Agenda Item 5.B.

Lake Michigan Committee
March 26, 2009

Status and Trends of Prey Fish Populations in Lake Michigan, 2008[1]

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Abstract

The Great Lakes Science Center (GLSC) 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 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 2008. 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 2008 was estimated at 8.27 kilotonnes (kt) (1 kt = 1000 metric tons), which was the smallest biomass estimate in the entire time series and 29% lower than the 2007 estimate. Lake-wide biomass of bloater in 2008 was estimated at 3.33 kt, which was the lowest estimate since 1977 and 38% lower than the 2007 estimate. Rainbow smelt lake-wide biomass equaled 0.89 kt, which was only 0.01 kt higher than 2007, which is the lowest estimate in the time series. Deepwater sculpin lake-wide biomass equaled 5.23 kt, which is the fourth straight year of declining biomass. The 2008 estimate is the second smallest in the time series, and 39% lower than the 2007 estimate. Slimy sculpin lake-wide biomass remained relatively high in 2008 (2.75 kt), increasing 25% over 2007. Ninespine stickleback lake-wide biomass equaled only 0.50 kt in 2008, which was 79% lower than the 2007 estimate. The final prey fish, exotic round goby, increased two orders of magnitude between 2007 and 2008, from 0.02 to 4.65 kt. Round gobies now represent 18% of the prey fish biomass. Burbot lake-wide biomass (0.91 kt in 2008) has remained fairly constant since 2002. Numeric density of age-0 yellow perch (i.e., < 100 mm) equaled 0.7 fish per ha, which is indicative of a relatively poor year-class. Lake-wide biomass of dreissenid mussels dropped precipitously in 2008, down to 9.47 kt, and a 96% decline from the 2007 biomass estimate. 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 2008 was 25.62 kt, which was the lowest observed since the survey began in 1973.

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The Great Lakes Science Center (GLSC) has conducted daytime bottom trawl surveys in Lake Michigan during the fall annually since 1973. 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 are performed on 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 2008.

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. Since 1998, we have corrected the width (W, in meters) of the area sampled according to $W = 9.693 - (43.93/D)$, as well as the actual time (AT, in minutes) spent on the bottom according to $AT = \text{tow time} - 3.875 + D^{0.412}$ (Fleischer et al. 1999). These relationships, along with boat speed, were used to estimate bottom area swept.

To facilitate comparisons of our estimates of fish abundance with abundance estimates in other lakes and with hydroacoustic estimates of abundance, we report both numeric (fish per hectare [ha]) and biomass (kg per ha) density. 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. Relative standard error (RSE) was calculated by dividing SE by mean fish density and multiplying this ratio by 100 to yield a percentage. SE and RSE for the estimate of lake-wide biomass were calculated in a manner analogous to that for calculating SE and RSE for the estimate of mean numeric or biomass density. For this report, we provide plots of prey fish RSE for numeric density only, as RSE for biomass density exhibited a similar trend.

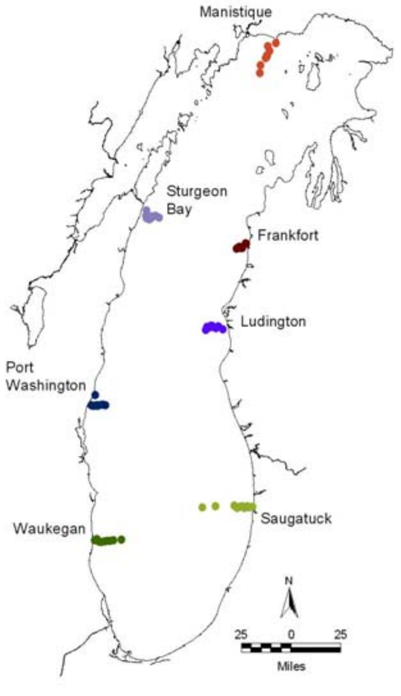

Figure 1. Established sampling locations for GLSC bottom trawls in Lake Michigan.

NUMERIC AND BIOMASS DENSITY

By convention, we classify "adult" prey fish as age 1 or older, based on length-frequency: alewives ≥ 100 mm total length (TL), rainbow smelt (*Osmerus mordax*) ≥ 90 mm TL, bloaters ≥ 120 mm TL, and yellow perch (*Perca flavescens*) ≥ 100 mm TL. We assume all fish smaller than the above length cut-offs are age-0. Catches of age-0 alewife, bloater, and rainbow smelt are not necessarily reliable indicators of future year-class strengths for these populations, because their small size and position in the water column make them less vulnerable to bottom trawls. Nevertheless, during the bloater recovery in Lake Michigan that began in the late 1970s, our survey contained unusually high numbers of age-0 bloaters, indicating some correspondence between bottom trawl catches and age-0 abundance in the lake. 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.

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 (*Lota lota*), 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 35 years (Jude et al. 1987; Stewart and Ibarra 1991; Warner et al. 2008). 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 rule changes and seasonal and area 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). There is presently no commercial fishery for alewives in Lake Michigan.

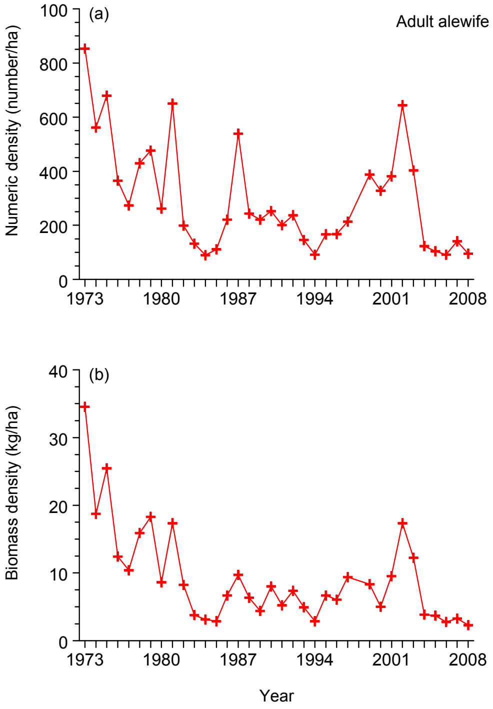

Figure 2. Density of adult alewives as number (a) and biomass (b) per ha in Lake Michigan, 1973-2008.

Adult alewife biomass density in 2008 (2.3 kg per ha) was the lowest observed in our 36-year time series (Figure 2b). This low biomass follows four years of similarly low levels (2004-2007 average = 3.4 kg per ha). Conversely, adult alewife biomass density averaged 14.8 kg per ha in 2002 and 2003. The trend for numeric density also depicts adult alewife to be at relatively low levels. In 2002 and 2003, numeric density exceeded 400 fish per ha, but has since consistently remained under 150 fish per ha (Figure 2a). Our estimate of 95 adult alewife per ha in 2008 was the fourth lowest ever observed: only in 1984, 1994, and 2006 were numeric densities lower. Given that predation by salmon and trout appears to be the most important factor regulating alewife abundance in Lake Michigan (Madenjian et al. 2002, 2005a), an increase in Chinook salmon abundance may have been the most likely cause for the pronounced decrease in adult alewife numeric density since 2002 and 2003.

During 1973-2007, RSE for adult alewife numeric density averaged 23% (Figure 3a). RSE has generally increased during 1999-2008 (mean=

35%) relative to earlier years (mean=18%) which suggests that adult alewives are more patchily distributed in recent years than in earlier ones.

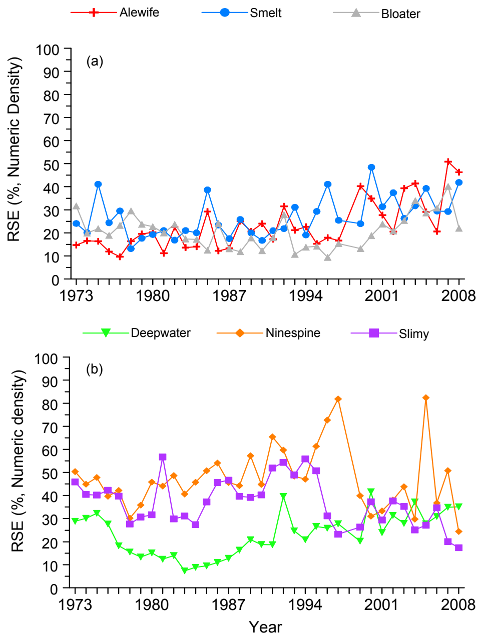

Figure 3. RSE for numeric density of Lake Michigan prey fishes, 1973-2008. Panel (a) provides estimates for adult alewife, adult rainbow smelt, and adult bloater. Panel (b) provides estimates for deepwater sculpin, slimy sculpin, and ninespine stickleback.

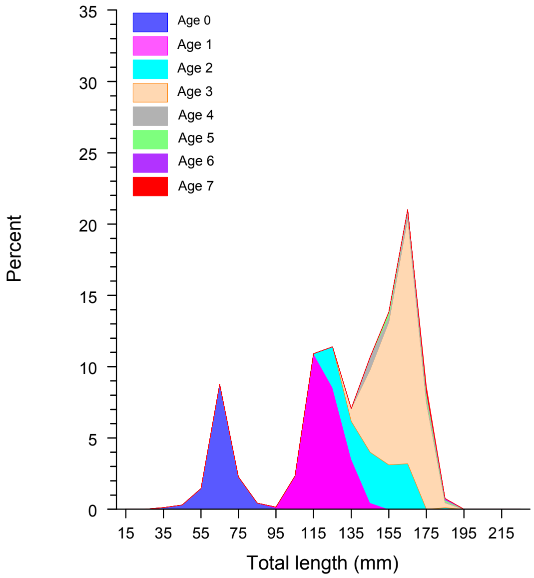

Figure 4. Age-length distribution of alewives caught in bottom trawls in Lake Michigan, 2008.

The alewife catch was dominated by age-3 and younger fish in 2008 (Figure 4). Age-3 (2005 year-class) fish dominated the catch with 42%, followed by age-1 fish, with 26%. In 2008, age-4 and older fish represented only 4% of the population. The alewife population has not been this young since 2001, when age-4 and older also was 4% of the population. Between 2002 and 2007, the percentage of age-4 and older fish was considerably higher, ranging 17-90% (mean = 48%). Hence, either excessive predation or relatively poor recruitment in recent years explains the current low percentage of older individuals in the alewife population.

Our results are different from the acoustic survey, which more accurately estimates densities of age-2 and younger alewives. Warner et al. (2009) reported alewife biomass to increase 120% relative to 2007, whereas we reported a 29% reduction. The increase in the acoustic survey was largely attributed to higher than expected densities of age-1 fish, which are not fully recruited to the bottom trawl (Madenjian et al. 2005a). Overall, however, alewife biomass was still 18% lower in 2008 than the long-term average for the acoustic survey (which includes years 1992-1996, 2001-2008).

Bloater - Bloaters are eaten by salmonines in Lake Michigan, but are far less prevalent in salmonine diets than alewives (Warner et al. 2008). Over 30% of the diet of large (≥ 600 mm) lake trout at Saugatuck and on Sheboygan Reef was 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). When available, juvenile bloaters have been a substantial component of salmon and nearshore lake trout diets, particularly for intermediate-sized fish (Elliott 1993; Rybicki and Clapp 1996). The bloater population in Lake Michigan also supports a valuable commercial fishery.

Biomass density of adult bloater continued to decline in 2008, as we estimated only 0.7 kg per ha, which was a 57% decline from 2007, and the lowest level observed since 1977 (Figure 5a). Similarly, the 2008 adult bloater numeric density was 28 fish per ha, a 25% decline from 2007. RSE for adult bloater numeric density has averaged 21% from 1973-2007, but RSE for 2007 was 42% following a general trend of increasing RSE since 1999 (Figure 3a).

Overall, adult bloater numeric and biomass densities have been declining since 1989 (Figure 5a). These declines are attributable to relatively poor recruitment since 1992 (Madenjian et al. 2002, Bunnell et al. 2006a, Bunnell et al. 2009a). Recent work investigated whether a reduction in size-specific fecundity (owing to lower observed condition with the decline of *Diporeia* spp.) could be responsible for poor recruitment (Bunnell et al. 2009a). Although fecundity in 2006 was 24% lower than in the late 1960s (when adult condition was 69% higher), this reduction does not explain why bloater recruitment has been so consistently low.

Madenjian et al. (2002) proposed that the Lake Michigan bloater population may be cycling in abundance, with a period of about 30 years (i.e., ~15 years of increasing densities followed by ~15 years of declining densities). Densities have been declining for the past 19 years, but there are signs of modest increases in recruitment in recent years. Numeric density of age-0 bloaters (< 120 mm TL) was 35 fish per ha in 2008 (Figure 5b), which was similar to the 42 fish per ha observed in 2005. Although these densities pale in comparison to those observed between 1980 and 1990 (mean = 508 fish per ha), they are an order of magnitude greater than all of the other densities since 1992 (mean = 3 fish per ha). Future surveys will reveal whether these two years of relatively strong recruitment are indicators of a bloater recovery.

Similar to alewife, bloater age distribution is extremely young, with 79% of the population age 1 or younger. The percentage of age-4 and older bloater was only 4% in 2008. This percentage is not surprising, given the consistently low recruitment over the past 19 years. Presently, both the bloater and alewife populations are comprised of very young individuals.

The acoustic survey revealed bloater biomass to modestly increase between 2007 and 2008, although current biomass remains ~2% of the bloater biomass attained during the 1990s (Warner et al. 2009). The difference between the decline reported by the bottom trawl survey and stability reported by the acoustic survey is likely explained by the relative youth of the bloater population, as described above. As for alewife, bloater do not fully recruit to the bottom trawl until age 3 (Bunnell et al. 2006).

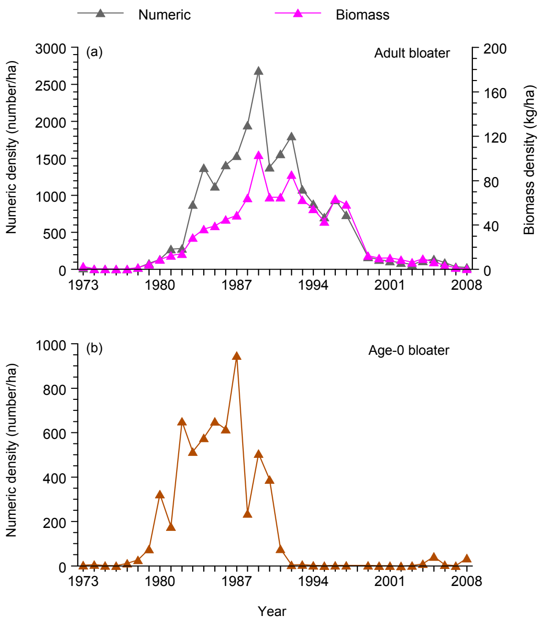

Figure 5. Panel (a) depicts numeric and biomass density of adult bloater in Lake Michigan, 1973-2008. Panel (b) depicts numeric density of age-0 bloater in Lake Michigan, 1973-2008.

<u>Rainbow smelt</u> – Adult rainbow smelt is an important diet constituent for intermediate-sized (400 to 600 mm) lake trout in the nearshore waters of Lake Michigan (Stewart et al. 1983; Madenjian et al. 1998). Overall, however, rainbow smelt are not eaten by Lake Michigan salmonines to the same extent as alewives. 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).

In 2008, adult rainbow smelt biomass density was at a record low level of 0.09 kg per ha (Figure 6a), a 62% decline from 2007, which was the previous record low. Adult rainbow smelt numeric density in 2008 was 10 fish per ha, another record low for the time series. Across the time series, adult rainbow smelt numeric density was highest from 1981 to 1993, and has remained at a relatively low density from 1994 to present. Causes for the decline 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 6b). Age-0 rainbow smelt has been highly variable since 2002. Age-0 numeric density in 2008 was 383 fish per ha, which was considerably above the average density for the entire time series (219 fish per ha). RSE for adult rainbow smelt numeric density averaged 27% from 1973-2008, and RSE for 2008 was 35% (Figure 3a).

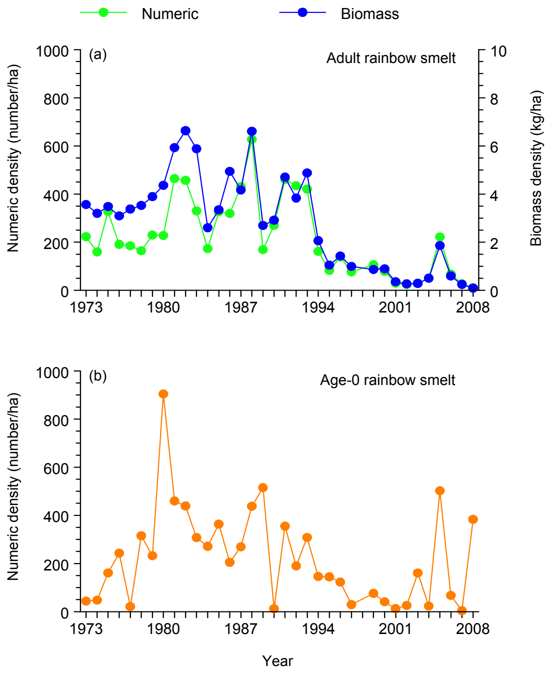

Figure 6. Panel (a) depicts numeric and biomass density of adult rainbow smelt in Lake Michigan, 1973-2008. Panel (b) depicts numeric density of age-0 rainbow smelt in Lake Michigan, 1973-2008.

Trends estimates for rainbow smelt biomass in the acoustic and bottom trawl surveys are somewhat similar since 2002. The bottom trawl survey has documented generally declining biomass estimates since 2002, except for 2004-2006 when smelt biomass increased to a high level in 2005 but then fell back to low levels after 2006. Similarly, biomass of rainbow smelt in the acoustic survey increased considerably in 2005 and 2006 before falling to lower levels in 2007 and 2008 (Warner et al. 2009). The acoustic survey revealed rainbow smelt biomass in 2008 to be only 10% of the average biomass attained during the 1990s.

<u>Sculpins</u> – From a biomass perspective, the cottid populations in Lake Michigan proper are 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 are still encountered in Lake Michigan, but in small numbers (Potter and Fleischer 1992).

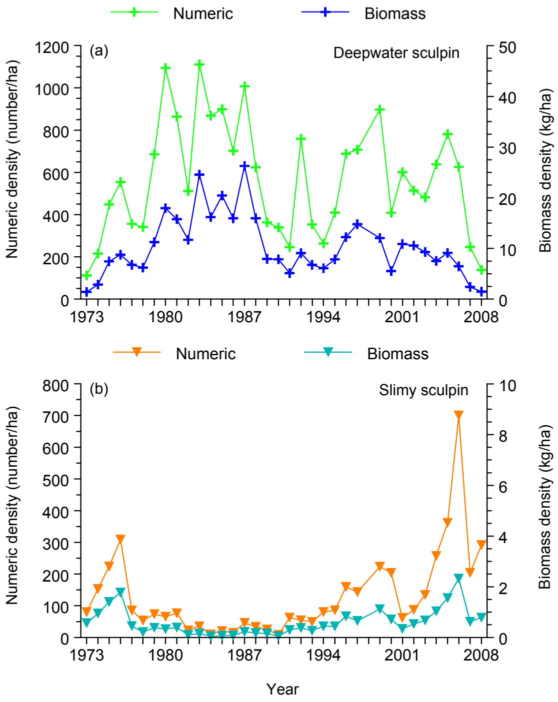

Figure 7. Numeric and biomass density for deepwater (a) and slimy sculpin (b) in Lake Michigan, 1973-2008.

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 are 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).

Numeric density of deepwater sculpins in Lake Michigan was 138 fish per ha in 2008, which surpassed only the density observed in 1973 (Figure 7a). Similarly, biomass density of deepwater sculpins in Lake Michigan was only 1.5 kg per ha, second lowest in the time series. Deepwater sculpins have been declining since 2005, following a 15-year period (1990-2005) of no discernable increase or decline. 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 occupying depths deeper than our survey samples (i.e., 110 m). 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). Neither alewife nor burbot have increased in recent years to explain this decline in deepwater sculpins. RSE for deepwater sculpin numeric density was 24% in 2008, close to the average of 23% for the entire time series (Figure 3b).

Numeric density of slimy sculpins in Lake Michigan in 2008 was 291 fish per ha, which is a 43% increase over 2007 (Figure 7b). Biomass density was 0.78 kg per ha, a 25% increase over 2007. RSE for slimy sculpin numeric density was 17% in 2008, which was lower than its average RSE of 38% from 1973-2008 (Figure 3b). Overall, slimy sculpin numeric density has generally increased since around 1990, with considerable interannual variation. This increase was likely attributable to greater emphasis on stocking lake trout on offshore reefs beginning in 1986 (Madenjian et al. 2002). *Diporeia* has dominated the diet of slimy sculpins in Lake Michigan since the 1970s (Madenjian et al. 2002), and *Diporeia* abundance in Lake Michigan has declined during the 1990s and 2000s (Nalepa et al. 2006). The effect of the decrease in *Diporeia* abundance on the slimy sculpin population remains to be determined.

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 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). Numeric density of ninespine stickleback remained fairly low from 1973-1995 (Figure 8a). Densities increased dramatically in 1996-1997, and have since been highly variable. Numeric density of ninespine stickleback was only 72 fish per ha in 2008, which is the third consecutive year of declining densities. Similarly, biomass density was only 0.14 g per ha in 2008. RSE for ninespine stickleback numeric density was 22% in 2008, which was considerably smaller than the long-term average RSE of 47% from 1973-2008 (Figure 3b). A recent analysis of ninespine stickleback densities in lakes Michigan and Superior reveal that the recent increase in Lake Michigan coincided with the expansion of dreissenid mussels in the lake, but mechanisms underlying the population increase of ninespine stickleback are unknown (Madenjian et al. in review).

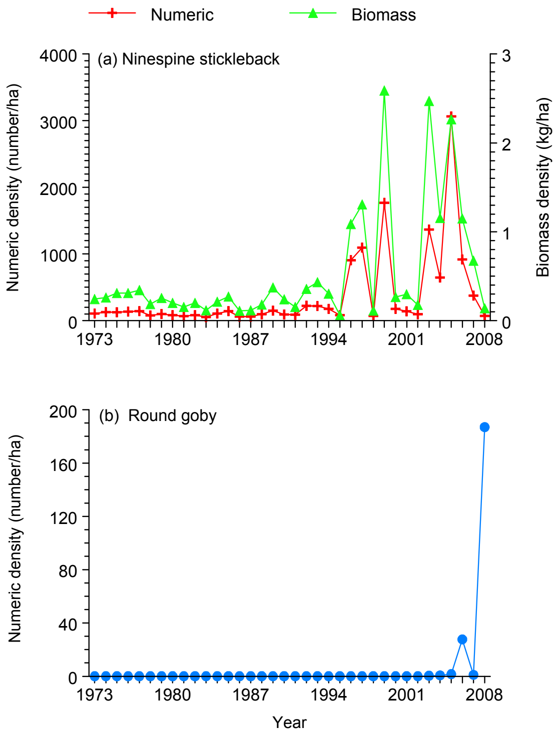

Figure 8. Panel (a) depicts numeric and biomass density of ninespine sticklebacks in Lake Michigan, 1973-2008. Panel (b) depicts numeric density of round goby in Lake Michigan, 1973-2008.

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 by Michigan DNR personnel 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 the Northern Refuge of Lake Michigan by 2006 (G.R. Jacobs, unpublished data, USGS Great Lakes Science Center).

According to our bottom trawl survey, round goby numeric density increased exponentially during 2003-2006, attaining a level of 27.7 fish per ha in 2006 (Figure 8b). In 2007, however, numeric density inexplicably dropped to 1.0 fish per ha. In 2008, numeric density surged to 187 fish per ha, a nearly 7-fold increase over the 2006 estimate. Round gobies have now been captured at all transects, at depths ranging 9 to 91 m, and will likely remain a large component of the prey fish community in Lake Michigan into the future.

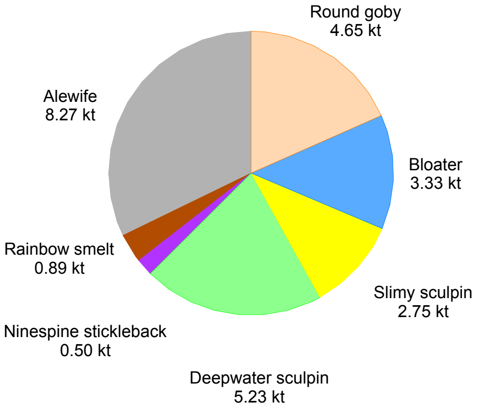

Figure 9. Estimated lake-wide (i.e., 5-114 m depth region) biomass of prey fishes in Lake Michigan, 2008, based on the bottom trawl survey.

LAKE-WIDE BIOMASS

We estimated a total lake-wide biomass of prey fish available to the bottom trawl in 2008 of 25.62 kilotonnes (kt) (1 kt = 1000 metric tons) (Figure 9, Appendix 1). Total prey fish biomass was the sum of the population biomass estimates for alewife, bloater, rainbow smelt, deepwater sculpin, slimy sculpin, ninespine stickleback, and, in this year, we added round goby. In previous years, round goby had never constituted more than 1% of the total prey fish biomass. In 2008, however, round goby was 18% of the total prey fish biomass (with an estimate of 4.65 kt) Percentages of total prey fish biomass (and biomass estimates) for the other species were: alewife 32% (8.27 kt), deepwater sculpins 20% (5.23 kt), bloaters 13% (3.33 kt), slimy sculpins 11% (2.75 kt), rainbow smelt 4% (0.89 kt) and ninespine stickleback 2% (0.50 kt).

Total prey fish biomass in Lake Michigan has trended downward since 1989 (Figure 10). Between 1989 and 2000, this decline was largely driven by the tremendous decrease in bloater biomass. In the past eight or so years, however, several species have contributed to declining prey fish biomass, including alewife, deepwater sculpin, and bloater. The total lake-wide biomass of prey fish available to the bottom trawl in 2008 was the lowest biomass recorded in our time series, and a 94% decline from the peak in 1989.

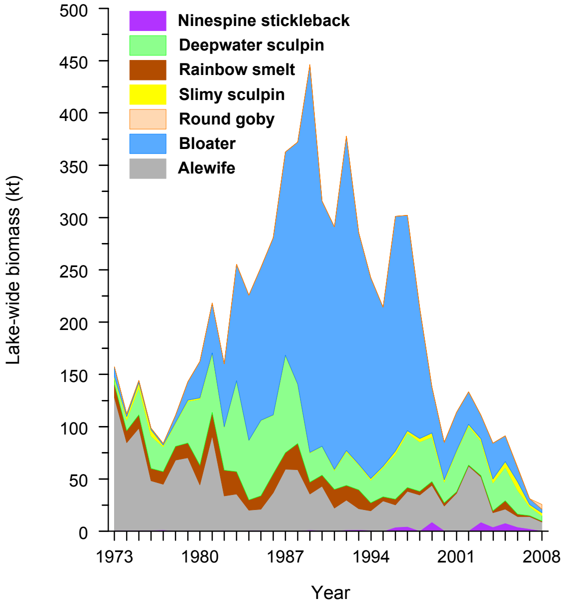

Figure 10. Estimated lake-wide (i.e., 5-114 m depth region) biomass of prey fishes in Lake Michigan, 1973-2008, based on the bottom trawl survey.

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.

After a period of low numeric density in the 1970s, burbot showed a strong recovery in the 1980s (Figure 11). Densities increased through 1997, and we interpret the decline between 1997 and 2002 as a leveling off in response to density-dependent forces. Since 2002, burbot numeric densities have been remarkably stable. In 2008, numeric density was 0.37 fish per ha.

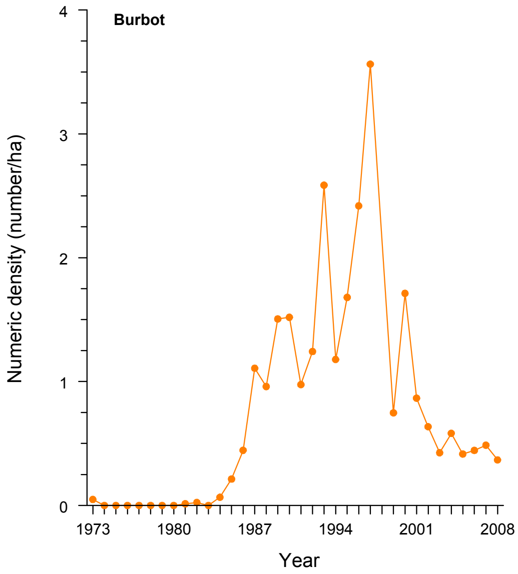

Figure 11. Numeric density of burbot in Lake Michigan, 1973-2008.

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 12). This huge year-class was likely attributable to a sufficient abundance of female spawners and favorable weather. Numeric density of the 2008 year-class was 0.7 fish per ha, an indication of a poor year-class, and similar to the densities observed during most of the 1989-2002 period). Most researchers believe that the poor yellow perch recruitment over this period was a combination of several factors, including poor weather conditions, low abundance of female spawners, and possibly a low availability of zooplankton for yellow perch larvae (Makauskas and Clapp 2000).

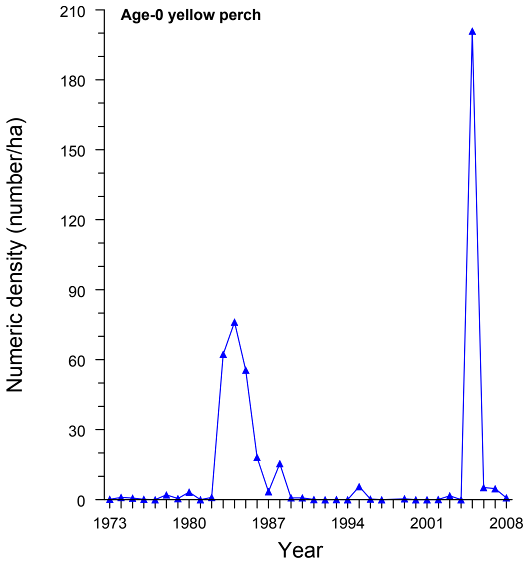

Figure 12. Numeric density of age-0 yellow perch in Lake Michigan, 1973-2008.

Dreissenid mussels – The first zebra mussel (*Dreissena polymorpha*) noted in Lake Michigan was found in May 1988 (reported in March 1990) 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 weights from each tow. Lake Michigan dreissenid mussels include two species: the zebra mussel and the quagga mussel (*Dreissena bugensis*). 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 13a), which followed an exponential like increase between 2004 and 2006 (Bunnell et al. 2009b). 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 13b). Some authors have attributed the recent decline in prey fish to the expansion of dreissenids (Nalepa et al. 2008). In a recently published paper, however, we argue that the decline in prey fish biomass is better explained by factors other than dreissenids, including poor fish recruitment (that preceded the mussel expansion), shifts in fish habitat, and higher fish predation by Chinook salmon (Bunnell et al. 2009b).

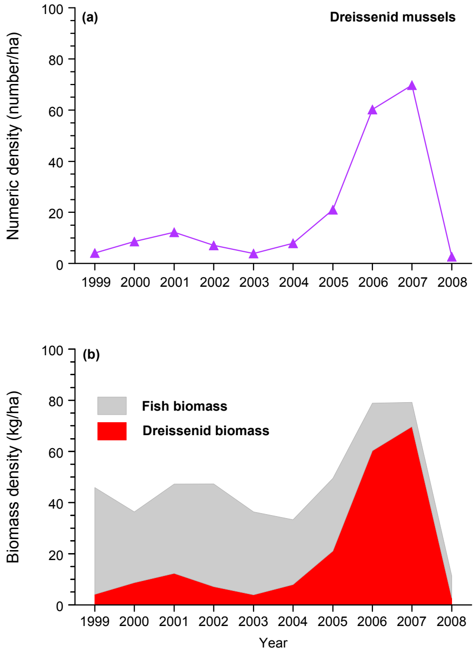

Figure 13. Panel (a) depicts biomass density of dreissenid mussels in the bottom trawl in Lake Michigan, 1999-2008. Panel (b) depicts biomass of dreissenids and total fish biomass estimated by the bottom trawl between 1999 and 2008.

The biomass density of dreissenid mussels in 2008 was only 2.69 kg per ha, which represents only 4% of the biomass density estimated in 2007 and the lowest estimate recorded since we began monitoring dreissenids in 1999. Similarly, dreissenid mussels represented 24% of the total bottom trawl catch, which was a dramatic decline from the 88% of the catch in 2007. We cannot explain this steep decline in dreissenid catch in 2008. Although we expected the quagga population in Lake Michigan to overshoot their carrying capacity in Lake Michigan, just as zebra mussels exceeded their carrying capacity in western Lake Erie during the early 1990s (J. Leach, Ontario Ministry of Natural Resources, Wheatley, ON, personal communication), this drop occurred more quickly than we would have predicted. In addition, monitoring of benthic macroinvertebrates by Tom Nalepa at NOAA-GLERL has indicated no steep drop in offshore quagga mussels in their preliminary 2008 data processing. One possible explanation for our steep decline is that repeated bottom trawl sampling over the same sites disrupts the population growth and colonization of dreissenids in the immediate area. After all, we have never sampled large dreissenid hauls (i.e., > 50 g/m^2) at the same site in more than one year, which suggests that the high mussel densities are either patchily distributed or the population does not recover quickly from our sampling.

CONCLUSIONS

Since the Lake Michigan bottom trawl survey began in 1973, prey fish biomass has never been lower. Several species are at either record or near-record lows, including alewife, bloater, rainbow smelt, deepwater sculpins, and ninespine sticklebacks. Slimy sculpin is the only native species whose biomass is above the long-term average. The invasive round goby also dramatically increased in 2008, and now represents 18% of the total prey fish biomass. Our bottom trawl results are somewhat tempered by the results of the acoustic survey (Warner et al. 2009), which revealed increases in alewife and bloater biomass in 2008 relative to 2007 (though both species remain far below the biomasses attained in the 1990s). Nonetheless, prey fish biomass in 2008 was at an unprecedented low, and managers should consider how this could influence salmonines production in coming years. An obvious question is whether excessive predation by salmonines is underlying these downward trends in prey fish biomass. The truncated age distribution of alewives and bloater is suggestive of high predation. However, excessive predation cannot be responsible for the decline of all species, given that several do not figure prominently in salmonine diets (i.e., deepwater sculpins, ninespine sticklebacks).

The GLFC Fish Community Objective for planktivores is not being fully achieved according to the bottom trawl survey. 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 25 kt. The Objective also calls for a diversity of prey species. Based on Figure 9, the prey fish community is quite diverse, with five different species each contributing at least 10% to the total prey fish biomass.

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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 various fishes and dreissenid mussels in Lake Michigan during 2008. 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	24.74	0.05	0.16
	(19.32)	(0.04)	(0.13)
adult alewife	95.25	2.30	8.11
	(44.11)	(0.89)	(3.14)
age-0 bloater	35.16	0.29	1.01
	(17.65)	(0.15)	(0.510)
adult bloater	27.76	0.66	2.33
	(11.62)	(0.22)	(0.79)
age-0 rainbow smelt	383.31	0.16	0.57
	(334.88)	(0.14)	(0.49)
adult rainbow smelt	10.30	0.09	0.33
	(3.62)	(0.03)	(0.12)
deepwater sculpin	138.11	1.49	5.23
	(33.76)	(0.35)	(1.25)
slimy sculpin	291.35	0.78	2.75
	(50.67)	(0.15)	(0.53)
ninespine stickleback	71.96	0.14	0.50
	(15.79)	(0.04)	(0.12)
burbot	0.37	0.26	0.91
	(0.12)	(0.11)	(0.40)
age-0 yellow perch	0.71	(2.00^{-3})	0.01
	(0.32)	(1.00^{-3})	(3.00^{-3})
round goby	186.98	1.32	4.65
	(102.96)	(0.87)	(3.05)
dreissenid mussels	NA	2.69	9.47
		(0.51)	(1.81)