Lake Michigan Committee
March 23, 2006

Status and Trends of Prey Fish Populations in Lake Michigan, 2005[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 lake-wide survey were completed in 2005. Lake-wide biomass of alewives in 2005 was estimated at 13.401 kilotonnes (kt) (1 kt = 1000 metric tons), which was very similar to the lake-wide biomass estimate of 13.721 kt for alewives in 2004. Catch of adult alewives in 2005 was dominated by the 2002 year-class. Lake-wide biomasses of deepwater sculpin, bloater, rainbow smelt, and slimy sculpin in 2005 were estimated at 32.030 kt, 24.546 kt, 7.816 kt, and 5.474 kt, respectively. Bloater biomass drastically declined between 1989 and 2005. Abundance of juvenile bloaters steadily increased during 2003-2005, perhaps signaling the start of a bloater recovery. Rainbow smelt biomass increased substantially from 1.854 kt in 2004 to 7.816 kt in 2005. Deepwater sculpin biomass has not shown a pronounced temporal trend during 1990-2005. Burbot abundance showed a slight decrease during the early 2000s. Slimy sculpin abundance showed an increasing trend during 1985-2005. Yellow perch year-class strength in 2005 was the highest on record dating back to 1973. The lake-wide biomass estimate of dreissenid mussels was relatively high in 2005. Total catch of round gobies in 2005 was 37 fish, compared with 26 fish in 2004.

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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 and bloaters from our bottom trawl catches (TeWinkel et al. 2002; Madenjian et al. 2003). 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 index transects are situated off Manistique, Frankfort, Ludington, and Saugatuck, Michigan; Waukegan, Illinois; and Port Washington and Sturgeon Bay, Wisconsin (Figure 1). All seven index transects were completed in 2005.

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 fishing depth (D, in meters) to influence 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.

Beginning last year, we made several changes in our reporting of the bottom trawl survey data. To better facilitate comparison of our estimates of fish abundance in Lake Michigan with abundance estimates in other lakes and with hydroacoustic estimates of abundance, we report fish density, expressed both as number of fish per hectare (ha) and kg of fish per ha, rather than catch per tow. A weighted mean fish 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 of the depth zones, then weighting each depth zone mean density by the respective proportion of lake surface area assigned that depth zone. Standard error (SE) of mean fish 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 then 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 fish density.

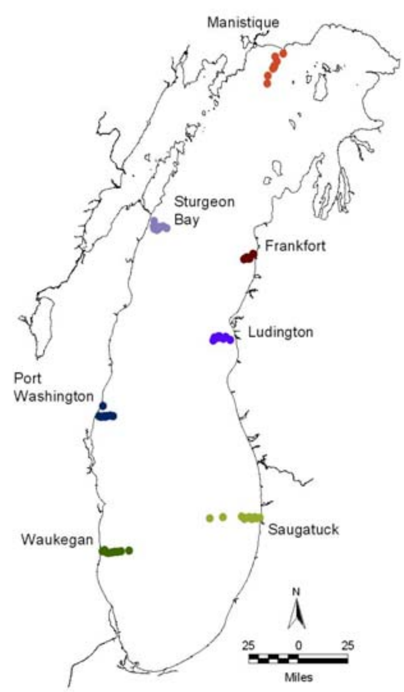

Figure 1. Established sampling locations for GLSC bottom trawls in Lake Michigan.

ABUNDANCE

By convention, we classify "adult" prey fish as those individuals age 1 or older. Life stage classification was assigned based on length-frequency, where alewives greater ≥ 100 mm, rainbow smelt ≥ 90 mm, and bloaters ≥ 120 mm were classified as "adults". Unless otherwise stated, all length measurements refer to total length.

Catches of small alewives, bloaters, 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 trawling survey indicated that the lake contained unusually-high abundances of age-0 bloaters, so there is some correspondence between our bottom trawl catches of age-0 prey fish and their actual abundance in the lake.

Alewife – Since its establishment in the 1950s, the alewife has become a key member of the fish community. The 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; P. Peeters, Wisconsin Department of Natural Resources, Sturgeon Bay, WI, personal communication; R. Elliott, U. S. Fish and Wildlife Service, Green Bay, WI, personal communication). Most of the alewives consumed by salmonines in Lake Michigan are eaten by chinook salmon (Madenjian et al. 2002). A commercial alewife 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 alewife harvest declined from about 7,600 metric tons in 1985 to an estimated average annual incidental harvest of only 12 metric tons after 1990 (M. Toneys, [retired], Wisconsin Department of Natural Resources, Sturgeon Bay, WI, personal communication). There is presently no commercial fishery for alewives in Lake Michigan.

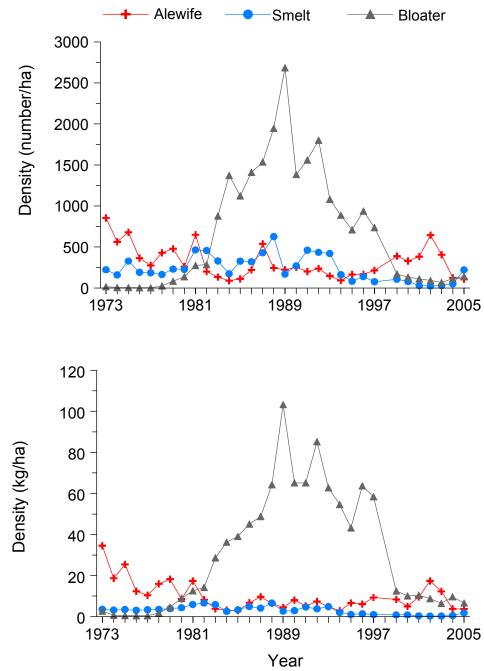

Figure 2. Density of adult alewives, rainbow smelt and bloaters as number (top) and weight (bottom) of fish per ha in Lake Michigan, 1973-2005.

Adult alewife abundance in 2005 was very similar to that in 2004. Measured as number of fish per ha, density of adult alewives in Lake Michigan was 123 fish per ha in 2004 and 105 fish per ha in 2005 (Figure 2; Appendix 1). Alewife densities, on a weight basis, were 3.9 kg per ha and 3.7 kg per ha in 2004 and 2005, respectively (Figure 2). Only in years 1984, 1985, and 1994 was adult alewife density less than that observed in 2005. 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), a recent increase in chinook salmon biomass may be a likely cause for the recent pronounced decrease in adult alewife abundance during 2002-2005.

RSEs for adult alewife density ranged from 10% to 42% (Figure 3). During 1973-2005, RSE averaged 21% for density on a number of fish per ha basis and 20% for density on a kg of fish per ha basis. Relatively high RSEs during 2003-2005 suggested that adult alewives were patchier in their spatial distribution during these last three years than during previous years.

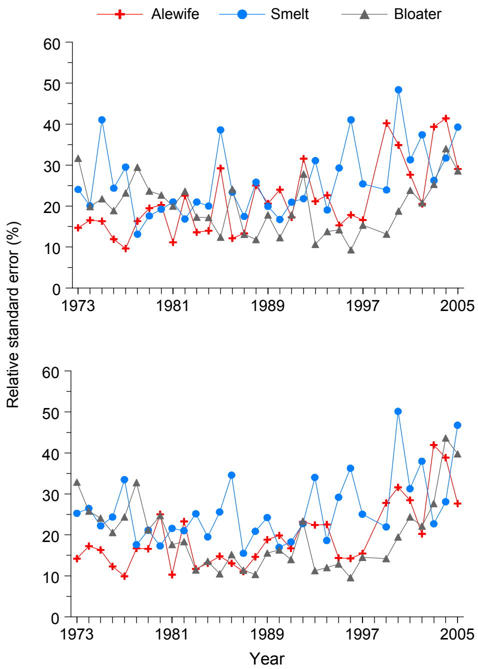

Figure 3. RSE for density of adult alewives, rainbow smelt and bloaters as number (top) and weight (bottom) of fish per ha in Lake Michigan, 1973-2005.

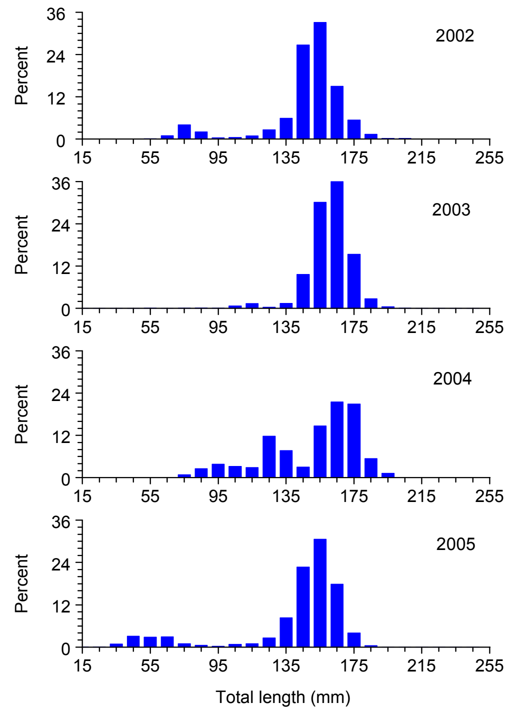

Figure 5. Length-frequency distribution of alewives caught in bottom trawls in Lake Michigan, 2002-2005.

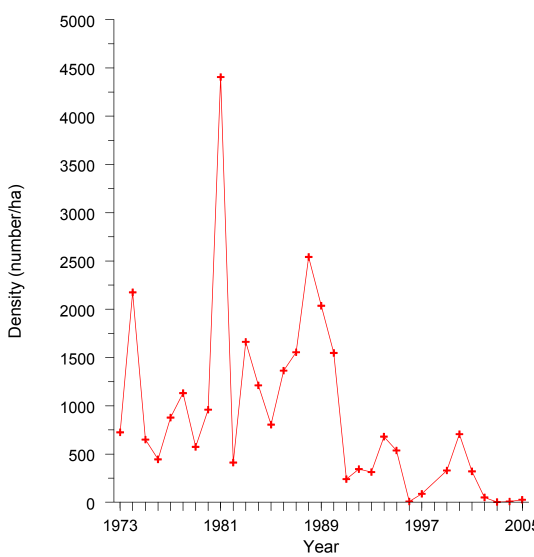

Figure 4. Density of age-0 alewives in Lake Michigan, 1973-2005.

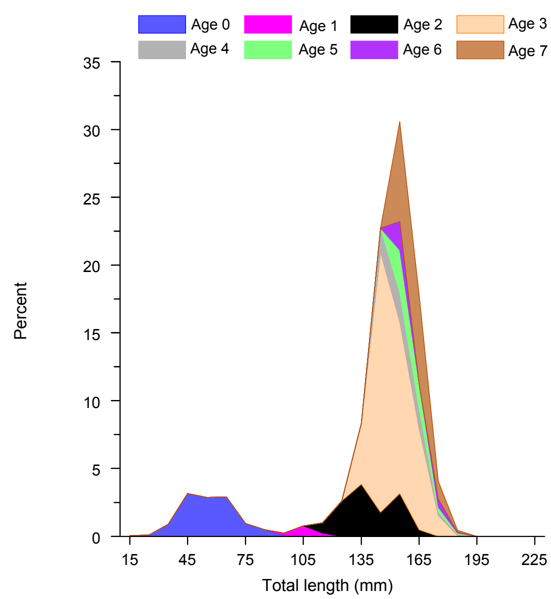

Figure 6. Age-length distribution of alewives caught in bottom trawls in Lake Michigan, 2005. The 2002 and 1998 year-classes are age-3 and age-7 fish respectively.

Density of age-0 alewives, as measured by the bottom trawl survey, was relatively low at 28 fish per ha in 2005 (Figure 4).

The 2002 year-class (i.e., age 3) dominated the catch of adult alewives during 2005 (Figures 5 and 6), although the 1998 year-class constituted nearly 20% of the adult catch. The 1998 year-class (i.e., age 7) had dominated the catch of age-1 and older alewives during 1999-2004 (Madenjian et al. 2005b). The 1998 year-class was a strong one (Madenjian et al. 2005a), despite the relatively low energy density of the spawning alewives in 1998. Energy density of adult alewives in Lake Michigan decreased by 23% between the 1979-1981 and 2002-2004 periods (Madenjian et al. 2006). The decrease in adult alewife energy density is believed to have occurred in 1995 in response to decreasing abundance of the amphipod *Diporeia*. The decrease in *Diporeia* abundance during the 1990s was strongly linked to the dreissenid mussel invasion of the lake (Nalepa et al. 2006).

Bloater - Bloaters are eaten by salmonines in Lake Michigan, although not to the extent that adult alewives are consumed. 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.

The overall trend in adult bloater density during 1989-2005 was a dramatic decline (Figure 2). This decline was attributable to relatively poor recruitment during 1992-2003 (Madenjian et al. 2002, 2005b). Adult bloater density decreased from 9.7 kg per ha in 2004 to 6.6 kg per ha in 2005 (Figure 2). Age-0 bloater density ranged from 0.2 to 6.5 fish per ha during 1992-2003, whereas age-0 bloater density ranged from 177 to 947 fish per ha between during 1980-1990 (Figure 7). In 2005, age-0 bloater density was 42.1 fish per ha, which was the highest value in the time series since 1991. Moreover, age-0 bloater density in 1977, the year in which the bloater recovery in Lake Michigan began (Eck and Wells 1987), was 11.8 fish per ha. Madenjian et al. (2002) have proposed that the Lake Michigan bloater population may be cycling in abundance, with a period of about 30 years. Further, these cycles may be regulated by factors intrinsic to the bloater population (Bunnell et al. 2006). The recent increase in age-0 abundance may be signaling the start of a bloater recovery.

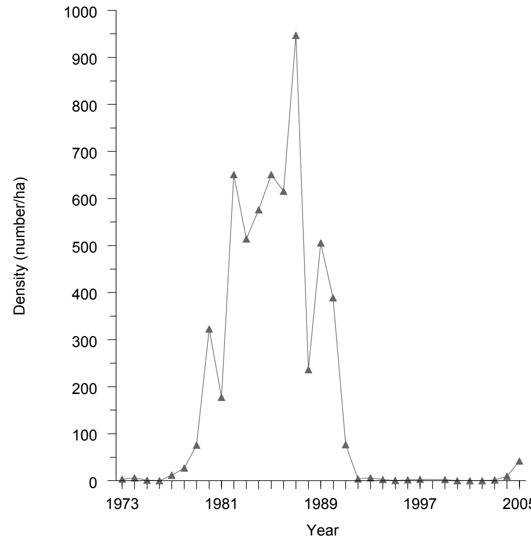

Figure 7. Density of age-0 bloaters in Lake Michigan, 1973-2005.

Rainbow smelt – Adult rainbow smelt is an important diet item 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 consumed by Lake Michigan salmonines to the same extent as alewives. The rainbow smelt population supports commercial fisheries operated in Wisconsin and Michigan waters (Belonger et al. 1998; P. Schneeberger, Michigan Department of Natural Resources, Marquette, MI, personal communication).

Adult rainbow smelt density substantially increased from 50 fish per ha in 2004 to 222 fish per ha in 2005 (Figure 2). On a weight basis, density increased from 0.5 to 1.9 kg per ha between 2004 and 2005. Adult rainbow smelt abundance declined substantially from 1992 to 1997, remained low during 1997-2004, but has now appeared to be showing preliminary signs of recovery (Figure 2). Causes for the decline during 1992-1997 remain unclear. Consumption of smelt by salmonines was higher in the mid 1980s than during 1992-1997 (Madenjian et al. 2002), yet adult smelt abundance remained high during the 1980s. Average density of age-0 rainbow smelt during 1973-1979 was not appreciably higher than average abundance of age-0 rainbow smelt during the 1990s (Figure 8). Age-0 smelt abundance in

2005 was 502 fish per ha, representing the third highest value in the time series (Figure 8). Interpretation of the long-term time series for adult rainbow smelt density remains difficult.

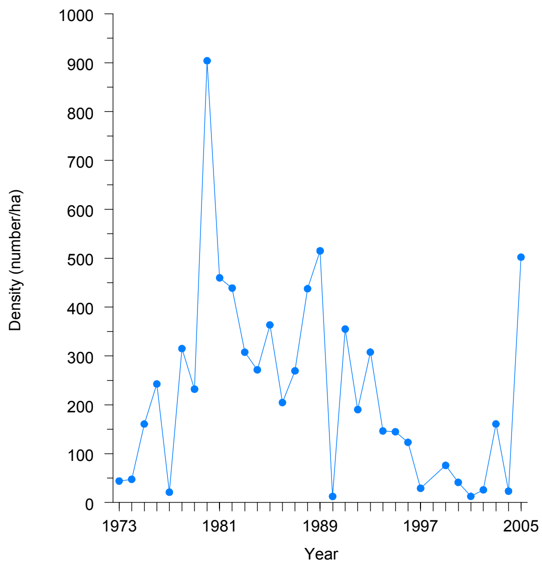

Figure 8. Density of age-0 rainbow smelt in Lake Michigan, 1973-2005.

Sculpins – The cottid populations in Lake Michigan proper are dominated by deepwater, and to a lesser degree, slimy sculpins. Spoonhead sculpins, 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).

Slimy sculpin is a favored prey of juvenile lake trout in nearshore regions of the lake (Stewart et al. 1983; Madenjian et al. 1998). As lake trout grow, the importance of sculpins in lake trout diet decreases substantially so that sculpins form only a minor portion of adult lake trout diet. Deepwater sculpin is an important diet item for burbot in Lake Michigan, especially in deeper waters (Van Oosten and Deason 1938; Brown and Stedman 1995; Fratt et al. 1997).

Density of deepwater sculpins in Lake Michigan increased to 781 fish per ha in 2005, compared with 638 fish per ha in 2004 (Figure 9). On a weight basis, density of deepwater sculpins increased from 7.5 to 9.1 kg per ha between 2004 and 2005. From the standpoint of number of fish per ha, deepwater sculpin density has increased during 1990-2005. From the standpoint of kg of fish per ha, deepwater sculpin density has just increased slightly or leveled off between 1990 and 2005 (Figure 9). Leveling off of deepwater sculpin abundance during the 1990s coincided with a leveling off of burbot abundance.

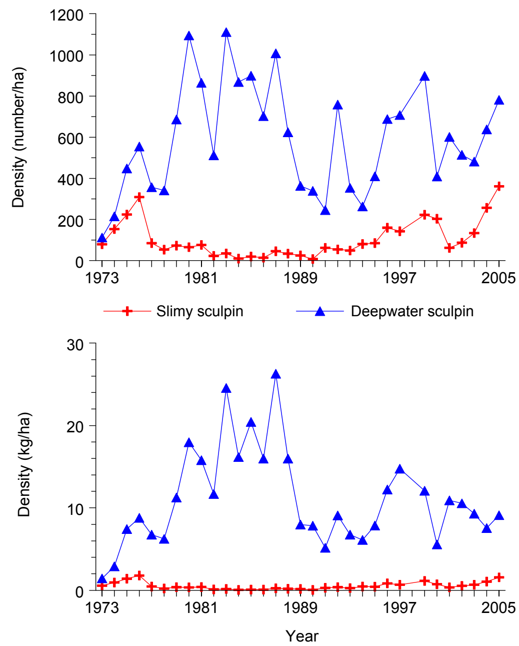

Figure 9. Density of slimy and deepwater sculpins as number (top) and weight (bottom) of fish per ha in Lake Michigan, 1973-2005.

Density of slimy sculpins in Lake Michigan increased from 257 fish per ha in 2004 to 362 fish per ha in 2005 (Figure 9). Overall, slimy sculpin abundance showed an increasing trend during the 1990s. This increase in abundance may have actually begun in 1986, when an emphasis was first placed on stocking lake trout on offshore reefs rather than stocking lake trout in areas closer to shore in Lake Michigan. Slimy sculpin is a favored prey of juvenile lake trout. The GLSC bottom trawl survey does not cover the rocky, offshore reefs that have been heavily stocked with lake trout since 1986. Thus, the observed increase during the 1990s in slimy sculpin abundance detected in the GLSC bottom trawl survey was likely attributable to the 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 (Nalepa et al. 2005). Whether the decrease in *Diporeia* abundance will eventually have a negative impact on slimy sculpin abundance remains to be determined.

Analysis of the bottom trawl survey data has indicated that alewives interfering with deepwater sculpin reproduction and predation by burbot on deepwater sculpins have been the most important factors affecting deepwater sculpin abundance in Lake Michigan (Madenjian et al. 2005c). The survey data provided no evidence to support the contention that slimy sculpins exerted a significant negative effect on deepwater sculpin abundance.

BIOMASS

We estimated a total lake-wide biomass of prey fish available to the bottom trawl in 2005 of 83.276 kilotonnes (kt) (1 kt = 1000 metric tons) (Figure 10). This total prey fish biomass was the sum of the population biomass estimates for alewife, bloater, rainbow smelt, deepwater sculpin, and slimy sculpin. Deepwater sculpins constituted 38% (32.030 kt), bloaters constituted 29% (24.546 kt), and alewives constituted 16% (13.401 kt) of the total prey fish biomass in Lake Michigan in 2005.

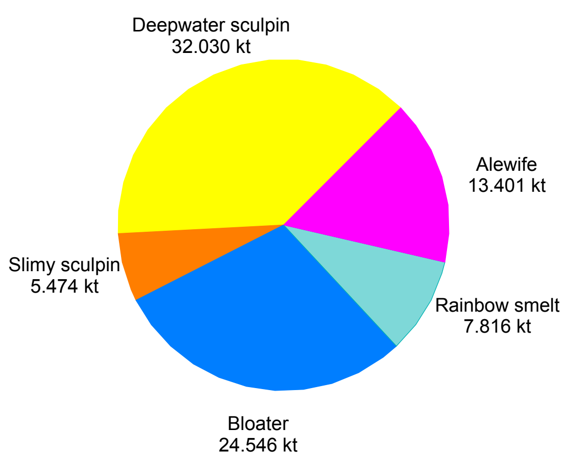

Figure 10. Estimated lake-wide biomass of prey fishes in Lake Michigan, 2005, based on bottom trawl surveys (between 5-m and 114-m depth contours).

Total prey fish biomass in Lake Michigan has shown a declining trend since 1989, and this decline is mainly attributable to the tremendous decrease in bloater biomass (Figure 11). The current bloater biomass is about 7% of the peak value in 1989. Total prey fish biomass did increase slightly between 2000 and 2002 due to an increase in alewife biomass (Figure 11). The slight decline in total prey fish biomass between 2002 and 2005 was primarily due to a decrease in alewife biomass. The slight increase in total prey fish biomass time series during 2000-2002 was due to the exceptionally large 1998 alewife year-class. Nonetheless, alewife biomass declined during the 1970s, but fluctuated with no consistent trend during 1982-2005. Long-term trends in alewife biomass suggested that the salmonine stocking program was not only effective in reducing alewife abundance in Lake Michigan, but also effective in maintaining relatively low alewife abundance for the last 23 years (Madenjian et al. 2002). Rainbow smelt biomass declined between 1992 and 1997, and remained low from 1997 to 2004. Beginning in 2005, the rainbow smelt population may be showing some early signs of recovery. Deepwater sculpin biomass has fluctuated without significant trend during 1990-2005 (Figure 11).

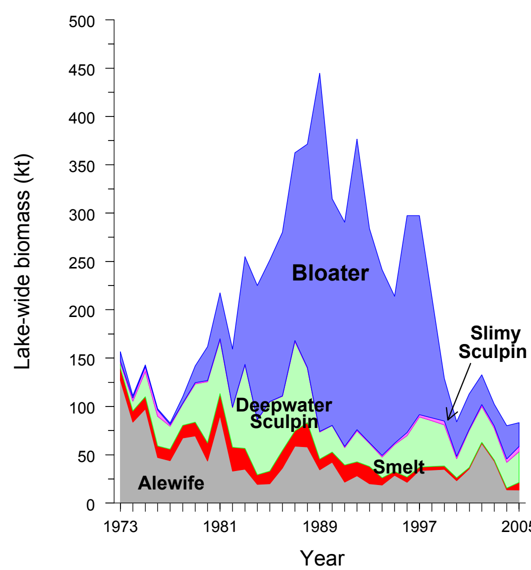

Figure 11. Estimated lake-wide biomass of prey fishes in Lake Michigan, 1973-2005, based on bottom trawl surveys (between 5-m and 114-m depth contours).

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.

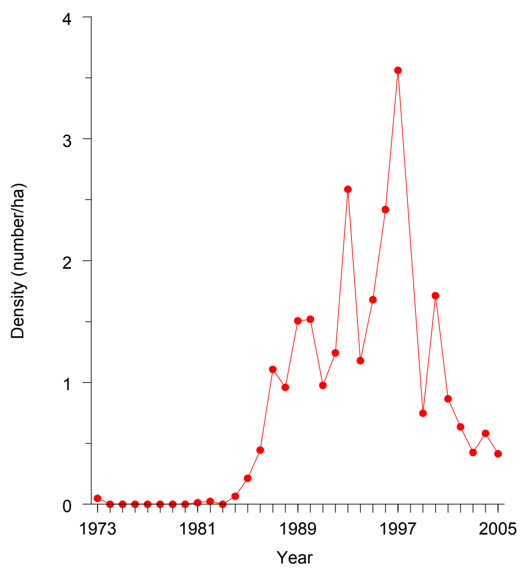

Figure 12. Density of burbot in Lake Michigan, 1973-2005.

According to the GLSC bottom trawl survey data, the recovery of burbot in Lake Michigan appears to be complete. After a period of initial low abundance, catches of burbot in the bottom trawls increased sharply from 1983 to 1990 (Figure 12). Burbot catch leveled off during 1990-2001, and then generally decreased during 2001-2005. The decrease in burbot density during 2001-2005 may have been partly due to increased predation by sea lampreys; lake-wide estimates of spawning sea lampreys in Lake Michigan tributaries increased during 2000-2004 (D. Lavis, U. S. Fish and Wildlife Service, Ludington, MI, personal communication). Burbot density decreased from 0.58 fish per ha in 2004 to 0.42 fish per ha in 2005 (Figure 12).

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 abundance, which serves as an indication of yellow perch recruitment success. According to the bottom trawl survey, the 2005 year-class of yellow perch was the largest year-class on record (Figure 13). This huge year-class was likely attributable to a sufficiently large abundance of female spawners and to favorable weather. Year-class strength was poor in most years during 1989-2004 (Figure 13). Most researchers believe that a combination of several factors are responsible for this prolonged period of low recruitment success; these factors include poor weather conditions in some years, a low abundance of female spawners in some years, and possibly a low availability of zooplankton for yellow perch larvae in some years (Makauskas and Clapp 2000).

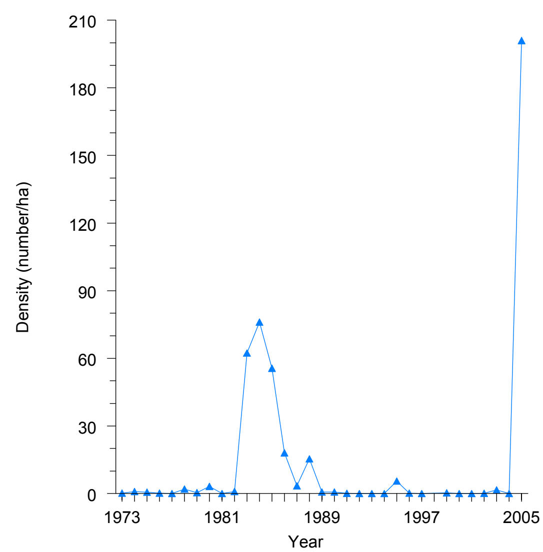

Figure 13. Density of age-0 yellow perch in Lake Michigan, 1973-2005.

Round goby – The first catch of round gobies in the GLSC bottom trawl survey of Lake Michigan occurred in 2003, and round gobies have been caught in each of the following years. Total catches for years 2003, 2004, and 2005 were 23, 26, and 37 round gobies, respectively. Catches have been limited to the Manistique, Saugatuck, and Ludington transects at depths ranging from 9 to 27 m. Round goby total lengths have ranged from 51 to 161 mm.

The round goby is an invader from the Black and Caspian seas. Round gobies have been observed in bays and harbors of Lake Michigan since 1993, and round gobies have been captured by Michigan DNR personnel in the southern main basin of the lake as early as 1997 (Clapp et al. 2001). With additional years of continued surveillance, results from the GLSC bottom trawl survey should prove useful in detecting significant effects of round gobies on the Lake Michigan fish community.

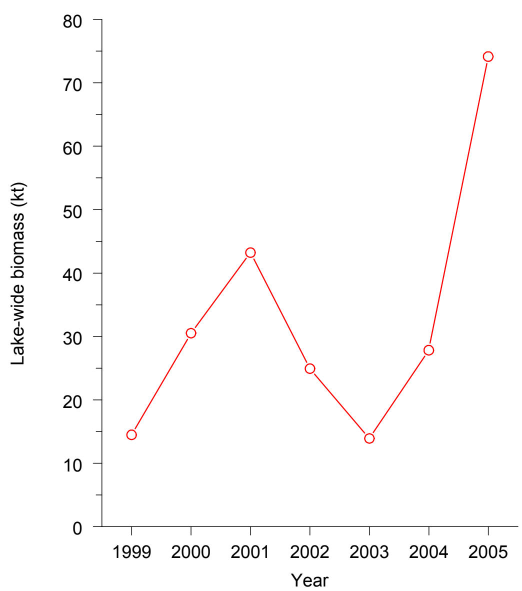

Figure 14. Estimated lake-wide biomass of dreissenid mussels in Lake Michigan, 1999-2005, based on bottom trawl surveys.

<u>Dreissenid mussels</u> – The first zebra mussel 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. 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, lake-wide biomass of dreissenid mussels was highest in 2005 (Figure 14). Reasons for the substantial increase in estimated lake-wide biomass from 27.8 kt in 2004 to 74.2 kt in 2005 were unclear. The dreissenid mussel invasions have been associated with the decline in the amphipod *Diporeia* in Lake Michigan, although the mechanism by which dreissenid mussels are negatively affecting *Diporeia* remains unidentified (Madenjian et al. 2002; Nalepa et al. 2005).

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Appendix 1. Mean density and lake-wide biomass estimates for various fishes and dreissenid mussels in Lake Michigan during 2005. Estimates based on the bottom trawl survey. Standard error enclosed in parentheses. NA denotes that estimate is not available.

Taxon	Density (number/ha)	Density (kg/ha)	Lake-wide biomass (kt)
age-0 alewife	27.80 (17.27)	0.080 (0.053)	0.281 (0.187)
adult alewife	104.75 (30.47)	3.725 (1.029)	13.120 (3.624)
age-0 bloater	42.07 (11.72)	0.358 (0.101)	1.259 (0.354)
adult bloater	140.25 (40.11)	6.613 (2.631)	23.287 (9.266)
age-0 rainbow smelt	502.18 (194.06)	0.362 (0.123)	1.273 (0.435)
adult rainbow smelt	221.53 (87.02)	1.858 (0.869)	6.543 (3.061)
deepwater sculpin	781.38 (216.73)	9.095 (2.396)	32.030 (8.439)
slimy sculpin	361.59 (98.12)	1.554 (0.455)	5.474 (1.601)
burbot	0.42 (0.11)	0.572 (0.176)	2.013 (0.619)
age-0 yellow perch	200.91 (166.64)	0.633 (0.527)	2.228 (1.857)
dreissenid mussels	NA	21.057 (2.580)	74.156 (9.085)