Lake Michigan Committee
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Status of Pelagic Prey Fishes in Lake Michigan, 1992-2006

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ABSTRACT

Acoustic surveys were conducted in late summer/fall during the years 1992-1996 and 2001-2006 to estimate 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 2006 survey provided data from 13 acoustic transects and 23 midwater tows. Mean total prey biomass was 10.1 kg/ha (RSE=8.9%), similar to the estimate for 2005 (12.7 kg/ha, RSE=9.7%). The 2006 alewife year-class contributed ~10% of alewife biomass, while the 2005 alewife year-class contributed ~46% of alewife biomass. Another 36% of alewife biomass consisted of similar contributions (11-13%) of the 2002-2004 year-classes. The 1998 year-class was still present and made up 1% of biomass. In 2006, alewife and rainbow smelt biomass were similar (4.6 and 4.2 kg/ha, respectively), whereas in the previous five years rainbow smelt biomass was only 2-36% of alewife biomass. Rainbow smelt biomass has exhibited an increasing trend since 2002 and in 2006 consisted primarily of larger fish (≥90 mm, 92% of rainbow smelt biomass). Bloater biomass was again much lower (1.4 kg/ha, RSE=7.1%) than in the 1990s, but mean density of small bloater in 2006 (50.0 fish/ha, RSE=16.7) was the fourth highest observed since 1992. 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. Without recovery of the bloater population to levels in the 1980s and early 1990s, it seems likely that preyfish biomass will remain below the target level.

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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 influence of humans through introduction of exotic species, pollution, fishing, and fish stocking, enhancement 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*). 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.

Alewives are, and have been, the primary prey of introduced salmonines in the Great Lakes (Stewart and Ibarra 1991; Madenjian et al. 1998). Alewife dynamics typically reflect occurrences of strong year-classes. Much of the biomass contributing to a strong year-class will not be recruited to bottom trawls in its first year of life, and significant predation by salmonines may occur on age-0 and yearling alewives before they are recruited to the bottom trawl (R. Claramunt, Michigan Department of Natural Resources, Charlevoix, MI, unpublished data). The dynamic nature of the Lake Michigan food web and the potential for high levels of predation on age-0 and yearling alewives warrant an increased focus on abundance, distribution, and survival of alewives throughout all stages of life.

Given the importance of accurate estimates of prey fish abundance for salmonine management (Madenjian et al. 2005), initiation of a lakewide fall acoustic prey fish survey was critical. A cooperative survey based on recommendations in Argyle et al. (1998) was initiated in 2001 and the survey was first completed according to protocol in 2003. In 2004-2005, survey effort was expanded and resulted in the most extensive coverage to date. Data collected in 1992-1996 during the pilot research done by Argyle et al. (1998) are also included here.

METHODS

Sampling Design

Acoustic survey design has developed a great deal in the past ten years with a focus on understanding the assumptions and biases of different designs (Rivoirard et al. 2000). Classical variance estimates can be biased if sample sites are not randomly selected (Rivoirard et al. 2000), but in practice this randomization can be difficult to achieve. 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.

For the 2007 report, we made several changes, both in methodology for data analysis and in reporting format, to limit bias and improve clarity. First, assignment of species/size composition at depths ≥40 m is now based on an assumption that fish in this depth range are primarily bloater. Second, methods for removing noise from dual beam data collected 2001-2004 were modified. Third, rather than reporting

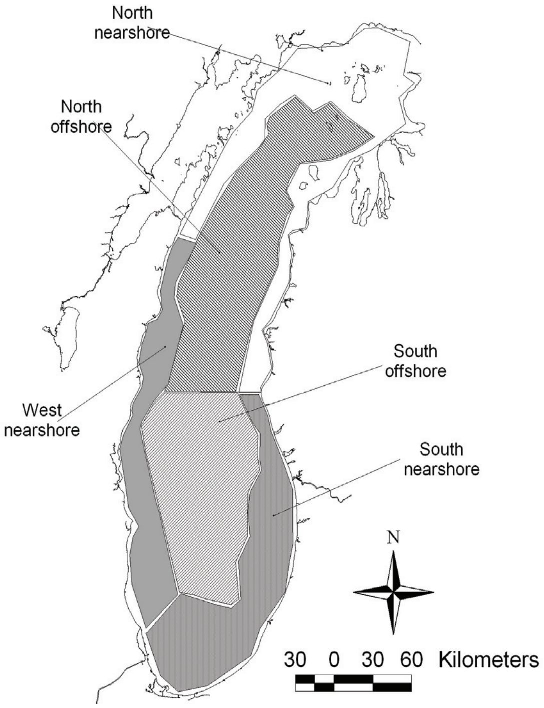

Figure 1. Map of Lake Michigan showing strata used in design and analysis of the lakewide acoustic survey conducted in 2004.

alewife densities for size classes, we report age-specific densities ((age-0 and yearling-and-older (YAO). Fourth, the technique for merging acoustic and trawl data was refined to more closely match trawl and acoustic data. Additionally, because of engine problems on the S/V Steelhead and sewage system problems on the R/V Sturgeon, only 13 of the 30 originally planned transects were completed.

Data Collection and Processing

The lakewide acoustic survey has been conducted as a cooperative effort in most years. Several different vessels and echosounders have been used through the years. 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 include 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 this variation has been assumed to have no influence. 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. Sampling has been conducted between August and November, with acoustic data collection initiated ~1 hour after sunset and ending ~1 hour before sunrise.

The dual beam echosounder used in 2001-2004 was visibly susceptible to noise at depths >80 m. To compensate for high noise levels in deep water, we subtracted noise at depth with noise estimated from target strength data using the time-varied gain function and a target strength (TS) noise at 1 m of -125 dB. This value (-125 dB) was somewhat higher than the lowest estimated noise at 1 m (-120 to -150 dB) but was required to remove visible noise. The TS data (with noise subtracted) were then converted to volumetric scattering (Sv) data for echo integration. Echo integration thresholds for data collection were -80 or -85 dB. A -80 dB echo integration threshold was employed during analyses. Noise levels for split beam units were much lower (Sv noise at 1 m -145 dB or less). Given the large acoustic size of targets in deeper water (bloater) and the relatively low noise levels, noise was not subtracted from split beam data.

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 >100m were assigned to offshore strata. Data from the 1990s were analyzed using custom software (Argyle et al. 1998). Data collected from 2001-2006 were analyzed with Echoview 4.0 software.

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 fishing locations were typically 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, 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 (total lengths, nearest 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), while for bloater this length was 120 mm. Alewife 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 interpolation between the 1991 and 1993 keys.

Estimates of Abundance

Acoustic density estimates for each transect were made for two groups: all targets and those that corresponded to fish targets. An estimate of absolute density (including all targets) was made using the formula

$$(1)\, Total\ density\ (\#\cdot ha^{-1}) = 10^4 \times \frac{ABC}{\sigma}$$

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 -70 and -30 dB, a range including all fish catchable with our trawl. The estimate from equation 1 provided density for all targets, potentially including invertebrates such as *Mysis relicta*, as aggregations of *Mysis* have TS similar to individual age-0 rainbow smelt (-70 to -64 dB, Rudstam et al. 2003; D.M. Warner, unpublished data). To maintain consistency with acoustic surveys of Lake Michigan in the 1990s (Argyle et al. 1998), targets <-60 dB were excluded. To accomplish this, density of fish targets was estimated by multiplying total density (equation 1) by the proportion of the total number of targets that were between -60 and -20 dB. This threshold should have included targets corresponding to the smallest age-0 alewives (20-30 mm) at most orientations based on in situ TS-length relations (-60 to -52 dB) published by Warner et al. (2002). This threshold likely resulted in underestimation of rainbow smelt density given expected target strengths published by Rudstam et al. (2003).

To facilitate assignment of trawl data to acoustic cells, trawl and acoustic data were classified by transect, depth layer (0-10, 10-20 m, etc., depending on headrope depth or upper depth of the acoustic cell) and by bottom depth with (10 m intervals). Trawl and acoustic data at water column depths <40 m were linked in steps ranging from fine-scale to coarse-scale. First, trawl data were matched to acoustic data cells using transect, depth layer, and bottom depth categories, which provided essentially a one-to-one match by location. Second, trawl data were averaged by stratum, depth layer, and bottom depth, and then merged with acoustic data still lacking trawl data from step 1. Third, trawl data were averaged by depth layer and bottom depth and then merged with acoustic data still lacking data from step 2. Fourth, trawl data were averaged by depth layer and merged with acoustic data still lacking data from step 3. Finally, trawl data were averaged by coarse depth layers corresponding to epilimnion (0-20 m depths), metalimnion (20-50 m depths), and hypolimnion (depth ≥50 m) and then merged with acoustic data still lacking data from step 4. 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 in this stratum during 2002-2003 were used. For depths ≥40 m, we assumed that acoustic targets were large bloater (Tewinkel and Fleischer 1999). Mean mass of bloater in these cells was estimated using the mass-TS equation of Fleischer et al. (1997).

Densities (fish/ha) of the different species were estimated as the product of 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 trawling (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.

RESULTS

Alewife – Density of alewife in 2006 (528 fish/ha, RSE=8.2%) was ~21% of that in 2005. This decrease was primarily the result of lower age-0 density (269 fish/ha, RSE=11.8%, Figure 2), which was lower in

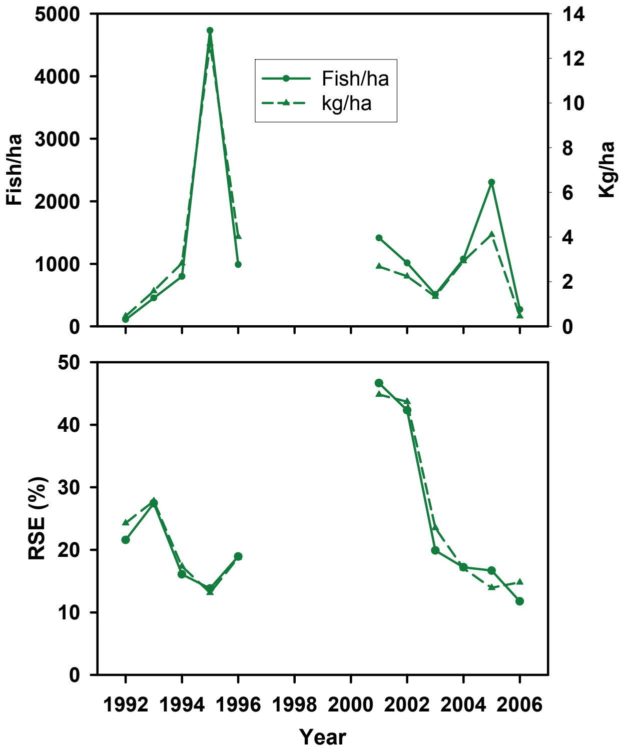

Figure 2. Acoustic estimates of age-0 alewife density and biomass in Lake Michigan,1992-2006 (upper panel) shown with relative standard error of the estimates (RSE, lower panel).

2006 than in any year except 1992 and 53% of that in 2003 (the lowest value from 2001-2005). Alewife biomass (4.6 kg/ha, RSE=13.4%) in 2006 was 58% of the 2005 biomass. The decline in biomass was not as drastic as density because age-0 alewife contribute less biomass per individual than YAO alewife. Age-0 alewife made up only 7% of density in 2006 but made up 48% of density in 2005. Age-1 and older alewife biomass has been relatively constant since 2001 (Figure 3). In 2006 the YAO group consisted of fish from every year-class after 1997. The 2002-2004 year-classes contributed 36.3% of YAO alewife biomass, while the 2005 year-class contributed 45.5% (Figure 4). The 2005 alewife year-class was the second largest on record (Figure 2). Density and biomass of age-1 alewife in 2006 were the third highest estimates since 1992, further evidence that the 2005 year-class was large.

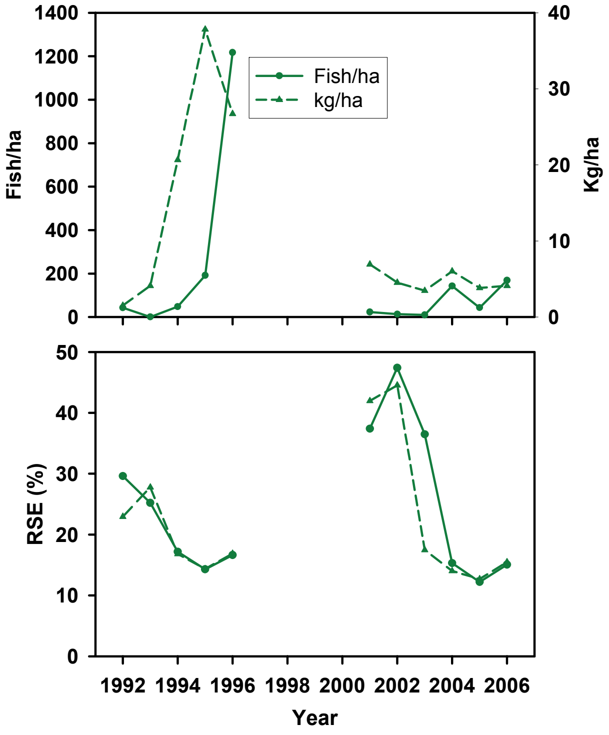

Figure 3. Acoustic estimate of yearling-and-older alewife density in Lake Michigan, 1992-2006 (upper panel) shown with relative standard error of the estimates (RSE, lower panel).

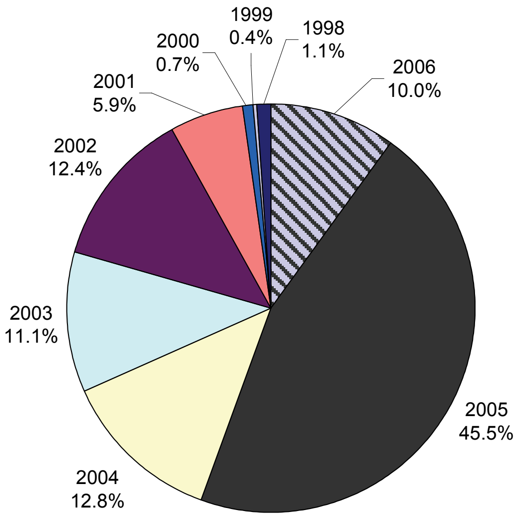

Figure 4. Percent contribution of alewife year-classes to alewife biomass. Labels show year class and percent of alewife biomass.

Rainbow smelt – For the first time since 1992, mean density of rainbow smelt (696 fish/ha, RSE=12.4%) was higher than alewife density in 2006. Biomass of rainbow smelt (4.2 kg/ha, RSE=17.9%) was 41% of total prey biomass and was only slightly lower than alewife biomass (largely due to smaller mean mass). Density has been increasing steadily since 2002, and biomass has increased three out of the four years since 2002 (Figure 5). Rainbow smelt > 90 mm in length constitute roughly half of the population and 92% of rainbow smelt biomass.

Bloater – Bloater continue to be present at low densities relative to the 1990s. Mean density in 2006 was 131 fish/ha (RSE=14.4%). Mean density of small bloater (<120 mm) was 50.0 fish/ha (RSE=16.7%), which was 17x higher than

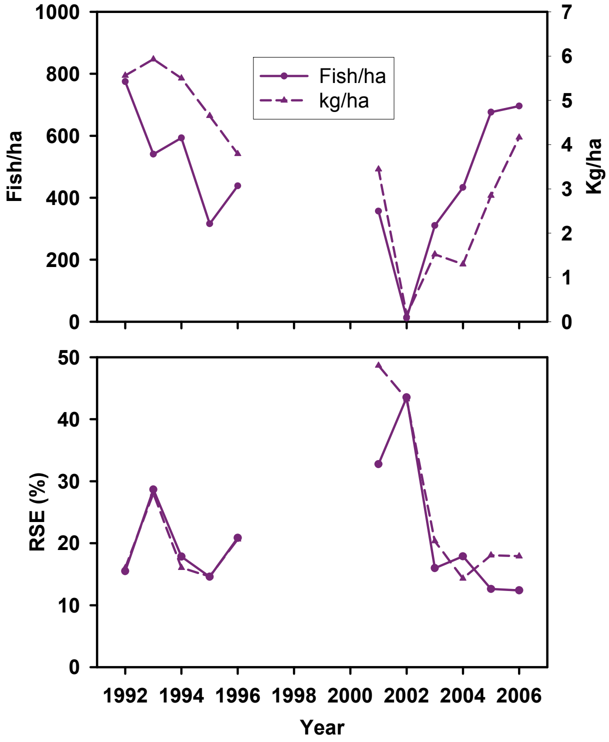

Figure 5. Acoustic estimates of rainbow smelt density and biomass in Lake Michigan in fall 1992-2006 (upper panel) shown with relative standard error of the estimates (RSE, lower panel).

the mean for 1992-1996 (2.9 fish/ha) and similar to the mean for 2001-2004 (45 fish/ha). In spite of the increased density of small bloater, density of bloater remains much lower than in the 1990s (Figure 6). In 2006, the mean density of large bloater was 81 fish/ha (RSE=21.5%). Mean biomass of large bloater in 2006 was 1.3 kg/ha (RSE=18.1%), which was similar to the 2001-2005 mean of 2.2 kg/ha. Bloater densities are probably underestimated because of the tendency of some portion of the population to be associated with bottom. Yule et al. (2007) found that in Lake Superior, ~60% of bloaters were detected acoustically. Given that detectability is <1, density may be as high as 135 fish/ha and 2.2 kg/ha.

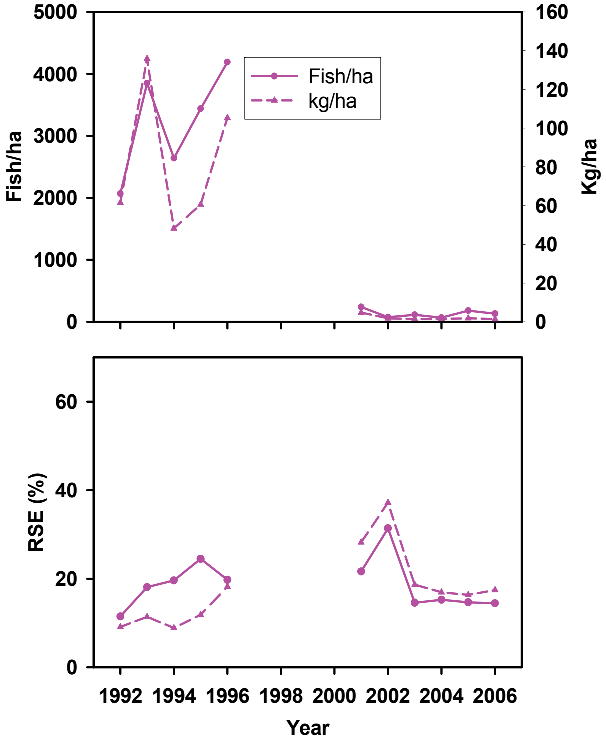

Figure 6. Acoustic estimates of bloater density in and biomass Lake Michigan in fall 1992-2006 (upper panel) shown with relative standard error of the estimates (RSE, lower panel).

CONCLUSIONS

As with any survey, it is important to note that acoustic estimates of fish biomass are potentially biased and, when possible, we should describe the effects of any bias when interpreting results. 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. It is doubtful that the bottom deadzone contributes much bias to alewife and rainbow smelt densities because of their pelagic distribution at night. Bloater tend to be more demersal, and in Lake Superior, acoustic/midwater trawl sampling may detect only 60% of bloater present (Yule et al. 2007). Additionally, sculpins are not well sampled acoustically and we must rely on bottom trawl estimates for these species. However, 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). Additionally, we assumed that all targets below 40 m were bloater. It is possible that this resulted in a slight underestimation of rainbow smelt density. Additionally, the target strength threshold we used in an attempt to limit density estimates to fish (not invertebrates) may have led to an underestimation of age-0 rainbow smelt density. Approximately one third of the standard area represented by the survey was not sampled in 2006 (Figure 7). In spite of this, RSE values were low because of relatively low, uniform fish densities and distribution. Unfortunately, it is not possible to count on similar combinations of low degree of coverage, low density, and even distribution *a priori*, so we recommend against exclusion of large areas of the lake in the future.

Prey fish biomass in Lake Michigan in 2006 remains at levels much lower than in the 1990s. The large difference in biomass from the 1990s resulted primarily from the decrease in bloater abundance. Alewife and bloater abundance have been relatively consistent from 2001-2006. Moderate year-classes in 2002-2004 and a strong year-class in 2005 have been the primary contributors to consistent alewife abundance. Although we think a relatively strong bloater year-class was observed in 2005, large bloater abundance remains low. In contrast, abundance of large rainbow smelt has been increasing since 2002 and now this species makes up almost 50% of total biomass.

Prey biomass available to the acoustic survey in 2006 (95% CI = 41.0 – 57.6 kt) was low relative to Fish Community Objectives (FCO, Eshenroder et al. 1995), 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. 2007) added to the acoustic biomass of other species, estimated lakewide biomass (72-88 kt) is still less than the FCO target range. Fleischer et al. (2005) argued this FCO target range was attainable when bloater abundance was high but was not sustainable. Bloater biomass is now quite low relative to the 1990s, so it is not surprising that preyfish biomass is well below the target range. Pelagic fish biomass was more evenly split among the species present in 2006, which is evidence of some progress toward the FCO of maintaining a diverse planktivore community. The pelagic preyfish community in 2006 was dominated by YAO alewife and large rainbow smelt (Table 1) and the biomass of these two species was more similar in 2006 than in the previous five years. However, both of these species are non-native. Bloater and emerald shiner (*Notropis atherinoides*) were historically important species. Bloater currently exist at low biomass levels, while emerald shiner

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 2006.

Species	**Density (kg/ha)**	**RSE (%)**	**95% CI**
Age-0 alewife	0.5	15	(0.3, 0.6)
YAO alewife	4.1	16	(2.9, 5.3)
Total alewife	4.6	13	(3.4, 5.7)
rainbow smelt	4.2	18	(2.6, 5.6)
bloater	1.4	17	(0.9, 1.8)
total	10.1	9	(8.4, 11.8)

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. 2007). It appears that emerald shiners are suppressed by all but the lowest levels of alewife abundance.

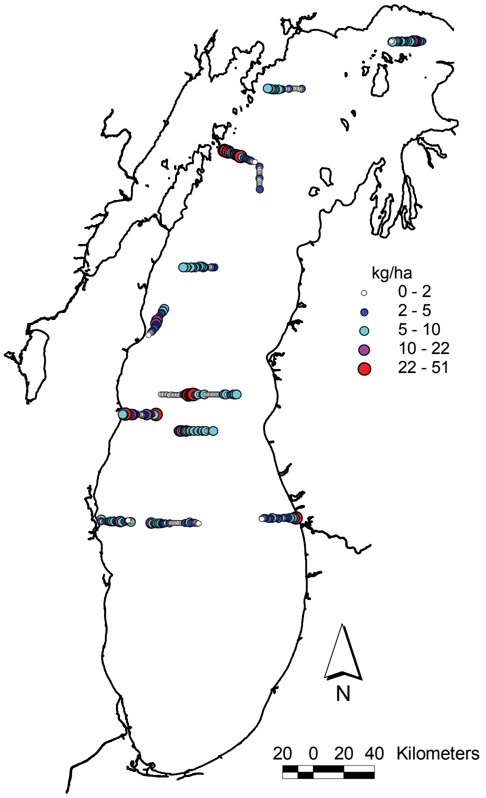

Figure 7. Map of 2006 Lake Michigan acoustic transects. Symbols represent individual 1,000 m segments. Symbol size and color are scaled by alewife biomass (kg/ha).

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