typically occupy. Finally, we have assumed that the estimates of abundance and biomass are relative and do not represent absolute measures. This assumption is supported by recent estimates of catchability derived from a multispecies age structured stock assessment model (Tsehaye et al. 2014).

Summary

Acoustic survey total biomass density has been quite variable but there was a marked, significant decreasing trend from 2004 to 2015 (Pearson's $r = -0.7$, $p = 0.01$), followed by three years of increasing density (Figure 9). The estimate for 2018, 8.5 kg/ha, is the third highest in the period from 2004-2018. There has been and continues to be debate about the causes of the decline in fish density in Lake Michigan, which has also been observed in the bottom trawl survey (Bunnell et al. 2019) and commercial catch records (USGS Great Lakes Science Center, Great Lakes Commercial Fishing Catch 1929-2014: USGS data release, http://dx.doi.org/10.5066/F74B2ZD1). Some have argued the cause is bottom-up limitation while others have argued the cause is predation (top-down). The states surrounding Lake Michigan have made several cuts to predator stocking because of the decline to promote a better balance between the demand and availability of prey in the system. How this balance plays out in the future remains to be seen. Alewife biomass has stopped declining and has increased from 2015, and much of the alewife biomass is composed of fish that are likely old enough to be sexually mature, which should contribute to a higher chance of average or better recruitment.

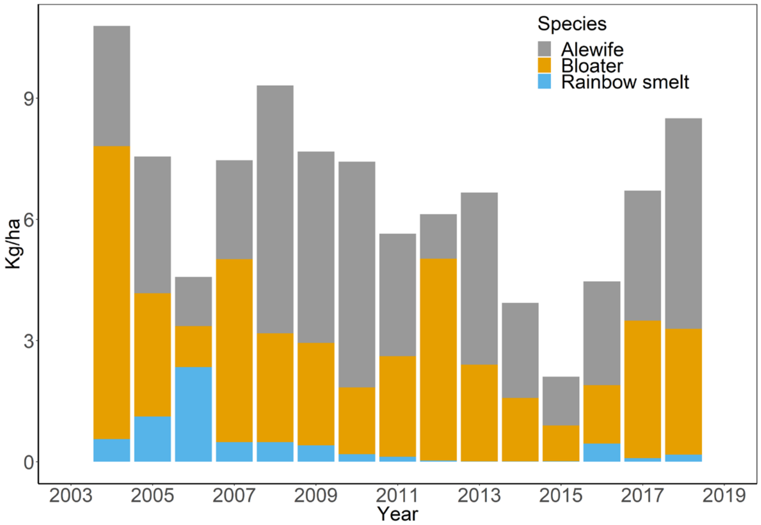


Figure 9. Total prey fish biomass density estimated for the Lake Michigan acoustic survey, 2004-2018.

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Notice

The acoustic data associated with this report have not received final approval by the U.S. Geological Survey (USGS) and are currently under review. However, the trawl data associated with this report have met final approval by USGS and are available from the GLSC website: https://doi.org/10.5066/F75M63X0 . 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. Please direct any immediate questions to our Information Technology Specialist, Scott Nelson, at snelson@usgs.gov.

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).

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