Status and Trends of Prey Fish Populations in Lake Michigan, 2012[1]

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Abstract

The U.S. Geological Survey Great Lakes Science Center has conducted lake-wide surveys of the fish community in Lake Michigan each fall since 1973 using standard 12-m bottom trawls towed along contour at depths of 9 to 110 m at each of seven index transects. The resulting data on relative abundance, size and age structure, and condition of individual fishes are used to estimate various population parameters that are in turn used by state and tribal agencies in managing Lake Michigan fish stocks. All seven established index transects of the survey were completed in 2012. The survey provides relative abundance and biomass estimates between the 5-m and 114-m depth contours of the lake (herein, lake-wide) for prey fish populations, as well as burbot, yellow perch, and the introduced dreissenid mussels. Lake-wide biomass of alewives in 2012 was estimated at 9 kilotonnes (kt, 1 kt = 1000 metric tonnes), which continues the trend of unusually low alewife biomass since 2004 but represented a 20% increase from the 2011 estimate. The age distribution of alewives larger than 100 mm was dominated (i.e., 84%) by age-2. Record low biomass was observed for several species, including bloater (0.4 kt), rainbow smelt (0.1 kt), deepwater sculpin (1.5 kt), and ninespine stickleback (0.01 kt). Slimy sculpin lake-wide biomass was 0.73 kt in 2012, which was the third consecutive year revealing a decline. Estimated biomass of round goby increased by 79% to 3 kt. Burbot lake-wide biomass (0.5 kt in 2012) has remained below 3 kt since 2001. Numeric density of age-0 yellow perch (i.e., < 100 mm) was only 2 fish per ha, which is indicative of a relatively poor year-class. Lake-wide biomass estimates of dreissenid mussels have continued to increase from 2010, from 12 to 95 kt in 2012. Overall, the total lake-wide prey fish biomass estimate (sum of alewife, bloater, rainbow smelt, deepwater sculpin, slimy sculpin, round goby, and ninespine stickleback) in 2012 was 15 kt, which represented the lowest total biomass of the time series.

The U.S. Geological Survey Great Lakes Science Center (GLSC) has conducted daytime bottom trawl surveys in Lake Michigan during the fall annually since 1973. Estimates from the 1998 survey are not reported, however, given the trawls were towed at non-standard speeds. From these surveys, the relative abundance of the prey fish populations are measured, and estimates of lake-wide biomass available to the bottom trawls (for the region of the main basin between the 5-m and 114-m depth contours) can be generated (Hatch et al. 1981; Brown and Stedman 1995). Such estimates are critical to fisheries managers making decisions on stocking and harvest rates of salmonines and allowable harvests of fish by commercial fishing operations.

The basic unit of sampling in our surveys is a 10-minute tow using a bottom trawl (12-m headrope) dragged on contour at 9-m (5 fathom) depth increments. At most survey locations, towing depths range from 9 or 18 m to 110 m. Age determinations were estimated for alewives (*Alosa pseudoharengus*, using otoliths) and bloaters (*Coregonus hoyi*, using scales) from our bottom trawl catches (Madenjian et al. 2003; Bunnell et al. 2006a). Although our surveys have included as many as nine index transects in any given year, we have consistently conducted the surveys at seven transects. These transects are situated off Manistique, Frankfort, Ludington, and Saugatuck, Michigan; Waukegan, Illinois; and Port Washington and Sturgeon Bay, Wisconsin (Figure 1). All seven transects were completed in 2012.
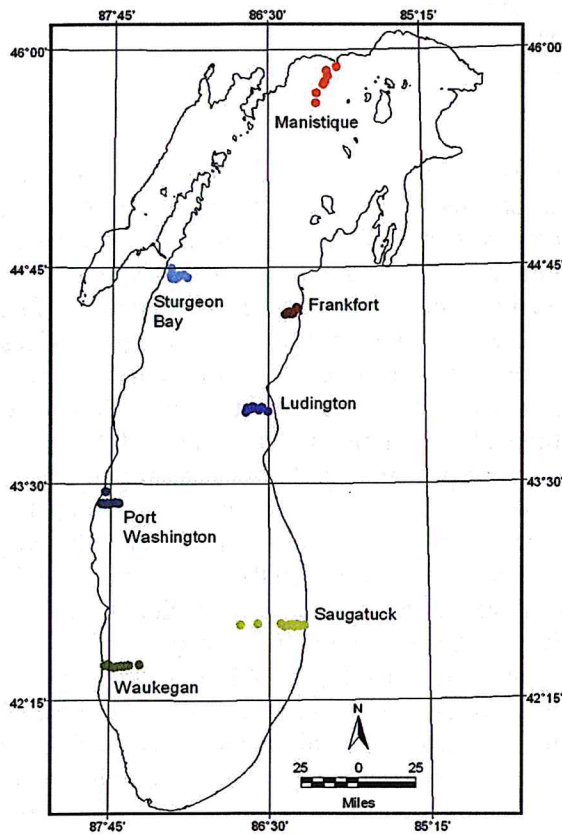
Lake-wide estimates of fish biomass require (1) accurate measures of the surface areas that represent the depths sampled and (2) reliable measures of bottom area swept by the trawl. A complete Geographical Information System (GIS) based on depth soundings at 2-km intervals in Lake Michigan was developed as part of the acoustics study performed by Argyle et al. (1998). This GIS database was used to estimate the surface area for each individual depth zone surveyed by the bottom trawls. Trawl mensuration gear that monitored net configuration during deployment revealed that fishing depth (D, in meters) influenced the bottom area swept by the trawl. We have corrected the width (W, in meters) of the area sampled according to $W = 3.232 + 7.678(1 - e^{-0.044*D})$, as well as the actual time (AT, in minutes) spent on the bottom according to $AT = \text{tow time} - 0.945 + (0.056D)$, based on trawl measurements made during June 2009 (Madenjian et al. 2010a). These relationships, along with boat speed, were used to estimate bottom area swept.

Figure 1. Established sampling locations for GLSC bottom trawls in Lake Michigan.

We estimate both numeric (fish per hectare [ha]) and biomass (kg per ha) density, although we display graphical trends mostly in biomass for brevity. A weighted mean density over the entire range of depths sampled (within the 5-m to 114-m depth contours) was estimated by first calculating mean density for each depth zone, and then weighting mean density for each depth zone by the proportion of lake surface area assigned to that depth zone. Standard error (SE) of mean density was estimated by weighting the variances of fish density in each of the depth zones by the appropriate weight (squared proportion of surface area in the depth zone), averaging the weighted variances over all depth zones, and taking the square root of the result.

By convention, we classify "adult" prey fish as age 1 or older, based on total length (TL): alewives ≥ 100 mm, rainbow smelt (*Osmerus mordax*) ≥ 90 mm, bloaters ≥ 120 mm, and yellow perch (*Perca flavescens*) ≥ 100 mm. We assume all fish smaller than the above length cut-offs are age-0; length cut-offs are also aided by aging of alewife (by otoliths) and bloater (by scales). Catches of age-0 alewife are not reliable indicators of future year-class strength (Madenjian et al. 2005a), because their position in the water column makes them less vulnerable to bottom trawls. Catches of age-0 bloater, though biased low, can be used as an index of relative abundance given the positive correlation between density of age-0 bloater and density of age-3 bloater (the age at which catch curves reveal full recruitment to our gear, Bunnell et al. 2006a, 2010). Catch of age-0 yellow perch is likely a good indicator of year-class strength, given that large catches in the bottom trawl during the 1980s corresponded to the strong yellow perch fishery. At the end of this report, we report densities of age-0 yellow perch and other bottom-dwelling species such as burbot (*Lota lota*) and dreissenid mussels that are not necessarily "prey fish" but are caught in sufficient numbers to index. Unfortunately lake whitefish are only rarely sampled in our trawl and the resultant trends are not meaningful.

Alewife – Since its establishment in the 1950s, the alewife has become a key member of the fish community. As a larval predator, adult alewife can depress recruitment of native fishes, including burbot, deepwater sculpin (*Myoxocephalus thompsonii*), emerald shiner (*Notropis atherinioides*), lake trout (*Salvelinus namaycush*), and yellow perch (Smith 1970; Wells and McLain 1973; Madenjian et al. 2005b, 2008; Bunnell et al. 2006b). Additionally, alewife has remained the most important constituent of salmonine diet in Lake Michigan for the last 45 years (Jude et al. 1987; Stewart and Ibarra 1991; Warner et al. 2008; Jacobs et al. 2013). Most of the alewives consumed by salmonines in Lake Michigan are eaten by Chinook salmon (*Oncorhynchus tshawytscha*, Madenjian et al. 2002). A commercial harvest was established in Wisconsin waters of Lake Michigan in the 1960s to make use of the then extremely abundant alewife that had become a nuisance and health hazard along the lakeshore. In 1986, a quota was implemented, and as a result of these restrictions, the estimated annual alewife harvest declined from about 7,600 metric tons in 1985 to an incidental harvest of only 12 metric tons after 1990 (Mike Toneys, Wisconsin Department of Natural Resources, Sturgeon Bay, personnel communication). Lake Michigan currently has no commercial fishery for alewives.

Adult alewife biomass density was 1.4 kg per ha in 2012 (Figure 2a), which was only 20% of the long-term average biomass. Only 2010 yielded a lower adult alewife biomass estimate. Similarly, adult alewife numeric density in 2012 (62.8 fish/ha, Figure 2b) was only 27% of the long-term average. The overall temporal trends in alewife recruitment to age 3 and subsequent adult biomass are likely driven by consumption by salmonines (Madenjian et al. 2002, 2005a).
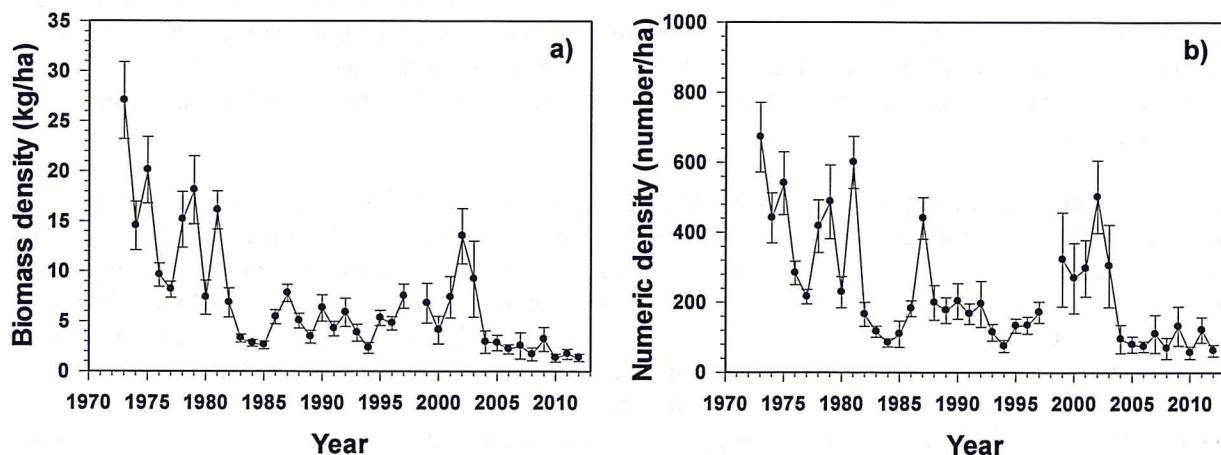

Figure 2. Density of adult alewives as biomass (a) and number (b) per ha (+/- standard error) in Lake Michigan, 1973-2012.

Adult alewife density has remained at low levels during 2004-2012 (Figure 2). This continued depression of adult alewife abundance may reflect a recently intensified amount of predation exerted on the alewife population by Chinook salmon due to four factors: (1) a relatively high percentage of wild Chinook salmon in Lake Michigan (averaging 50% age-1 individuals between 2006-2010, Williams 2012), (2) increased migration of Chinook salmon from Lake Huron in search of alewife (Adlerstein et al. 2007), (3) increased importance of alewives in the diet of Chinook salmon in Lake Michigan between the 1990s and the 2000s (Jacobs et al. 2013), and (4) a decrease in the energy density of adult alewives during the late 1990s (Madenjian et al. 2006).

Of the 123 alewife otoliths aged, two independent readers arrived at the same estimate 90% of the time (and they were able to reach a consensus age on the 12 disagreements). Using an age-length key and a length distribution that corrected for densities, we estimated that 84% of <u>adult</u> alewives captured in the bottom trawl during 2012 were age 2 and classified as the 2010 year-class (Figure 3). This unevenness in age composition was also observed in 2011, as the 2010 year-class comprised 83% of the adults captured. These two years are in stark contrast to the previous four years (2007-2010) when more evenness was estimated among the age-classes, as indicated by at least three age-classes each contributing at least 10% to the catch. One additional change in recent years is a truncation in the age distribution. The maximum age sampled has decreased from age 9 in 2007 to age 7 in 2008-2009 to age 6 in 2010-2011 to age 4 in 2012.
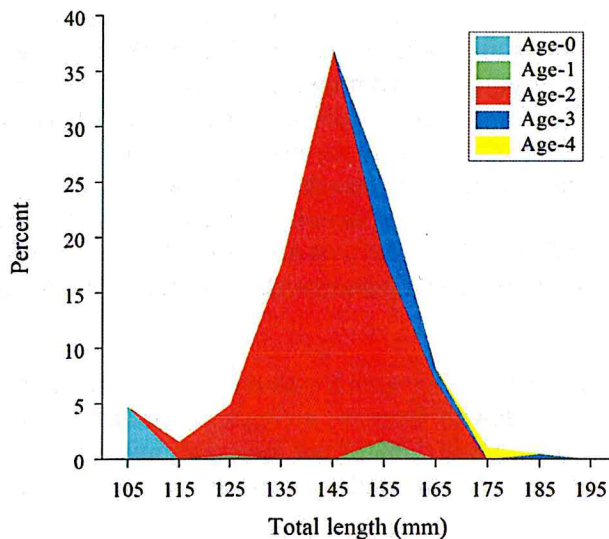
Figure 3. Age-length distribution of alewives ≥100 mm total length caught in bottom trawls in Lake Michigan, 2012. Note that smaller alewives were captured but were not included herein.

Our results for temporal trends in adult alewife density were in partial agreement with results from the lake-wide acoustic survey, which reported biomass of adult alewife during 2004-2012 to be relatively low in comparison to the biomass during 1994-1996 (Warner et al. 2013). However, Warner et al. (2013) did report a substantial increase in adult alewife biomass during 2007-2010 that was not detected by the bottom trawl survey. Comparisons between the age-distributions measured in the two surveys also exhibited commonality in the dominance of the 2010 year-class among the adults (84% in the bottom trawl and 89% in the acoustic survey). The biomass estimate for adult alewife in the acoustic survey, however, is over three times higher than what was estimated in the bottom trawl survey.

<u>Bloater</u> - Bloaters are eaten by salmonines in Lake Michigan, but are far less prevalent in salmonine diets than alewives (Warner et al. 2008; Jacobs et al. 2010, 2013). For large (≥ 600 mm) lake trout, over 30% of the diets offshore of Saugatuck and on Sheboygan Reef were composed of adult bloaters during 1994-1995, although adult bloaters were a minor component of lake trout diet at Sturgeon Bay (Madenjian et al. 1998). For Chinook salmon, the importance of bloater (by wet weight) in the diets has declined between 1994-1995 and 2009-2010. For small (< 500 mm) Chinook salmon the proportion declined from 9% to 6% and for large Chinook salmon the proportion declined from 14% to <1% (Jacobs et al. 2013). The bloater population in Lake Michigan also supports a valuable commercial fishery, although its yield has generally been declining since the late 1990s.

Adult bloater biomass density was 0.11 kg per ha in 2012 (Figure 4a), which was only 0.5% of the long-term average biomass and the lowest estimate of the time series. The estimate for 2012 was also 90%

lower than that measured in 2011. Similarly, adult bloater numeric density in 2012 (2.5 fish/ha) was only 0.5% of the long-term average. Adult bloater numeric and biomass densities have shown an overall declining trend since 1989 (Figure 4a). Numeric density of age-0 bloaters (< 120 mm TL) was only 2 fish per ha in 2012 (Figure 4b). 2012 was the third consecutive year of very low densities of age-0 bloater following relatively high values in 2005, 2008, 2009.
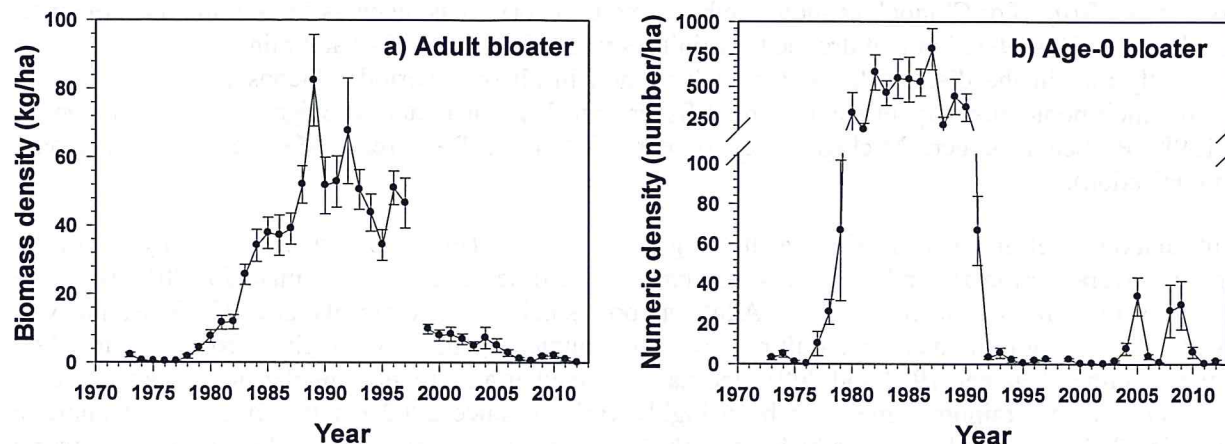

Figure 4. Panel (a) depicts biomass density (+/- standard error) of adult bloater in Lake Michigan, 1973-2012. Panel (b) depicts numeric density (+/- standard error) of age-0 bloater in Lake Michigan, 1973-2012.

The exact mechanisms underlying the relatively poor bloater recruitment since 1992, and the resultant low biomass of adult bloater, remain unknown. Of the mechanisms that have been recently evaluated, reductions in fecundity associated with poorer condition (Bunnell et al. 2009a) and egg predation by slimy and deepwater sculpins (Bunnell et al. 2013) are likely contributing to the reduced bloater recruitment, but none is the primary regulating factor. Another hypothesized mechanism, predation by adult alewife on bloater larvae, has been discounted (Madenjian et al. 2002; Bunnell et al. 2006a). Madenjian et al. (2002) proposed that the Lake Michigan bloater population may be cycling in abundance, with a period of about 30 years, although the exact mechanism by which recruitment is regulated remains unknown. Finally, a regional climate driver was hypothesized to underlie the synchrony in bloater recruitment among lakes Michigan, Huron, and Superior between 1978 and 2006 (Bunnell et al. 2010). The recent asynchrony in bloater recruitment, as measured by the Lake Michigan (relatively poor) and Lake Huron bottom trawl surveys (relatively strong; Roseman et al. 2013), suggests that some factor other than climate is likely important.

One additional consideration when interpreting these bottom trawl survey results is that catchability of bloater may have decreased in recent years, in response to the proliferation of quagga mussels and the associated increased water clarity and decreased *Diporeia* spp. densities. First, bloaters (both age-0 and adult) may be increasingly pelagic, rather than benthic, during the day, as diet information from 2010 revealed an increasing reliance on zooplankton to compensate for fewer *Diporeia* (D. B. Bunnell, unpublished data). Second, bloaters have exhibited plasticity in bottom depth, increasing the depth at which peak densities occurred from 50 m in the 1930s to 85-110 m by 2004-2007 (Bunnell et al. 2012). Hence, not only could bloaters be above the bottom trawl during the day, but some portion of the population also could have shifted to waters deeper than are surveyed by the bottom trawl.

Results from the acoustic survey can provide some insight into catchability concerns raised above. With regard to bloater moving deeper than 110 m, the acoustic survey estimated bloater densities ranging 8-25 fish/ha in depths 125-220 m between 2003 and 2012 (D. M. Warner, unpublished data). However, the survey also documented that the bulk of the bloater population was sampled in depths 30-100 m.

In terms of comparing trends between the two surveys, for the adults an order of magnitude decrease between 1992-1996 and 2001-2012 was revealed by both surveys. Similarly, low densities of age-0 bloaters in the 1990s and strong interannual variability in the 2000s were detected in both surveys. However, the years (2005, 2008, 2009) in which relatively high age-0 densities were estimated by the

bottom trawl survey were a subset of the high density years (2001, 2005, 2007-2009, 2012) estimated by the acoustic survey (Warner et al. 2013).

Rainbow smelt – Adult rainbow smelt are an important part of the diet for intermediate-sized (400 to 600 mm) lake trout in the nearshore waters of Lake Michigan (Stewart et al. 1983; Madenjian et al. 1998; Jacobs et al. 2010). For Chinook salmon, rainbow smelt comprised as much as 18% in the diets of small individuals in 1994-1996, but that dropped precipitously to 2% in 2009-2010 and rainbow smelt has been consistently rare in the diets of larger Chinook salmon in all time periods (Jacobs et al. 2013). The rainbow smelt population supports commercial fisheries in Wisconsin and Michigan waters (Belonger et al. 1998; P. Schneeberger, Michigan Department of Natural Resources, Marquette, MI, personal communication).

Adult rainbow smelt biomass density was 0.02 kg per ha in 2012 (Figure 5a), which was only 1% of the long-term average biomass and the lowest estimate of the time series. The estimate for 2012 was also 81% lower than that measured in 2011. Adult rainbow smelt numeric density in 2012 (3 fish/ha) was only 2% of the long-term average. Adult rainbow smelt numeric density was highest from 1981 to 1993, but then declined between 1993 and 2001, and has remained at a relatively low density, except in 2005, since 2001. Age-0 rainbow smelt has been highly variable since 2002 (Figure 5b). Age-0 numeric density in 2012 was 26 fish per ha, which was only 14% of the long-term average. Causes for the general decline in rainbow smelt biomass and production remain unclear. Consumption of rainbow smelt by salmonines was higher in the mid 1980s than during the 1990s (Madenjian et al. 2002), yet adult and age-0 (< 90 mm TL) rainbow smelt abundance remained high during the 1980s (Figure 5b).
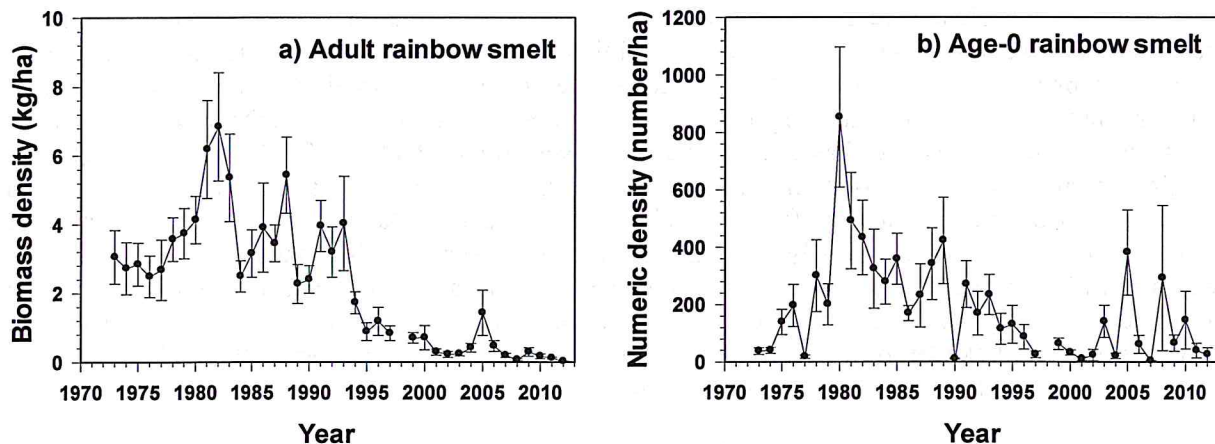
Figure 5. Biomass density (+/- standard error) of adult (a) and age-0 (b) rainbow smelt in Lake Michigan, 1973-2012.

Temporal trends in rainbow smelt biomass from the acoustic and bottom trawl surveys in Lake Michigan have been similar since 2001. The bottom trawl survey has documented relatively low rainbow smelt biomass during 2001-2012, with a minor peak in 2005 (Figure 5a). Similarly, biomass of rainbow smelt in the acoustic survey was relatively low during 2001-2012, with minor peaks occurring during 2005-2006 and 2008-2009 (Warner et al. 2013). Results from both the acoustic and bottom trawl surveys indicated that rainbow smelt biomass in Lake Michigan during 1992-1996 was roughly four times higher than rainbow smelt biomass during 2001-2012.

Sculpins – From a biomass perspective, the cottid populations in Lake Michigan have been dominated by deepwater sculpins, and to a lesser degree, slimy sculpins (*Cottus cognatus*). Spoonhead sculpins (*Cottus ricei*), once fairly common, suffered declines to become rare to absent by the mid 1970s (Eck and Wells 1987). Spoonhead sculpins were encountered in small numbers in our survey between 1990 and 1999 (e.g., Potter and Fleischer 1992), but have not been sampled since 1999.

Slimy sculpin is a favored prey of juvenile lake trout in nearshore regions of the lake (Stewart et al. 1983; Madenjian et al. 1998), but is only a minor part of adult lake trout diets. Deepwater sculpin is an

important diet constituent for burbot in Lake Michigan, especially in deeper waters (Van Oosten and Deason 1938; Brown and Stedman 1995; Fratt et al. 1997). A recent study of burbot from northern Lake Michigan sites revealed sculpins to comprise 11% of their diets (Jacobs et al. 2010).
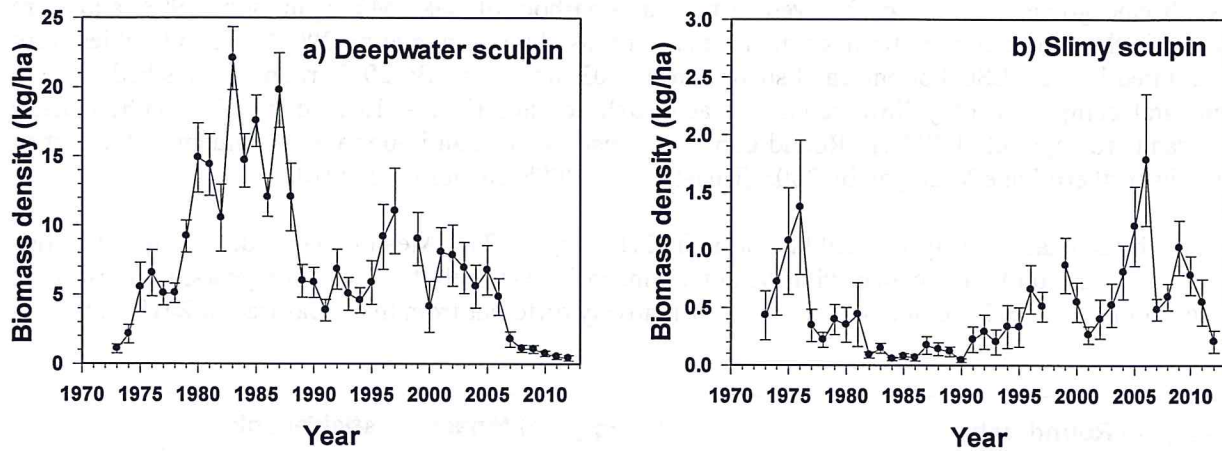

Figure 6. Biomass density (+/- standard error) for deepwater (a) and slimy sculpin (b) in Lake Michigan, 1973-2012.

Deepwater sculpin biomass density was 0.4 kg per ha in 2012 (Figure 6a), which was only 5% of the long-term average biomass and the lowest estimate of the time series. For every year since 2009, this biomass estimate has reached a record low. Similarly, deepwater sculpin numeric density in 2012 (44 fish/ha) was only 11% of the long-term average. During 1990-2005, both deepwater sculpin biomass density and numeric density trended neither downward nor upward. However, biomass of deepwater sculpin sampled in the bottom trawl has declined precipitously since 2005. Madenjian and Bunnell (2008) demonstrated that deepwater sculpins have been captured at increasingly greater depths since the 1980s. Therefore, one potential explanation for the recent declines in deepwater sculpin densities is that an increasing proportion of the population is now occupying depths deeper than those sampled by our survey (i.e., 110 m). Furthermore, because the deepwater sculpin occupies deeper depths than any of the other prey fishes of Lake Michigan, a shift to waters deeper than 110 m would seem to be a reasonable explanation for the recent declines in deepwater sculpin densities. Previous analysis of the time series indicated deepwater sculpin density is negatively influenced by alewife (predation on sculpin larvae) and burbot (predation on juvenile and adult sculpin, Madenjian et al. 2005b). Based on bottom trawl survey results, neither alewife nor burbot increased in abundance during 2007-2012 to account for this decline in deepwater sculpins. Which factor or factors could have driven the bulk of the deepwater sculpin population to move to waters deeper than 110 m during 2007-2011? This shift to deeper water by deepwater sculpins coincided with the population explosion of the profundal form of the quagga mussel (*Dreissena bugensis*) in depths between 60 and 90 m (Bunnell et al. 2009b; T. Nalepa, NOAA Great Lakes Environmental Research Laboratory, personal communication). Perhaps some consequences of the colonization of deeper waters by quagga mussels prompted a move of deepwater sculpins to deeper water. If this hypothesis were correct, then a substantial decline in quagga mussel abundance in the 60-m to 90-m deep waters could lead to a shift of deepwater sculpins back to shallower waters.

Slimy sculpin biomass density was 0.21 kg per ha in 2012 (Figure 6b). Among all of the prey fishes that have been sampled since 1973, the biomass of slimy sculpin was closest to its long-term average of 0.48 kg/ha (i.e., 43% of the long-term average biomass). Numeric density of slimy sculpin was 36 fish per ha in 2012, which was only 33% of the long-term average. Biomass densities of slimy sculpins from 2005-2006 were considerably higher than those estimated in the 1980s and even late 1990s, when slimy sculpins were recovering. Biomass of slimy sculpin has declined annually since 2009, however, with a marked 62% decline between 2011 and 2012. Previous analysis indicated slimy sculpin density was negatively influenced by lake trout, with the putative mechanism identified as predation by juvenile lake trout (Madenjian et al. 2005b). As a result, we attribute the recovery that occurred during the 1990s to, in part, the 1986 decision to emphasize stocking lake trout on offshore reefs (as opposed to the nearshore

areas where our survey samples, Madenjian et al. 2002). Likewise, the slimy sculpin decline since 2009 coincided with an increase in lake trout stocking rate (FWS/GLFC 2010).

Round goby – The round goby (*Neogobius melanostomus*) is an invader from the Black and Caspian Seas. Round gobies have been observed in bays and harbors of Lake Michigan since 1993, and were captured in the southern main basin of the lake as early as 1997 (Clapp et al. 2001). Round gobies were not captured in the GLSC bottom trawl survey until 2003, however. By 2002, round gobies had become an integral component of yellow perch diet at nearshore sites (i.e., < 15 m depth) in southern Lake Michigan (Truemper et al. 2006). Round gobies also had become an important constituent of the diet of burbot in northern Lake Michigan by 2005 (Hensler et al. 2008; Jacobs et al. 2010).

Round goby biomass density was 0.9 kg per ha in 2012 (Figure 7a). Mean numeric density was 121 fish per ha. The variability associated with the annual mean is extremely high in some years, such as 2010. Hence, biomass in 2012 did not appear to be substantively different from that measured in 2010 and 2011.
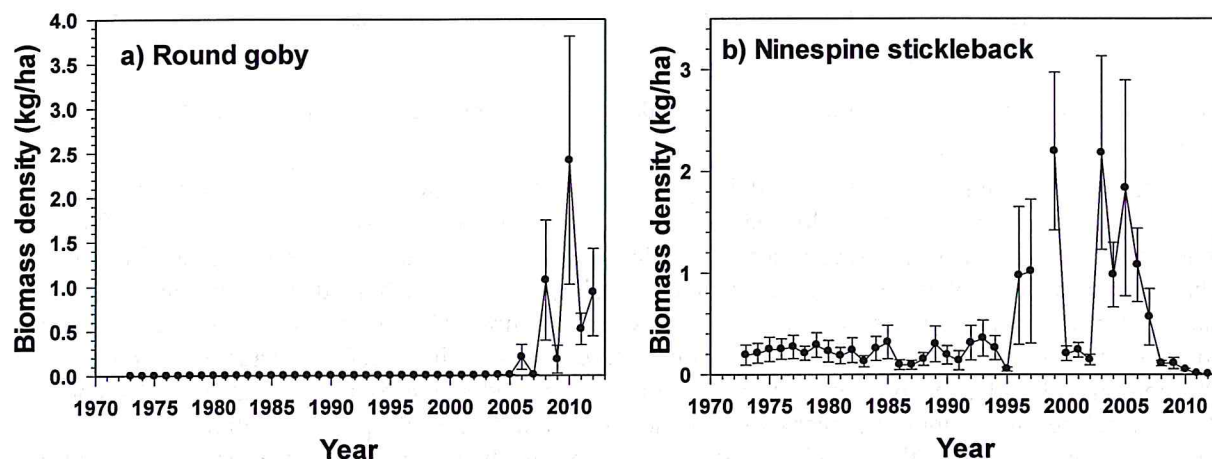
Figure 7. Biomass density (+/- standard error) of round goby (a) and ninespine stickleback (b) in Lake Michigan, 1973-2012.

Ninespine stickleback – Two stickleback species occur in Lake Michigan. Ninespine stickleback (*Pungitius pungitius*) is native, whereas threespine stickleback (*Gasterosteus aculeatus*) is non-native and was first collected in the GLSC bottom trawl survey during 1984 (Stedman and Bowen 1985). Ninespine stickleback is generally captured in far greater densities than the threespine, especially in recent years. Relative to other prey fishes, ninespine sticklebacks are of minor importance to lake trout and other salmonines. In northern Lake Michigan, for example, sticklebacks occur infrequently in the diet of lake trout (Elliott et al. 1996; Jacobs et al. 2010). Biomass density was 3 g per ha in 2012 (Figure 7b), the lowest value of the time series and only 0.9% of the long-term average. Mean numeric density was only 3 fish per ha. Biomass of ninespine stickleback remained fairly low from 1973-1995, increased dramatically in 1996-1997, and exhibited larger interannual variability between 1999 and 2007. Since 2008, however, biomass has been maintained at near record-low levels. An analysis of ninespine stickleback densities in lakes Michigan and Superior revealed that the increase in Lake Michigan in the mid-2000s coincided with the expansion of dreissenid mussels in the lake (Madenjian et al. 2010b). The proposed mechanism was that the prevalence of the green alga *Cladophora*, which increased with dreissenid mussel proliferation, improved spawning habitat quality for ninespine sticklebacks. One plausible explanation for the low ninespine stickleback abundance during 2008-2012 may be that piscivores have begun to incorporate ninespine sticklebacks in their diets as the abundance of alewives has declined. Jacobs et al. (2013) found ninespine sticklebacks to be a rare diet item (i.e., 2% occurrence) among large Chinook salmon in 2009-2010 after a 0% occurrence in 1994-1995. The decrease in ninespine stickleback abundance in Lake Superior between the 1978-1999 and 2000-2007 periods was attributed to increased predation by lake trout (Madenjian et al. 2010b).

We estimated a total lake-wide biomass of prey fish available to the bottom trawl in 2012 of 15 kilotonnes (kt) (1 kt = 1000 metric tonnes) (Figure 8a, Appendix 1), which was the lowest value in the time series and only 10% of the long-term average total prey fish biomass. Total prey fish biomass was the sum of the population biomass estimates for alewife, bloater, rainbow smelt, deepwater sculpin, slimy sculpin, ninespine stickleback, and round goby. Total prey fish biomass in Lake Michigan has trended downward since 1989 (Figure 8a). This decline was largely driven by the dramatic decrease in bloater biomass. During 2002-2012, decreases in alewife and deepwater sculpin biomasses also contributed to the continued decrease in total prey fish biomass. Total biomass first dropped below 30 kt in 2007, and has remained below 30 kt since that time.

As Figure 8b depicts, the 2012 prey fish biomass was apportioned as: alewife 60.3% (9.2 kt), round goby 21.6% (3 kt), deepwater sculpin 9.7% (1.5 kt), slimy sculpin 4.8% (0.7 kt), bloater 2.7% (0.4 kt), rainbow smelt 0.9% (0.1 kt), and ninespine stickleback < 0.1% (0.01 kt).
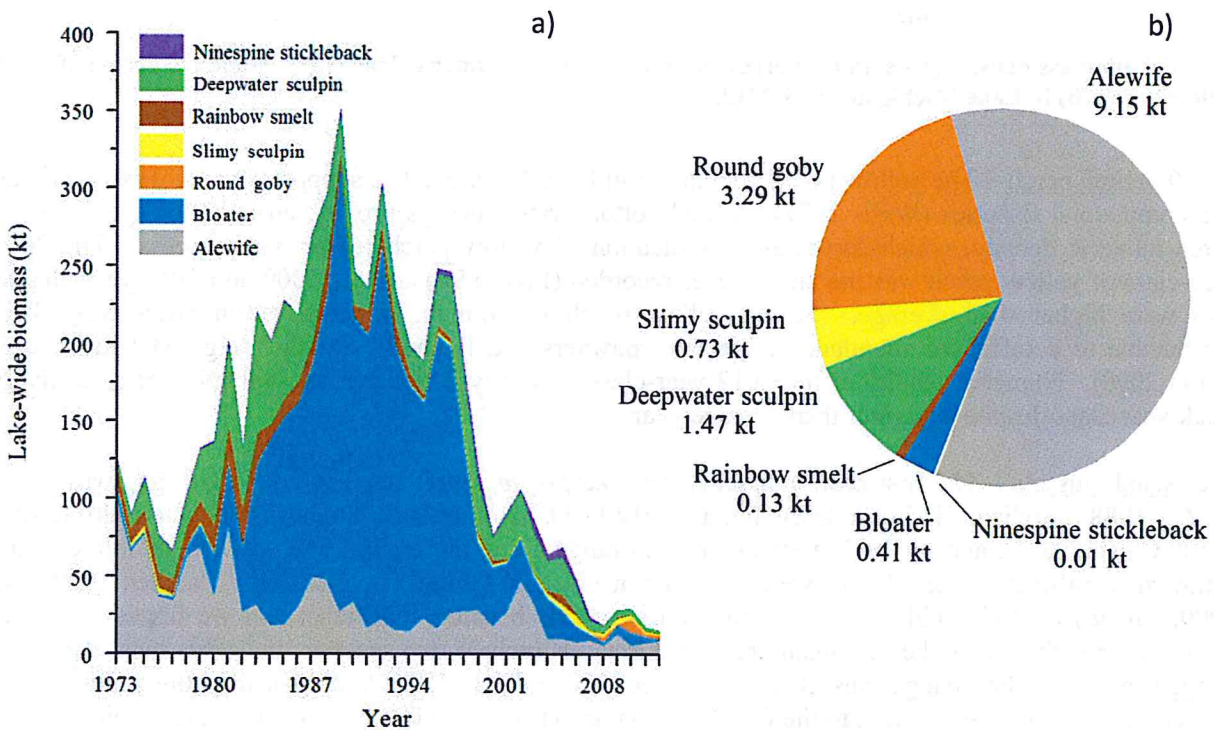

Figure 8. Estimated lake-wide (i.e., 5-114 m depth region) biomass of prey fishes in Lake Michigan, 1973-2012 (a) and species composition in 2012 (b).

OTHER SPECIES OF INTEREST

Burbot – Burbot and lake trout represent the native top predators in Lake Michigan. The decline in burbot abundance in Lake Michigan during the 1950s has been attributed to sea lamprey predation (Wells and McLain 1973). Sea lamprey control was a necessary condition for recovery of the burbot population in Lake Michigan, however Eshenroder and Burnham-Curtis (1999) proposed that a reduction in alewife abundance was an additional prerequisite for burbot recovery.

Burbot collected in the bottom trawls are typically large individuals (>350 mm TL); juvenile burbot apparently inhabit areas not covered by the bottom trawl survey.

Burbot biomass density was 0.1 kg per ha in 2012, which was 15% of the long-term average. After a period of low numeric density in the 1970s, burbot showed a strong recovery in the 1980s (Figure 9a).

Densities increased through 1997, but appear to have declined thereafter and have exhibited relatively stable, but low, levels of biomass since 2003.
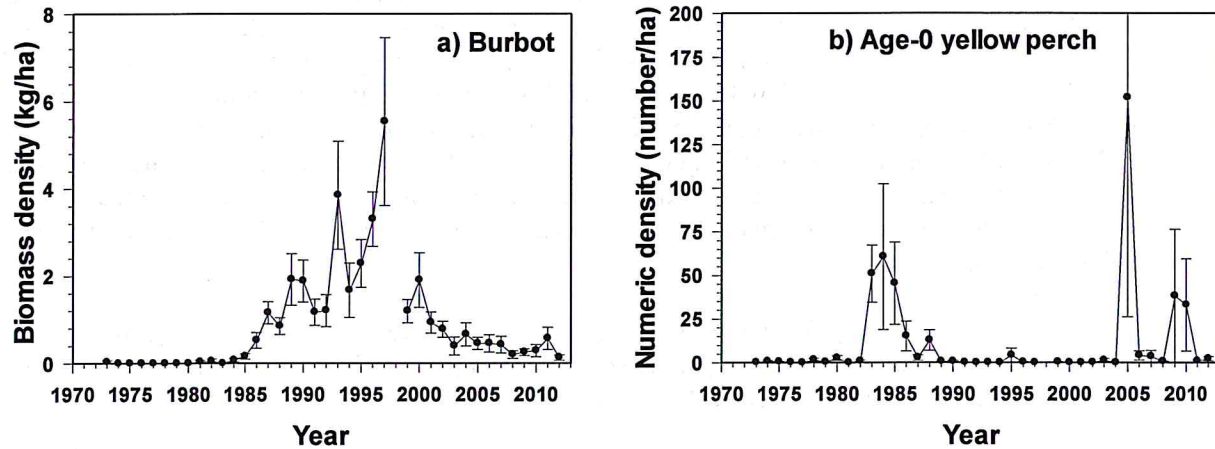

Figure 9. Biomass density (+/- standard error) of burbot (a) and numeric density (+/- standard error) of age-0 yellow perch (b) in Lake Michigan, 1973-2012.

Age-0 yellow perch – The yellow perch population in Lake Michigan has supported valuable recreational and commercial fisheries (Wells 1977). GLSC bottom trawl surveys provide an index of age-0 yellow perch numeric density, which serves as an indication of yellow perch recruitment success. The 2005 year-class of yellow perch was the largest ever recorded (Figure 9b) and the 2009 and 2010 year-classes also were higher than average. Strong yellow perch recruitment in these recent years was likely attributable to a sufficient abundance of female spawners and favorable weather (e.g., Makauskas and Clapp 2000). Numeric density of the 2012 year-class was only 2 fish per ha, indicative of a relatively weak year-class despite a warmer than average year.

Dreissenid mussels – The first zebra mussel (*Dreissena polymorpha*) noted in Lake Michigan was found in May 1988 in Indiana Harbor at Gary, Indiana. By 1990, adult mussels had been found at multiple sites in the Chicago area, and by 1992 were reported to range along the eastern and western shoreline in the southern two-thirds of the lake, as well as in Green Bay and Grand Traverse Bay (Marsden 1992). In 1999, catches of dreissenid mussels in our bottom trawls became significant and we began recording biomass for each tow. Lake Michigan dreissenid mussels include two species: the zebra mussel and the quagga mussel. The quagga mussel is a more recent invader to Lake Michigan than the zebra mussel (Nalepa et al. 2001). According to the GLSC bottom trawl survey, biomass density of dreissenid mussels was highest in 2007 (Figure 10a), which followed an exponential like increase between 2004 and 2006 (Bunnell et al. 2009b). The biomass density of dreissenid mussels in 2012 was 27 kg per ha, the highest value estimated since the peak in 2007 (Figure 10a). Some of the interannual variability is difficult to explain. The exceptionally high densities in 2006 and 2007 were attributable to the expansion of quagga mussels into deeper (> 60 m) waters of Lake Michigan. However, there was no clear explanation for the drastic drop in dreissenid mussel biomass density between 2007 and 2008. According to the results of the benthic macroinvertebrate survey led by Tom Nalepa at NOAA-GLERL, quagga mussel biomass density in Lake Michigan appears to have peaked sometime between 2008 and 2010. This peaking may be in response to the exceeding of the carrying capacity, and a decline in quagga mussel biomass density may be expected in upcoming years.

Over this same period of dreissenid mussel increases, prey fish biomass was declining, which led to a dramatic increase in the percentage of dreissenids in the total bottom trawl catch (Figure 10b). Some authors have attributed the recent decline in prey fish to food-web changes induced by the expansion of dreissenids (Nalepa et al. 2009). However, Bunnell et al. (2009b) proposed that the bulk of the decline in total prey fish biomass may be better explained by factors other than food-web-induced effects by

dreissenids, including poor fish recruitment (that preceded the mussel expansion), shifts in fish habitat, and increased fish predation by Chinook salmon and lake trout.
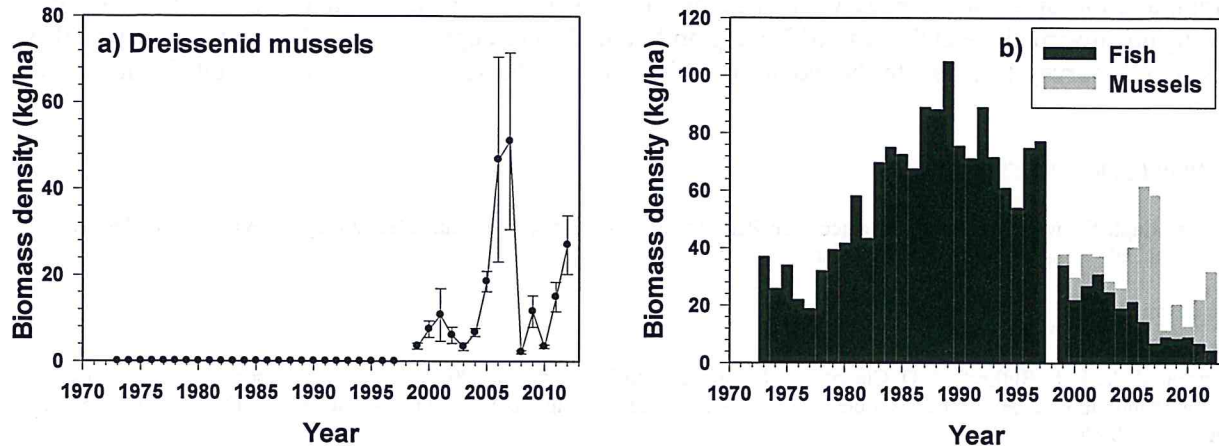

Figure 10. Panel (a) depicts biomass density (+/- standard error) of dreissenid mussels in the bottom trawl in Lake Michigan between 1999 (first year mussels were weighed) and 2012. Panel (b) depicts biomass of dreissenids and total fish biomass estimated by the bottom trawl between 1973 and 2012.

A comparison of the biomass density of dreissenid mussels (27 kg per ha) with biomass density of all species of fish (5 kg per ha) caught in the bottom trawl in 2012 indicated that 85% of the daytime benthic biomass available to the bottom trawl was dreissenid mussels (Figure 10b).

CONCLUSIONS

Total prey fish biomass in 2012 was the lowest since our bottom trawl survey began in 1973, and follows five years of sustained, record low biomass estimates. These low prey fish biomass estimates for 2007-2012 were probably due to a suite of factors. We can clearly identify two of these factors as: (1) a prolonged period of poor bloater recruitment since 1992 and (2) intensified predation on alewives by Chinook salmon during the 2000s. Adult alewife density has been maintained at a relatively low level over the last nine years and the age distribution of the adult alewife population has become especially truncated in recent years. As recent as 2007, alewives as old as age 9 were sampled in this survey whereas the oldest alewife sampled in 2012 was age 4. Whether or not the alewife population in Lake Michigan will undergo a collapse in coming years (similar to what occurred in Lake Huron) will depend on several factors. Primarily, the extent to which predation by salmonines influences the survival of the large 2010 year-class is critical. In addition, alewife sustainability will depend on the success of 2010 year-class in producing another strong year-class in the next few years, which will at least partially depend on appropriate environmental factors being met (Madenjian et al. 2005b).

Scientists and managers continue to ask critical questions regarding the importance of "bottom-up" effects on prey fish biomass in Lake Michigan. For example, to what extent do 1) ongoing declines in total phosphorus (Evans et al. 2011), 2) the proliferation in dreissenid mussels, and 3) the resultant diminishment of the spring phytoplankton bloom (Fahnenstiel et al. 2010) reduce the capacity of Lake Michigan to produce the biomass of prey fish that was observed only two decades ago? We point out that Lake Michigan has already demonstrated its capacity to produce a strong year-class of alewives in 2010 despite the changes described above. Nonetheless, having a complete understanding of the answers to these questions will require additional years of surveillance, across-lake comparisons, and food-web analyses.

The GLFC Fish Community Objective for planktivores is not being achieved according to the bottom trawl survey results. The Objective calls for a lake-wide biomass of 500-800 kt, and the total prey fish biomass estimated by the bottom trawl survey was only 15 kt. The Objective also calls for a diversity of

prey species. The diversity in 2012 was far less than that measured in recent years, and we note that native prey fishes comprised only 18% of total prey fish biomass. In fact, native bloater, deepwater sculpin, and ninespine stickleback were at record-low levels in 2012 and native slimy sculpin has been trending downward since 2009. In 2013, we plan to add deeper depths (out to 128 m at as many as three ports) to our survey to evaluate the extent to which some of these native species inhabit depths beyond 110 m.

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Appendix 1. Mean numeric and biomass density, as well as lake-wide biomass (defined as biomass available to the bottom trawls for the region of the main basin between the 5-m and 114-m depth contours) estimates for selected fishes and dreissenid mussels in Lake Michigan during 2012. Estimates are based on the bottom trawl survey. Standard error enclosed in parentheses. NA denotes that estimate is not available.

Taxon	Numeric density (fish per ha)	Biomass density (kg per ha)	Lake-wide biomass (kt)
age-0 alewife	843.96 (832.03)	1.225 (1.166)	4.313 (4.106)
adult alewife	62.83 (16.31)	1.375 (0.371)	4.841 (1.308)
age-0 bloater	1.50 (0.97)	0.007 (0.004)	0.023 (0.015)
adult bloater	2.50 (1.19)	0.110 (0.053)	0.386 (0.187)
age-0 rainbow smelt	26.01 (23.74)	0.015 (0.014)	0.054 (0.049)
adult rainbow smelt	2.74 (1.83)	0.022 (0.012)	0.078 (0.043)
deepwater sculpin	43.64 (18.92)	0.417 (0.189)	1.468 (0.667)
slimy sculpin	36.38 (13.50)	0.206 (0.097)	0.725 (0.341)
ninespine stickleback	2.69 (1.68)	0.004 (0.003)	0.014 (0.010)
burbot	0.13 (0.06)	0.132 (0.063)	0.463 (0.222)
age-0 yellow perch	2.23 (1.20)	0.007 (0.004)	0.026 (0.014)
round goby	127.17 (70.87)	0.933 (0.493)	3.285 (1.737)
dreissenid mussels	NA	27.057 (6.803)	95.284 (23.957)