



## Status of Pelagic Prey Fishes and Pelagic Macroinvertebrates in Lake Michigan, 2009<sup>1</sup>

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### ABSTRACT

Acoustic surveys were conducted in late summer/early fall during the years 1992-1996 and 2001-2009 to estimate pelagic prey fish biomass in Lake Michigan. Midwater trawling during the surveys provided a measure of species and size composition of the fish community for use in scaling acoustic data and providing species-specific abundance estimates. In 2005, we began sampling *Mysis diluviana* during the survey. The 2009 survey provided data from 22 acoustic transects (433 km), 27 midwater tows, and 14 mysid tows. Mean total prey fish biomass was 21.3 kg/ha (relative standard error, RSE = 27.5%) or  $\approx$ 114 kilotonnes (kt, = 1,000 metric tons), which was 1.4 times higher than the estimate for 2008 and 1.2 times the long-term mean. The increase from 2008 was because of increased biomass of age-2 and older alewife, of which the 2005 year-class showed the largest increase. The 2009 alewife year-class contributed  $\approx$ 2% of total alewife biomass (18.6 kg/ha, RSE = 29.0%), while the 2005 alewife year-classes contributed  $\approx$ 34%. In 2009, alewife comprised 87% of total prey fish biomass, while rainbow smelt and bloater were 8 and 5% of total biomass, respectively. Rainbow smelt biomass in 2009 (0.95 kg/ha, RSE = 39%) was lower than biomass in 2008 (1.6 kg/ha). Bloater biomass was much lower (1.75 kg/ha, RSE = 17.3%) than in the 1990s, but mean density of small bloater in 2009 (574 fish/ha, RSE = 22.9 %) was the highest observed in any acoustic survey on record. Additionally, this was the third consecutive year of increased small bloater density. Prey fish biomass remained well below the Fish Community Objectives target of 500-800 kt and only alewife and small bloater are above or near long-term mean abundance levels. Mean density of *Mysis diluviana* has remained relatively constant over time with an observed range from 185 ind./m<sup>2</sup> (RSE = 6.8%) in 2005 to 112 ind./m<sup>2</sup> (RSE = 5.1%) in 2007, and no significant difference in mean density among years. In 2009, mean density of *M. diluviana* was 117 ind./m<sup>2</sup> (RSE = 16 %)

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## INTRODUCTION

In light of changes in the Lake Michigan food web during the last 40 years (Madenjian et al. 2002) and the continuing anthropomorphic influences through introduction of exotic species, pollution, fishing, and fish stocking, regular evaluation of long-term data on prey fish dynamics is critical. The traditional Great Lakes Science Center (GLSC) prey fish monitoring method (bottom trawl) is inadequate for fish located off bottom (Fabrizio et al. 1997). In particular, bottom trawls do not adequately sample young-of-the-year alewives (*Alosa pseudoharengus*), rainbow smelt (*Osmerus mordax*), or bloater (*Coregonus hoyi*). Alewives are the primary prey of introduced salmonines in the Great Lakes (Stewart and Ibarra 1991; Elliot 1993; Rybicki and Clapp 1996; Warner et al. 2008), and, as such, constitute an important food web component. Alewife dynamics typically reflect occurrences of strong year-classes and total alewife density is highly correlated with the density of alewife  $\leq$  age 2 (Warner et al. 2008). Much of the alewife biomass will not be recruited to bottom trawls until age 3, but significant predation by salmonines may occur on alewives  $\leq$  age 2 (Warner et al. 2008). Because of the ability of acoustic equipment to count organisms far off bottom, this type of sampling is ideal for highly pelagic fish like age 0 alewives, rainbow smelt, and bloater and is a valuable complement to bottom trawl sampling.

## METHODS

### *Sampling Design*

The initial Lake Michigan survey adopted by the Lake Michigan 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 the strata (Argyle et al. 1998). A modified stratification (Figure 1) was developed in 2004 (Warner et al. 2005), which included two additional strata (north and south offshore). The initial three strata were retained, but their size was modified based on data collected in 2003 as well as NOAA CoastWatch Great Lakes node maps of sea surface temperature from 2001-2003. In 2007-2009, the number of transects in each stratum was optimized based on stratum area and standard deviation of total biomass using methods in Adams et al. (2006).

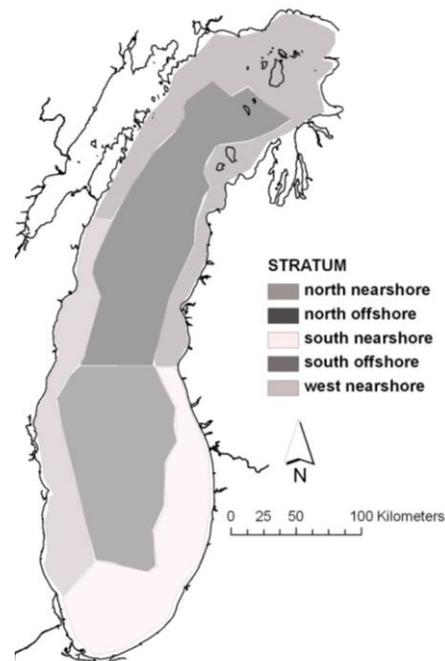


Figure 1. Map of Lake Michigan showing strata used in design and analysis of the lakewide acoustic survey conducted in 2009.

### *Fish Data Collection and Processing*

The lakewide acoustic survey has been conducted as a cooperative effort in most years. Sampling has been conducted between August and November, with acoustic data collection initiated  $\approx$  1 hour after sunset and ending  $\approx$  1 hour before sunrise. Several different vessels have been used ranging in length from 10-32 m and at speeds ranging from 5-11 km/hour. Different echosounders have been used through the years (Biosonics 102 dual beam, DE5000 dual beam, DT split beam, and DT-X split beam). However, acoustic data have always been collected using echosounders with a nominal frequency of 120 kilohertz. With the exception of one unit used in 2001, echosounders have been calibrated during the survey using methods described in Foote et al. (1987) and MacLennan and Simmonds (1992). Transducer deployment techniques have included a towfish, sea

chests (Fleischer et al. 2002), hull mounting, and sonar tubes. Different deployment methods cause variation in the depth of the transducer, and sea chest, hull mount, and sonar tube methods result in a larger portion of the upper water column remaining unsampled because the transducer is deeper.

Midwater trawls were employed to identify species in fish aggregations observed with echosounders and to provide size composition data. Tows targeted aggregations of fish observed in echograms while sampling, and typically trawling locations were chosen when there was uncertainty about the composition of fish aggregations observed acoustically. A trawl with a 5 m headrope and 6.35 mm bar mesh cod end was fished from the S/V Steelhead in all years, while on the USGS vessel R/V Grayling, a variety of trawls were used (Argyle et al. 1998). On the USGS vessels R/V Siscowet, R/V Kiyi and R/V Sturgeon (2001 to present), a trawl with  $\approx 15$  m headrope and 6.35 mm bar mesh cod end was used. In the 1990s, trawl depth was monitored using net sensors. Similar sensors were used in 2001-2005 (except 2002 on USGS vessel, 2001-2004 on MDNR vessel). In cases without trawl sensors, warp length and angle were used to estimate fishing depth.

Fish were measured as total length (TL, mm) either in the field or frozen in water and measured upon return to the laboratory. Lengths of fish in large catches ( $> 100$  fish) were taken from a random subsample. Fish were weighed in groups (total catch weight per species, nearest 2 g) in the field or individually in the laboratory (nearest 0.1 g). Total catch weight was recorded as the sum of weights of individual species. Rainbow smelt were assigned to two size categories ( $< 90$  mm,  $\geq 90$  mm), while the size cutoff for bloater was  $< \text{or} \geq 120$  mm. The small size category for these two species is predominantly age 0, while the large size category consists of fish that are predominantly older than age 0. Alewives were assigned to age classes using an age-length key based on sagittal otolith age estimates. Age-length keys were available for each year except 1992. The key for 1992 was constructed by averaging the 1991 and 1993 keys. Otoliths were aged by the same reader in all years.

#### *Estimates of Fish Abundance*

Transect data were subdivided into elementary distance sampling units (EDSU) consisting either of horizontal intervals between adjacent 10 m bottom contours that were 5 or 10 m deep (1990s) or of 1,000 m intervals that consisted of 10 m layers (2000s). Data collected at bottom depths  $> 100$  m were defined as offshore strata. Data from the 1990s were analyzed using custom software (Argyle et al. 1998). Data collected from 2001-2009 were analyzed with Echoview 4.8 software.

An estimate of total fish density for data from 2001-2009 was made using the formula

$$(1) \text{Total density (fish/ha)} = 10^4 \times \frac{ABC}{\sigma}$$

where  $10^4$  = conversion factor ( $\text{m}^2 \cdot \text{ha}^{-1}$ ),  $ABC$  = area backscattering coefficient ( $\text{m}^2 \cdot \text{m}^2$ ) and  $\sigma$  = the mean backscattering cross section ( $\text{m}^2$ ) of all targets between -60 and -30 dB. An echo integration threshold equivalent to a target strength of -64 dB was applied to  $ABC$  data. Based on a target strength (TS) – length relationship for alewives (Warner et al. 2002), the applied lower threshold should have allowed detection of our smallest targets of interest ( $\approx 20 - 30$  mm age 0 alewife). This threshold may have resulted in underestimation of rainbow smelt density given expected target strengths (Rudstam et al. 2003).

In order to assign species and size composition to acoustic data, we used a technique described by Warner et al. (2009), with different approaches depending on the vertical position in the water column. For cells with depth  $< 40$  m, midwater trawl and acoustic data were matched according to transect, depth layer (0-10, 10-20 m, etc., depending on headrope depth or upper depth of the acoustic cell), and by bottom depth. For acoustic cells without matching trawl data, we assigned the mean of each depth layer and bottom depth combination from the same geographic stratum. If acoustic data still had no matching trawl data, we used a lakewide mean for each depth layer-bottom depth combination. For any cells still lacking trawl

composition data, we assigned them lakewide means for each depth layer. Mean mass of species/size groups at depths < 40 m were estimated using weight-length equations from midwater trawl data. In 2001, trawl data were only available for the north nearshore and north offshore strata. To provide an estimate of species composition and size for other strata, the mean of catch proportions and sizes from 2002-2003 were used. For depths  $\geq 40$  m, we assumed that acoustic targets were large bloater if mean TS was > -45 dB (Tewinkel and Fleischer 1999). Mean mass of bloater in these cells was estimated using the mass-TS equation of Fleischer et al. (1997). If mean TS was  $\leq -45$  dB, we assumed the fish were large rainbow smelt and estimated mean mass from mean length, which was predicted using the TS-length equation of Rudstam et al. (2003).

As recommended by the Great Lakes Acoustic SOP (Parker-Stetter et al. 2009; Rudstam et al. 2009), we used a number of techniques to assess or improve acoustic data quality. We used the  $N_v$  index of Sawada et al. (1993) to determine if conditions in each acoustic analysis cell were suitable for estimation of *in situ* TS. We defined suitability as an  $N_v$  value < 0.1 and assumed that mean TS in cells at or above 0.1 was biased. We replaced mean TS in these cells with mean TS from cells that were in the same depth layer and transect with  $N_v < 0.1$ . We also estimated noise at 1 m in the 20 log range domain using ambient noise from each transect using either passive data collection or echo integration of data below the bottom echo. To help reduce the influence of noise, we used a technique described by De Robertis and Higginbottom (2007) to reduce background noise, which was estimated from ambient noise measurements for each transect. Additionally, we estimated the detection limit (depth) for the smallest targets we include in our analyses. Acoustic equipment specifications, software versions, single target detection parameters, noise levels, and detection limits can be found in Appendices 1 and 2.

Densities (fish/ha) of the different species were estimated as the product of total fish density and the proportion by number in the catch at that location. Total alewife, smelt, and bloater density was subdivided into size or age class-specific density by multiplying total density for these species by the numeric proportions in each age or size group. Biomass (kg/ha) for the different groups was then estimated as the product of density in each size or group and size or age-specific mean mass as determined from fish lengths in trawls (except as described for depths  $\geq 40$  m).

Mean and relative standard error ( $RSE = (SE/mean) \times 100$ ) for density and biomass in the survey area were estimated using stratified cluster analysis methods featured in the statistical routine SAS PROC SURVEYMEANS (SAS Institute Inc. 2004). Cluster sampling techniques are appropriate for acoustic data, which represent a continuous stream of autocorrelated data (Williamson 1982; Connors and Schwager 2002). Density and biomass values for each ESU in each stratum were weighted by dividing the stratum area (measured using GIS) by the number of ESUs in the stratum.

#### *Mysid Data Collection and Processing*

In order to collect *Mysis diluviana*, vertical tows (1-3 m above bottom to the surface) were made at many (but not all) midwater trawl locations in 2005-2009. In some cases, replicate tows were made. The nets used were conical and had a 1-m<sup>2</sup> opening area, net mesh of 1 mm, and cod end mesh of 0.252 mm. Tows were made no earlier than one hour after sunset and no later than one hour before sunrise. Vessel lights were extinguished at least 15 minutes prior to the tows, and the net was retrieved at a speed of  $\approx 0.5$  m/s. Upon net retrieval, specimens were narcotized with an antacid solution and preserved in 100% ethanol. All specimens in each sample were enumerated in the laboratory.

#### *Estimates of Mysid Abundance*

Areal density (#/m<sup>2</sup>) was estimated as the number of mysids in each tow assuming a net efficiency of 100%. In cases where replicate tows were made, the numbers per replicate were averaged. Because most of the variation in Lake Michigan mysid density can be explained by bottom depth (Warner et al. unpublished data), it was necessary to account for the influence of bottom depth in estimates of lakewide

abundance. To this end, lakewide abundance was estimated using a stratified estimator with bottom depth intervals (0-9, 10-19, 20-29 m, etc.) as strata. The area of these depth intervals was estimated using GIS software (excluding Green Bay and Grand Traverse Bay), and sample densities were assigned a weight estimated as the quotient of the number of samples in the individual strata and the area of the strata.

## RESULTS

**Alewife** – Density of alewife in 2009 (867 fish/ha, RSE = 30%) was 49% of the long-term (1992-2008) mean of 1,754 fish/ha. Alewife biomass (18.6 kg/ha, RSE = 29.0%) in 2009 was 21% higher than the long-term mean of 15.4 kg/ha. Mean age of alewife increased from 0.64 years in 2008 to 2.4 years in 2009. Age 0 density (95 fish/ha, RSE = 29%, Figure 2), was 7 % of long-term mean of 1,287 fish/ha and was the lowest of any acoustic survey. Age 0 alewife made up 11% of alewife density in 2009, but made up only 2% of alewife biomass. Age 1 and older alewife (YAO) biomass was relatively constant from 2001-2007 (Figure 3) but tripled from 2007 to 2008 and then nearly doubled from 2008 to 2009. In 2009 the YAO group consisted of fish from the 2002 -2007 year-classes. The 2005 year-class contributed 34% of alewife biomass, while the 2007 year-class made up 25 %. The 2002-2004 year-classes contributed a total of 7% (Figure 4). The 2005 alewife year-class was the second largest since 1995 and made up the largest portion of alewife biomass in 2009, supporting a previous report (Warner et al. 2006) that it was a strong year-class.

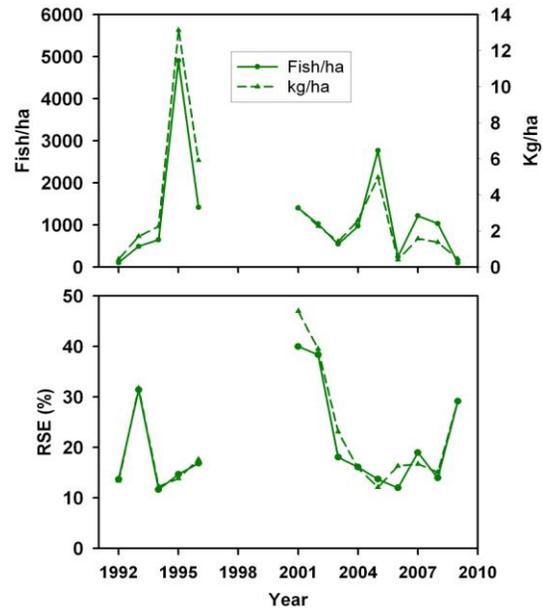


Figure 2. Acoustic estimates of age 0 alewife density and biomass in Lake Michigan, 1992-2009 (upper panel) shown with relative standard error of the estimates (RSE, lower panel).

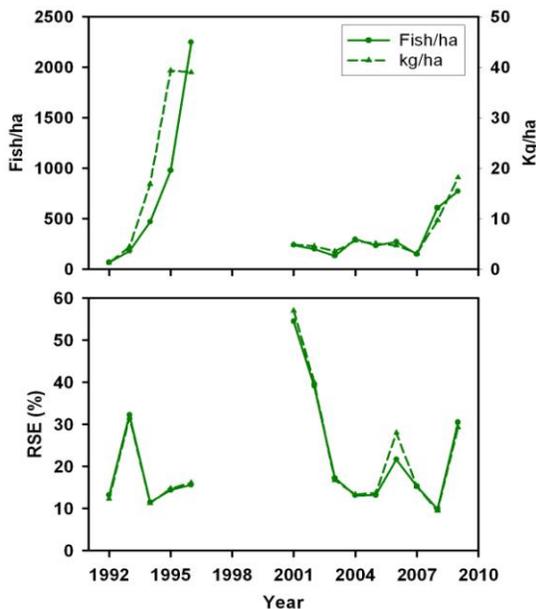


Figure 3. Acoustic estimate of yearling-and-older alewife density in Lake Michigan, 1992-2009 (upper panel) shown with relative standard error of the estimates (RSE, lower panel).

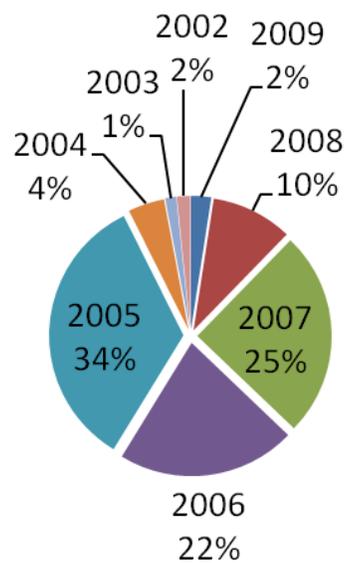


Figure 4. Percent contribution of alewife year-classes to alewife biomass during 2009. Labels show year class and percent of alewife biomass.

Acoustic and bottom trawl survey results differed in magnitude for adult alewife biomass in 2009, with the acoustic biomass estimate 5.7 times the bottom trawl biomass estimate. However, estimates from both surveys showed a similar increase from 2008 to 2009 with the 2009 estimate 1.9 times the 2008 estimate (Madenjian et al. 2010). The difference in YAO biomass between the surveys likely arose for two reasons. First, much of the increase observed in the acoustic survey was the result of growth of the 2007 and 2008 year classes, which are not yet recruited to the bottom trawl. Second, the two surveys sample different areas and depth ranges, which can contribute to differences in biomass estimates stemming from patchiness of fish. The acoustic survey RSE for YAO alewife increased in 2009, as did the bottom trawl RSE (Madenjian et al. 2010), suggesting patchiness may have increased.

**Rainbow smelt** – Acoustic density and biomass estimates increased steadily from 2002-2006 (Figure 5), as did commercial catch per unit effort (Scott Nelson, GLSC, 1451 Green Road, Ann Arbor MI 48105, unpublished data). Rainbow smelt density in 2009 (306 fish/ha, RSE = 28.5%) was only 24% of the 2008 density and biomass of rainbow smelt (0.95 kg/ha, RSE = 39.4%) was 59 % of the 2008 biomass. Biomass in 2009 was only 3 % of the long term mean. Rainbow smelt > 90 mm in length constitute roughly 54% of the population and 90% of rainbow smelt biomass. Acoustic survey results were not consistent with bottom trawl results for 2009, as the bottom trawl results indicated that rainbow smelt biomass increased in 2009 (Madenjian et al. 2010).

**Bloater** – Bloater continue to be present at low densities relative to the 1990s. However, mean density in 2009 (624 fish/ha, RSE = 22.3%) was the highest since 1996. The mean density of small bloater (< 120 mm) was 574 fish/ha (RSE = 22.9%, Figure 6) with small bloater being the largest component of total bloater density and exhibiting the highest density recorded in 14 years of acoustic sampling. In 2009, the mean density of large bloater was 74 fish/ha (RSE = 15.4%). Mean biomass of large bloater in 2009 was 1.6 kg/ha (RSE = 19.0 %, Figure 7), which was similar to the 2001-2008 mean (1.8 kg/ha). It is not clear what led to the drastic decline in bloater abundance from the 1980s to present. Madenjian et al. (2002) proposed that

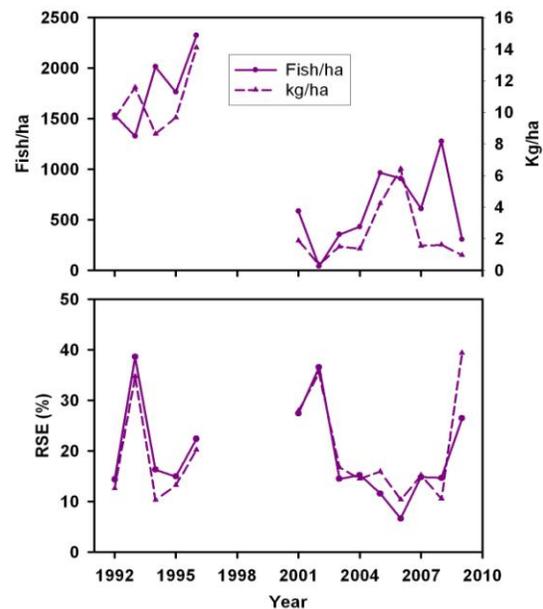


Figure 5. Acoustic estimates of rainbow smelt density and biomass in Lake Michigan in fall 1992-2009 (upper panel) shown with relative standard error of the estimates (RSE, lower panel).

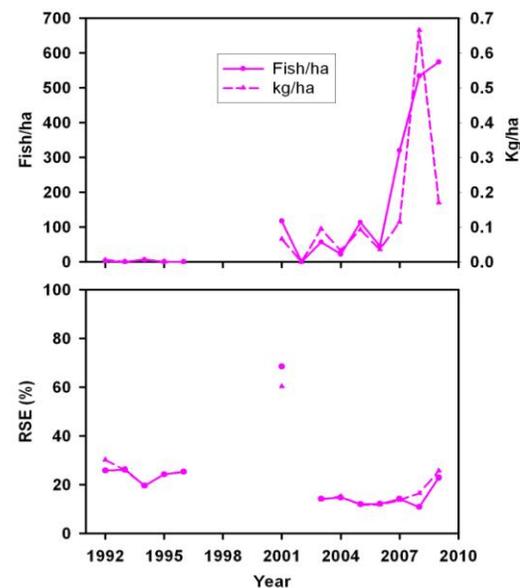


Figure 6. Acoustic estimates of small bloater density and biomass in Lake Michigan in fall 1992-2009 (upper panel) shown with relative standard error of the estimates (RSE, lower panel).

bloater recruitment and abundance are regulated by internal cycling, and Bunnell et al. (2006) found that during periods of low abundance and recruitment, the sex ratio of bloater is predominantly female, while during periods of high abundance and recruitment sex ratio is more balanced. The sex ratio was more balanced in 2009 than in earlier years (J.D. Holuszko, unpublished data). It is possible that predation influences bloater abundance because juvenile bloater can at times be important in the diets of some predators (Elliot 1993; Rybicki and Clapp 1996; Warner et al. 2008).

Seasonal predator diet data from a large portion of the lake might improve our understanding of the importance of bloater as prey. Madenjian et al. (2010) reported from the bottom trawl survey that there was a three-fold increase in large bloater biomass from 2008 to 2009, while acoustic and midwater trawl data suggest there was a decrease from 2008 to 2009. Although the change from 2008 to 2009 differed between these two surveys, both surveys estimated similar biomass levels of large bloater (1.58 and 1.76 kg/ha, for the acoustic and bottom trawl surveys, respectively). It is not clear when bloater become demersal and are fully recruited to the bottom trawl. Wells and Beeton (1963) suggested that the switch from pelagic to demersal occurred at age 3, while Crowder and Crawford (1984) suggested the switch occurred by age 1 in 1979-1980. Scale age estimates for bottom trawl-caught fish in 2009 indicate that many large bloaters are  $\leq$  age 3 (J.D. Holuszko, unpublished data) which suggests many bloaters may not be recruited to the bottom trawl.

*Mysis diluviana* –Estimates of *Mysis diluviana* density were available from 30, 12, 16, 27, and 14 sites in 2005, 2006, 2007, 2008, and 2009, respectively. Mean density ranged from 185 ind./m<sup>2</sup> (RSE = 6.8%) in 2005 to 112 ind./m<sup>2</sup> (RSE = 5.2%) in 2007, with a mean of 117 ind./m<sup>2</sup> (RSE = 16.0 %) in 2009 (Figure 8). Although density decreased from 2005 to 2009, there were not statistically significant differences in density among years based on results of general linear models ANOVA ( $P = 0.30$ ,  $F = 1.0$ ,  $df = 3, 94$ , and  $98$ ). The mean density observed in 2009 was similar to that observed in

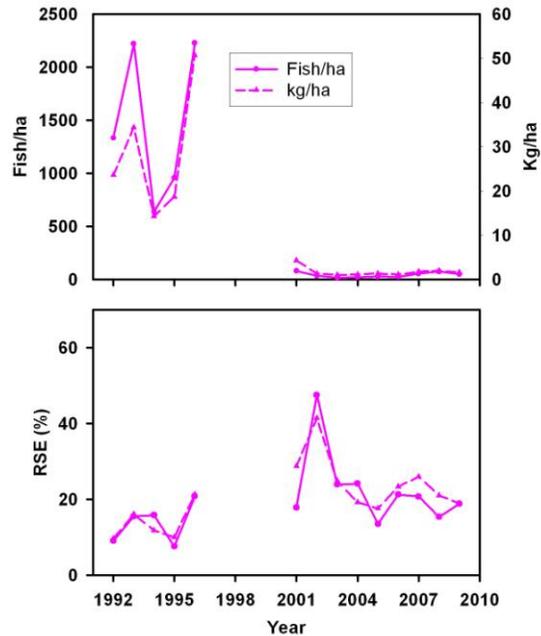


Figure 7. Acoustic estimates of large bloater density and biomass in Lake Michigan in fall 1992-2009 (upper panel) shown with relative standard error of the estimates (RSE, lower panel).

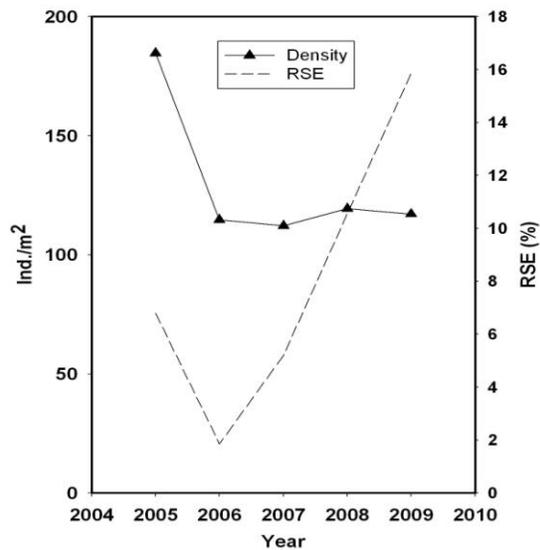


Figure 8. Mean density of *Mysis diluviana* in Lake Michigan in late summer/fall 2005-2009 shown with relative standard error of the estimates (RSE).

2000 (Pothoven et al. 2004) and 2006-2008. Our results as well as the results of Pothoven et al. (2004) suggest a) that densities in 2005 may have been unusually high and that values observed in 2000 and 2006-2009 are more typical and b) current late summer densities appear to be similar to levels in the late 1980s (Lehman et al. 1990). One caveat regarding comparisons with data from Lehman et al. (1990) is that even though their data represented the first synoptic surveys of mysids in Lake Michigan, there were typically few (6-8) stations sampled in each year. Although little evidence exists to suggest that *M. diluviana* density has decreased from the 1980s, it is worth pointing out that density has not increased in spite of a very large decrease in pelagic fish abundance and a presumed concomitant decrease in predation pressure (Claramunt et al. 2010). The lack of an increase in recent years may be a result of decreased availability/quality of food. The spring diatom bloom, which has been cited as an important source of energy for mysids (Johannsson et al. 2001), has decreased in recent years (Fahnenstiel et al. in press). Additionally, *M. diluviana* is still facing competition for zooplankton food from *B. longimanus*, which can consume its own body mass each day (Yurista and Schulz 1995). The abundance of *B. longimanus* is likely as high or higher than in the period from 1985-1996 when fish biomass and fish predation on both mysids and *B. longimanus* were much higher in Lake Michigan (Henry Vanderploeg, personal communication). This supposition is supported by a mean density of  $\approx 5$  individuals/m<sup>3</sup> from our mysid tows in 2008-2009, which are almost certainly biased low, but were half the late summer lakewide mean reported for the period 1983-1999 by Barbiero et al. (2004).

## CONCLUSIONS

As with any survey, it is important to note that trawl or acoustic 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 bottom (bottom 0.3-1 m) and the surface (0-3 m) are not sampled well or at all. The density of fish in these areas is unknown. Time limitations preclude the use of upward or side-looking transducers. If one assumes that fish available to a bottom trawl with  $\approx 1$  m fishing height at night are not available to acoustic sampling, it is doubtful that the bottom deadzone contributes much bias for alewife and rainbow smelt because of their pelagic distribution at night. 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. After examining these data we found that night bottom trawl estimates of alewife density in August/September 1987 were only 4% of day estimates (D.M. Warner, unpublished data). Similarly, night bottom trawl estimates of rainbow smelt density were  $\approx 3\%$  of day estimates. Evidence suggests bloater tend to be more demersal; in Lake Superior, night acoustic/midwater trawl sampling may detect only 60% of bloater present (Yule et al. 2007). Day-night bottom trawl data from Lake Michigan in 1987 suggests that the availability of bloater to acoustic sampling ranges from 7-76%. Slimy sculpins (*Cottus cognatus*) and deepwater sculpins (*Myoxocephalus thompsonii*) are poorly sampled acoustically and we must rely on bottom trawl estimates for these species. Alewife and rainbow smelt (primarily age 0) may occupy the upper 3 m of the water column and any density in this area results in underestimation of water column and mean lakewide density. Depending on season, in inland New York lakes and Lake Ontario, 37-64% of total alewife catch in gill nets can occur in the upper-most 3 m (D.M. Warner, unpublished data). However, 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).

We made additional assumptions about acoustic data not described above. For example, we assumed that all targets below 40 m with mean TS > -45 dB were bloater. 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) and biased TS estimates are used. However, we identified areas where TS was biased and replaced these biased values with unbiased values from nearby areas in the same depth area. Of 4,330 acoustic analysis cells in 2009, only 20 (< 1 %) were identified as being

unsuitable for estimation of in situ TS. Finally, we assumed that noise levels did not contribute significantly to echo integration data and did not preclude detection of key organisms. This assumption was supported by our estimates of noise and detection limits for targets of interest (Appendix 2).

Prey fish biomass in Lake Michigan remains at levels much lower than in the 1990s, but the estimate of total lakewide biomass (114 kt) from acoustic sampling was the highest in 2001-2009. However, the vast majority of biomass was YAO alewife, and with the exception of alewife and small bloater, other species or size categories we reported here were well below (> 20 %) their long-term averages. The large difference in biomass from the 1990s resulted primarily from the decrease in large bloater abundance, but alewife and rainbow smelt declined as well. Pelagic fish biomass was not evenly split among the species present in 2009 (Table 1), but increasing density of small bloater suggests that there may be some progress toward meeting the Fish Community Objectives (FCO, Eshenroder et al. 1995) of maintaining a diverse planktivore community. Bloater densities have shown an increasing trend since 2001, with most of the increase driven by increases in small bloater. A similar pattern has been observed in Lake Huron (Schaeffer et al. 2010), and in both lakes, bottom trawl estimates of large bloater density have increased in recent years (Madenjian et al. 2010; Riley et al. 2010), which is consistent with the conclusion of Bunnell et al. (2010) that bloater populations in lakes Michigan and Huron exhibited synchrony in abundance. Bloater and emerald shiner (*Notropis atherinoides*) were historically important species, but bloater currently exist at low biomass levels and emerald shiner have never been detected in this survey. In Lake Huron, near-collapse of the alewife population in 2003-2004 was followed by resurgence in emerald shiner abundance in 2005-2006 (Schaeffer et al. 2008) and by increased abundance of cisco [*Coregonus artedii*, (Warner et al. 2009)]. Given evidence from acoustic survey evidence from lakes Michigan and Huron as well as the evidence provided by Madenjian et al. (2008), it appears that emerald shiners are suppressed by all but the lowest levels of alewife abundance.

Predation by Chinook salmon has a strong influence on recruitment success of alewife in Lake Michigan (Madenjian et al. 2005). The recent increase in alewife biomass as well as the mean age of the alewife population suggests that predation pressure exerted by Chinook salmon has decreased. Measures of abundance and growth of predators including Chinook salmon and coho salmon (*Oncorhynchus kisutch*) support the observations of increased alewife biomass. Angler catch rates of Chinook salmon, indexed by the charter fishery reports, declined from a high of 0.300 fish / hr in 2006 to 0.247 fish / hr in 2009. The proportion of anglers harvesting three Chinook salmon per day can be used as an index of angler success related to the relative abundance of Chinook salmon (Claramunt et al. 2009). In 2009, the percent of successful anglers catching 3 fish per day in the charter fishery dropped from a high of 29.5% in 2006 down to 13.9%, supporting the assertion that Chinook abundance has declined. Growth of Chinook salmon has stabilized or increased, depending on the growth measure, and growth of coho salmon has increased (Claramunt et al. 2010). It has also been suggested that variation in alewife year-class strength influences recruitment of Chinook salmon, Warner et al. (2008) found that the abundance of age-1 Chinook salmon was positively correlated with the abundance of age 0 alewife in the previous year. Given that relationship, we predict relatively poor survival of the 2009 Chinook salmon year class and a potential continued decline in salmon abundance. Current research efforts focused on Chinook salmon recruitment may allow testing of such predictions in the near future.

Prey biomass based on the acoustic survey data collected in 2009 (95% CI = 60 – 169 kt) was low relative to the FCO, which calls for maintenance of a diverse planktivore community at abundance levels matched to primary production and predator demand (500-800 kt). With sculpin biomass from the bottom trawl survey (Bunnell et al. 2009a) added to the acoustic biomass of other species, estimated lakewide biomass (67-176 kt) is still less than the FCO range. Fleischer et al. (2005) argued this FCO target range was attainable when bloater abundance was high, but was likely not sustainable. Although planktivorous fish biomass is low relative to the FCO and values observed in the past, it does appear that *Mysis diluviana*, one organism key to the evolution of (and perhaps restoration of) the native coregonine community

(Eshenroder and Burnham-Curtis 1999) is probably at levels similar to pre-dreissenid years and is certainly present at levels similar to those observed prior to the recent expansion of dreissenid mussels described by Bunnell et al. (2009b). Although the decline in salmon abundance has likely influenced our observed increases in alewife biomass, recent declines in alewife recruitment (2008 and 2009 year class) may be the indirect result of expansion of dreissenid mussels and the associated disturbance of nutrient transfer in the food web.

Table 1. Biomass, RSE, and 95% CI for age 0, YAO, total alewife, rainbow smelt, and bloater estimated from acoustic and midwater trawl data collected in Lake Michigan in 2009.

| Species       | Biomass (kg/ha) | RSE (%) | 95% CI       |
|---------------|-----------------|---------|--------------|
| Age 0 alewife | 0.5             | 29      | (0.2,0.7)    |
| YAO alewife   | 18.1            | 29      | (8.9, 27.4)  |
| Total alewife | 18.6            | 29      | (9.1, 28.0)  |
| Rainbow smelt | 1.0             | 39      | (0.3, 1.6)   |
| Bloater       | 1.8             | 17      | (1.2, 2.3)   |
| Total         | 21.4            | 27      | (11.2, 31.6) |

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Appendix 1. Single target detection parameters used in acoustic data analyses in 1992-1996 and 2009.

| Parameter                                       | Split <sup>1</sup> | Dual beam 1992-1996 | Dual beam 2001-2005 |
|---|--------------------|---------------------|---------------------|
| TS threshold (dB)                               | -77                | -60                 | -77                 |
| Pulse length determination level (dB)           | 6                  | 6                   | 6                   |
| Minimum normalized pulse length                 | 0.8                | 0.32                | 0.8                 |
| Maximum normalized pulse length                 | 1.8                | 0.72                | 1.8                 |
| Maximum beam compensation (dB)                  | 6                  | 6                   | 6                   |
| Maximum standard deviation of minor-axis angles | 0.6                | NA                  | NA                  |
| Maximum standard deviation of major-axis angles | 0.6                | NA                  | NA                  |
| Over-axis angle threshold (dB)                  | NA                 | NA                  | -1.0                |

<sup>1</sup>Although a lower threshold was used in 2001-2009, only targets  $\geq -60$  dB were included as in analyses of the 1990s data.

Appendix 2. Noise levels (mean and range of Sv and TS at 1 m), detection limits, and acoustic equipment specifications in 2009 for the R/V Sturgeon and S/V Steelhead.

| Vessel   | R/V Sturgeon           | S/V Steelhead          |
|--|------------------------|------------------------|
| Collection software                                | Visual Acquisition 5.1 | Visual Acquisition 5.1 |
| Source level at 1 m (dB rel 1 $\mu$ Pa)            | 223                    | 223.8                  |
| Transducer beam angle (3dB)                        | 7.8° split beam        | 6.9° split beam        |
| Frequency (kHz)                                    | 120                    | 129                    |
| Pulse length (ms)                                  | 0.4                    | 0.4                    |
| Absorption coefficient range (dB/m)                | 0.0034 – 0.0058        | 0.0034 – 0.0059        |
| Mean of Sv noise at 1 m (dB)                       | -127 <sup>1</sup>      | -122 <sup>2</sup>      |
| Detection limit (m) for -60 dB target <sup>3</sup> | 104                    | 85                     |

<sup>1</sup> Mean of values estimated by integrating passive data collected on each transect.

<sup>2</sup> Mean of values estimated by integrating areas under the bottom echo for each transect.

<sup>3</sup> Assuming a density of 1 individual/m<sup>3</sup> and a signal-to-noise ratio of 3 dB.