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Status of Pelagic Prey Fishes in Lake Michigan, 1992-2007

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ABSTRACT

Acoustic surveys were conducted in late summer/early fall during the years 1992-1996 and 2001-2007 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. The 2007 survey provided data from 21 acoustic transects and 41 midwater tows. Mean total prey biomass was 8.2 kg/ha (RSE = 6.4%) or ~40 kilotonnes (kt) (or 1,000 metric tons), which was 32% lower than the estimate for 2006 and, largely a result of decreased rainbow smelt biomass. Total biomass in 2007 was 47% lower than in 2005, largely a result of decreased biomass of alewife and rainbow smelt. The 2007 alewife year-class contributed ~33% of total alewife biomass (4.7 kg/ha, RSE = 10.7%), while the 2005 alewife year-class contributed ~47% of alewife biomass. The remaining 20% of alewife biomass consisted of the 2000, 2002, 2003, 2004, and 2006 year-classes. In 2007, alewife comprised 57% of total biomass, while rainbow smelt and bloater were 19 and 23% of total biomass, respectively. Rainbow smelt biomass exhibited an increasing trend from 2002-2006 with the population consisting primarily of larger fish (≥ 90 mm), but rainbow smelt biomass was much lower in 2007 (1.6 kg/ha, RSE = 15.8%) than in 2006. Bloater biomass was again much lower (1.9 kg/ha, RSE = 24.0%) than in the 1990s, but mean density of small bloater in 2007 (320 fish/ha, RSE = 14.2) was the highest observed in any acoustic survey on record. Although acoustic and midwater trawl data suggest that the preyfish community is somewhat more diverse than in the previous five years, preyfish biomass remained well below the Fish Community Objectives target of 500-800 kt.

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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, and have been, the primary prey of introduced salmonines in the Great Lakes (Stewart and Ibarra 1991; Elliot 1993; Rybicki and Clapp 1996; Warner et al. accepted). Alewife dynamics typically reflect occurrences of strong year-classes and total alewife density is highly correlated with the density of alewife ≤ age–2 (Warner et al. accepted). Much of the alewife biomass will not be recruited to bottom trawls until age–3, but significant predation by salmonines may occur on alewives ≤ age–2 (Warner et al. accepted). 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, 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).

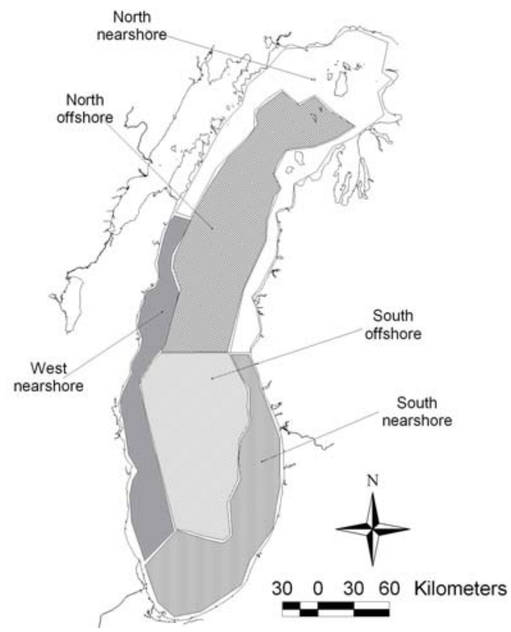

Figure 1. Map of Lake Michigan showing strata used in design and analysis of the lakewide acoustic survey conducted in 2004.

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 ~1 hour after sunset and ending ~1 hour before sunrise. Several different vessels have been used (10-32 m in length) at speeds the range of 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. Variation in vessels has had an unknown influence on the data but it is doubtful that this variation has contributed to observed patterns or masked unknown patterns. 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. On the USGS vessels R/V Siscowet, R/V Kiyi and R/V Sturgeon (2001 to present), a trawl with ~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 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, ≥ 90 mm TL), while the size cutoff for bloater was < or > 120 mm TL (Madenjian et al. 2008). 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 except 1991.

Estimates of Abundance

Transect data were subdivided into elementary sampling units (ESU) 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 2001-2007 were analyzed with Echoview 4.0 software.

An estimate of total fish density for data from 2001-2007 was made using the formula

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

where 10^4 = conversion factor ($m^2 \cdot ha^{-1}$), *ABC* = area backscattering coefficient ($m^2 \cdot m^2$) and σ = the mean backscattering cross section (m^2) of all targets between -60 and -30 dB. 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 (~20 – 30 mm age-0 alewife). This threshold may have resulted in underestimation of rainbow smelt density given expected target strengths published by Rudstam et al. (2003).

In order to assign species and size composition to acoustic data, we used 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 ≥ 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 ≤ -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).

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 group. Biomass (kg/ha) for the different groups was then estimated as the product of density and species or age-specific mean mass as determined from fish lengths in trawls (except as described for depths ≥ 40 m).

Mean and relative standard error (RSE = (SE/mean) x 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.

A map of interpolated biomass (kg/ha) was created for all species age or size groups to present spatial patterns present during the survey in 2007. Biomass data with a spatial resolution of 1,000 m were interpolated using second-power inverse distance weighting with a fixed search radius of 40,000 m and a minimum of 10 points included for each predicted 4,000 x 4,000 m cell.

Results

Alewife – Density of alewife in 2007 (1,361 fish/ha, RSE=16.6%) was ~2.7 x higher than in 2006. This increase was primarily the result of higher age-0 density (1,212 fish/ha, RSE=19.0%, Figure 2), which was similar to the long-term mean (± 95% confidence interval) of 1,367 ± 976 fish/ha. Alewife biomass (4.7 kg/ha, RSE=10.7%) in 2007 was 92% of the 2006 biomass. Age-0 alewife made up 89% of alewife density in 2007, but made up only 7% of alewife density in 2006. Age-1 and older alewife (YAO) biomass has been relatively constant since 2001 (Figure 3). In 2007 the YAO

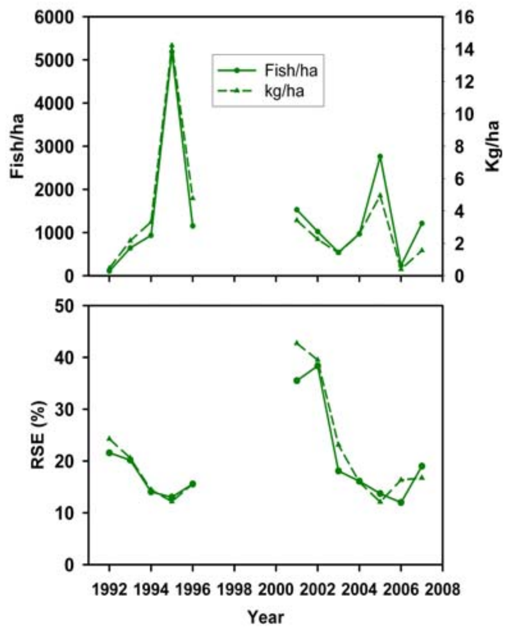

Figure 2. Acoustic estimates of age-0 alewife density and biomass in Lake Michigan,1992-2007 (upper panel) shown with relative standard error of the estimates (RSE, lower panel).

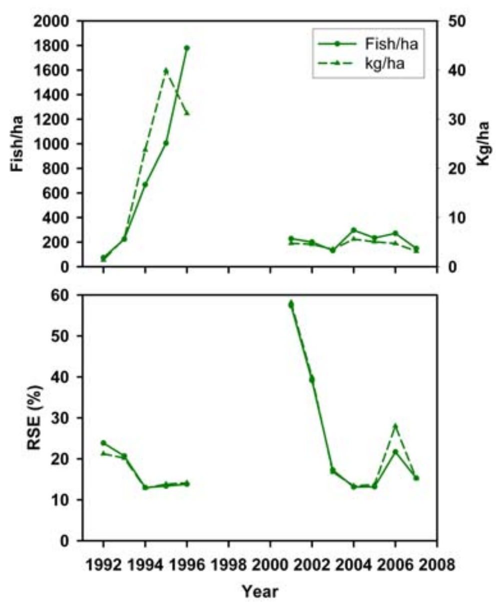

Figure 3. Acoustic estimate of yearling-and-older alewife density in Lake Michigan, 1992-2007 (upper panel) shown with relative standard error of the estimates (RSE, lower panel).

group consisted of fish from the 2000 and 2002-2006 year-classes. The 2006 year-class was the second smallest observed at age-0 in 12 years of acoustic surveys, which explains the minor contribution (5%) it made to total alewife biomass in 2007. The 2005 year-class contributed 47.2% of YAO alewife biomass, while the 2000 and 2002-2004 and 2006 year-classes contributed a total of 19.4% (Figure 4). The 2005 alewife year-class was the second largest since 1995 and made up the largest portion of alewife biomass in 2007, supporting a previous report (Warner et al. 2006) that it was a strong year-class. Age-0 and YAO alewife exhibited very different spatial distributions. With the exception of the area between Frankfort and the Manitou Islands, age-0 biomass was less than 1

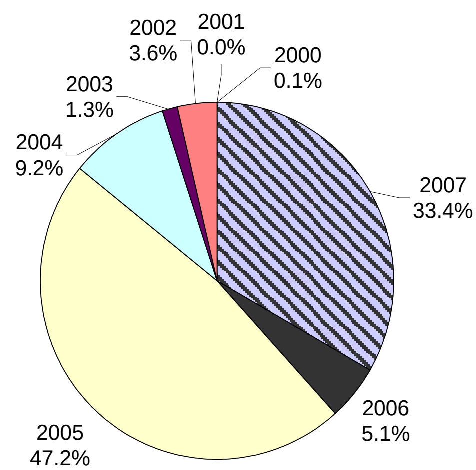

Figure 4. Percent contribution of alewife year-classes to alewife biomass during 2007. Labels show year class and percent of alewife biomass.

kg/ha in the entire northern half of the lake (Figure 5). The highest biomass estimates (2.2-14.1 kg/ha) were observed in an area between Whitehall and St. Joseph, Michigan. Biomass of YAO alewife was more patchy, with high biomass areas spread throughout the northern and eastern portion of the lake. The highest biomass occurred in small patches west of St. Joseph and Ludington, MI but there were other areas in Michigan waters with high biomass in the vicinity of Grand Haven, Frankfort-Pyramid Point, Charlevoix, and Manistique. In Wisconsin waters, a small area of high biomass was observed near Washington Island. Acoustic and bottom trawl survey results were relatively consistent; Madenjian et al. (2008) reported a slight increase in alewife biomass, while acoustic survey

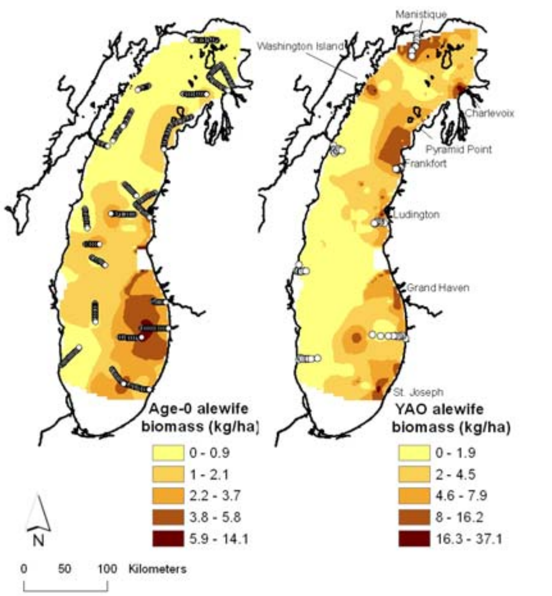

Figure 5. Map of 2007 Lake Michigan acoustic transects and interpolated alewife biomass estimated using acoustic data from Lake Michigan, August/September 2007. Symbols in left panel represent individual 1,000 m segments of acoustic transects. Symbols in the right-hand panel represent locations from the bottom trawl survey.

results suggest there was a small decrease. In both cases, the differences were probably smaller than that which can be deemed significant by each survey. Differences between the surveys may have been the result of spatial distribution and patchiness of alewife biomass; the RSE for bottom trawl-estimated alewife biomass was at an all-time high in 2007 (Madenjian et al. 2008), suggesting increased patchiness in 2007.

<u>Rainbow smelt</u> – Acoustic density and biomass estimates increased steadily from 2002-2006 (Figure 6), as did commercial catch per unit effort (Scott Nelson, GLSC, 1451 Green Road, Ann Arbor MI 48105, unpublished data). However, rainbow smelt density in 2007 (610 fish/ha, RSE=14.9%) was ~33% lower than in 2006. Biomass of rainbow smelt (1.6 kg/ha, RSE=15.8%) was 19% of total prey biomass. Rainbow smelt > 90 mm in length constitute roughly 40% of the population and 94% of rainbow smelt biomass.

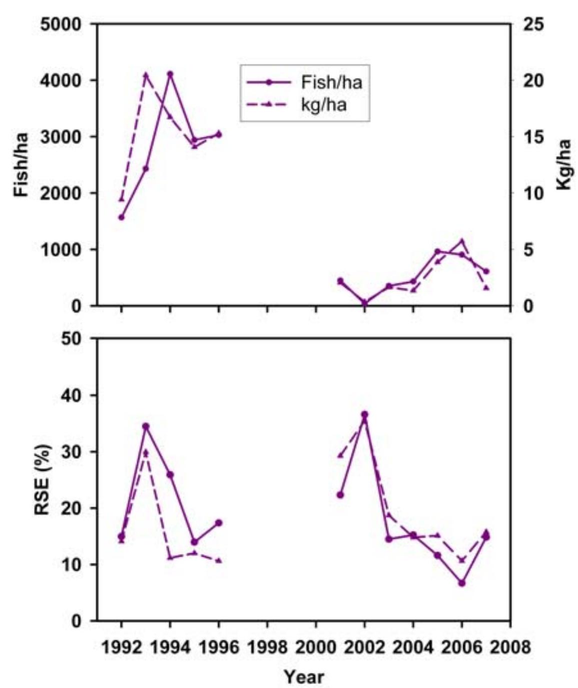

Figure 6. Acoustic estimates of rainbow smelt density and biomass in Lake Michigan in fall 1992-2007 (upper panel) shown with relative standard error of the estimates (RSE, lower panel).

The cause(s) for the large decrease in rainbow smelt biomass observed in 2007 are not clear. Rainbow smelt are consumed by intermediate-sized lake trout in nearshore waters (Madenjian et al. 1998), and statistical catch-at-age estimates suggest that lake trout biomass in Michigan waters may have doubled since 2002 (Jory Jonas, Michigan DNR Charlevoix Fisheries Research Station, 96 Grant Street, Charlevoix MI 49720, personal communication). Acoustic survey results indicated a larger decrease in rainbow smelt biomass (73%) than observed in bottom trawl data (63%). This difference could have been the result of distribution patterns (Figure 7). The biomass of small rainbow smelt was highest from the eastern shoreline to mid-lake, with the largest area of high biomass observed between Frankfort and Pyramid Point. The biomass of large rainbow smelt was more evenly distributed throughout the lake.

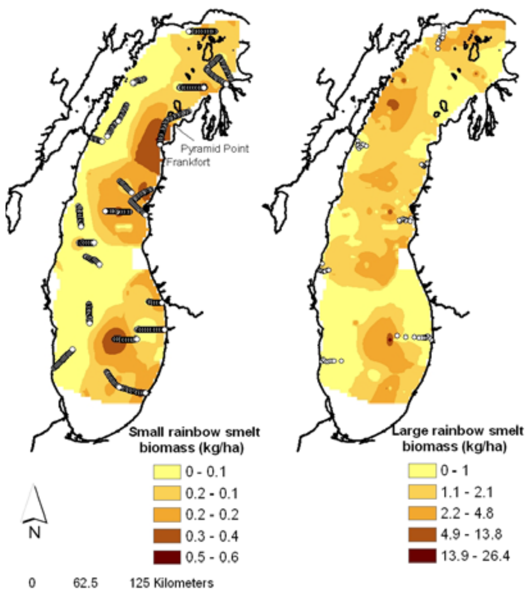

Figure 7. Map of interpolated rainbow smelt biomass estimated using acoustic data from Lake Michigan, August/September 2007. Symbols in left panel represent individual 1,000 m segments of acoustic transects. Symbols in the right-hand panel represent locations from the bottom trawl survey.

Bloater – Bloater continue to be present at low densities relative to the 1990s. However, mean density in 2007 (374 fish/ha, RSE = 12.3%, Figure 8) was the highest since 1996. The mean density of small bloater (<120 mm) was 320 fish/ha (RSE = 14.2%), the highest recorded in 12 years of acoustic sampling. In 2007, the mean density of large bloater was 54 fish/ha (RSE=20.8%). Mean biomass of large bloater in 2007 was 1.8 kg/ha (RSE=26.0%), which was 58% higher than in 2006 but similar to the 2001-2006 mean of 1.7 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 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 2007 than in earlier years, but the ratio is still skewed

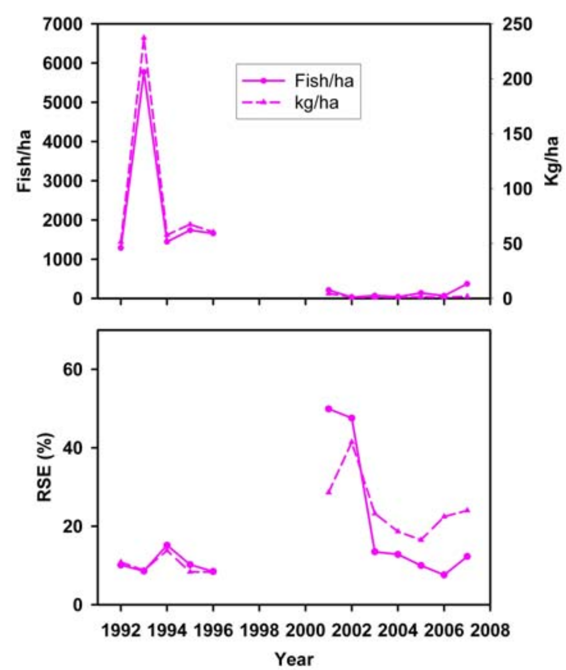

Figure 8. Acoustic estimates of bloater density and biomass in Lake Michigan in fall 1992-2007 (upper panel) shown with relative standard error of the estimates (RSE, lower panel).

with higher abundance of females (J.D. Holuszko, unpublished data). It is possible that predation has influenced 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. accepted). For example, Chinook salmon can consume bloaters and their abundance was probably well below the 1976-2004 average during 1992-1995 and well above average in recent years (2000-2004). However, there is little evidence of substantial bloater consumption by Chinook salmon in the period from 2001-2004 (Warner et al. accepted; R.M. Claramunt unpublished data). Madenjian et al. (2008) reported from the bottom trawl survey that there was a 59% decrease in bloater biomass from 2006 to 2007, while acoustic and midwater trawl data suggest there was a 63% increase in bloater biomass relative to 2006. Two factors may have contributed to this difference. First, it appears that spatial distribution of bloater biomass may have been such that many high-biomass areas were only sampled acoustically (Figure 9). Second, 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 2007 suggest that many large bloater are ≤ age-2 (J.D. Holuszko, unpublished data) which suggests many bloater may not be recruited to the bottom trawl. Spatial patterns for biomass of small and large bloater differed. The highest biomass of small bloater was found well offshore in the southern end of the lake, while the highest biomass of large bloater occurred somewhat further north near the Mid-Lake Plateau (Figure 9).

CONCLUSIONS

As with any survey, it is important to note that trawl or acoustic estimates of fish biomass are potentially biased and, when

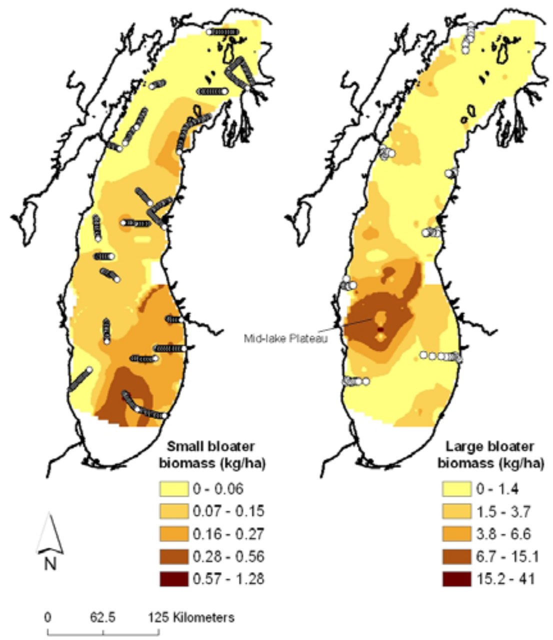

Figure 9. Map of interpolated bloater biomass estimated using acoustic data from Lake Michigan, August/September 2007. Symbols in left panel represent individual 1,000 m segments of acoustic transects. Symbols in the right-hand panel represent locations from bottom trawl survey.

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 ~ 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 ~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 suggest that the availability of bloater to acoustic sampling varies by depth with night bottom trawl densities ranging from 7-76% of day estimates. Sculpins 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 (D.M. Warner, unpublished data). Additionally, 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.

Prey fish biomass in Lake Michigan remains at levels much lower than in the 1990s, and the estimate of total lakewide biomass (40 kt) from acoustic sampling was the second lowest observed in 12 years (the lowest was in 2003). The large difference in biomass from the 1990s resulted primarily from the decrease in bloater abundance, while the decrease in biomass from 2005 to 2007 was primarily a result of a decrease in rainbow smelt and alewife biomass.

Pelagic fish biomass was more evenly split among the species present in 2007 than in some years (Table 1), which is evidence of some progress toward the Fish Community Objectives (FCO, Eshenroder et al. 1995) of maintaining a diverse planktivore community. However, the two most dominant species are non-native. 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. accepted). It appears that emerald shiners are suppressed by all but the lowest levels of alewife abundance.

Table 1. Density, 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 2007.

Species	**Biomass (kg/ha)**	**RSE (%)**	**95% CI**
Age-0 alewife	1.6	16	(1.1,2.0)
YAO alewife	3.1	15	(2.3, 3.9)
Total alewife	4.7	11	(3.8, 5.6)
Rainbow smelt	1.6	16	(1.1, 2.0)
Bloater	1.9	24	(1.1, 2.7)
Total	8.2	6	(7.3, 9.1)

Prey biomass available to the acoustic survey in 2007 (95% CI = 35.5 – 44.4 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 (Madenjian et al. 2008) added to the acoustic biomass of other species, estimated lakewide biomass (49-58 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.

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