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Status and Trends of Prey Fish Populations in Lake Michigan, 2007[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 2007. 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 and round gobies. Lake-wide biomass of alewives in 2007 was estimated at 11.67 kilotonnes (kt) (1 kt = 1000 metric tons), which was 18% higher than in 2006. Lake-wide biomass estimates of bloater (5.39 kt) and rainbow smelt (0.88 kt) in 2007 were 59% and 63%, respectively, lower than in 2006. Bloater biomass has declined drastically since 1989, and the 2007 estimate was the lowest since 1978. The 2007 rainbow smelt lake-wide biomass estimate was the lowest biomass estimate for rainbow smelt on record. Deepwater sculpin lake-wide biomass had shown neither an increasing nor decreasing trend during 1990-2006, but then decreased from 22.86 kt in 2006 to 8.53 kt in 2007. Slimy sculpin lake-wide biomass had been steadily increasing since 2001, but then decreased from 8.16 kt in 2006 to 2.20 kt in 2007. Ninespine stickleback lake-wide biomass remained relatively high in 2007 (2.37 kt), as the species has generally increased in abundance from 1996-present compared to 1973-1995. Burbot lake-wide biomass (1.91 kt in 2007) has remained fairly constant since 2002. After a record-high 2005 year-class, numeric density of age-0 yellow perch (i.e., < 100 mm) remained relatively high (4.7 fish per ha) in 2007 compared with the 1996-2004 period. Lake-wide biomass of dreissenid mussels appeared to be leveling off in 2007 at 245.51 kt, after increasing exponentially during 2003-2006. Round goby abundance decreased from 27.7 fish per ha in 2006 to 1.0 fish per ha in 2007. Overall, the total lake-wide prey fish biomass estimate (sum of alewife, bloater, rainbow smelt, deepwater sculpin, slimy sculpin, and ninespine stickleback) in 2007 was 31.04 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 (using otoliths) and bloaters (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 2007.

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.

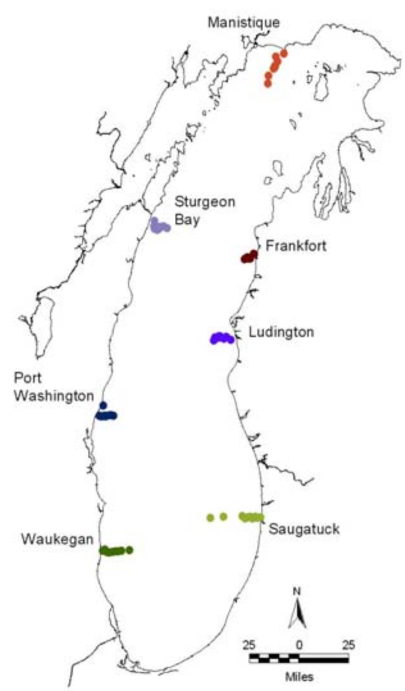

Figure 1. Established sampling locations for GLSC bottom trawls in Lake Michigan.

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 ≥ 90 mm TL, bloaters ≥ 120 mm TL, and yellow perch ≥ 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.

<u>Alewife</u> – 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, emerald shiner, lake trout, and yellow perch (Smith 1970; Wells and McLain 1973; Madenjian et al. 2005c; 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; 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 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.

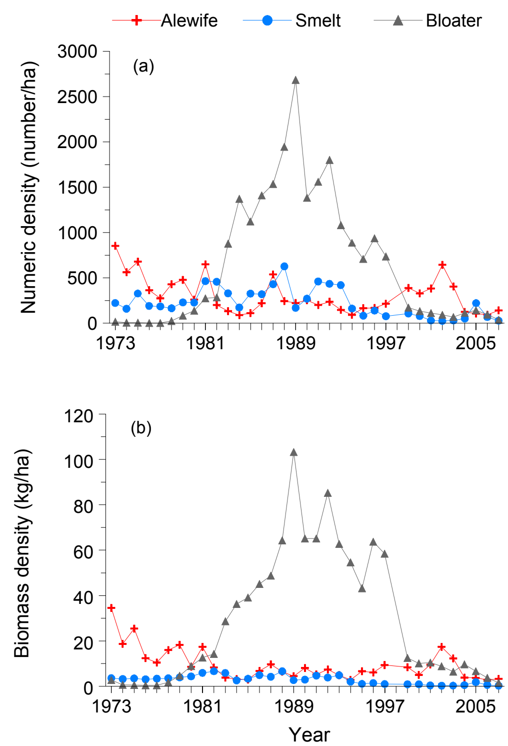

Figure 2. Density of adult alewives, rainbow smelt and bloaters as number (a) and mass (b) of fish per ha in Lake Michigan, 1973-2007.

Adult alewife numeric density steadily declined during 2002-2006, but then increased in 2007 (Fig. 2a). Numeric density of adult alewives in Lake Michigan was 142 fish per ha in 2007 (Figure 2a; Appendix 1). Adult alewife biomass density was 18% higher in 2007 (3.3 kg per ha) than in 2006 (2.8 kg per ha; Figure 2b). Only in 1984, 1985, 1994, and 2006 were adult alewife biomass densities less than that observed in 2007. 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. In addition, 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).

During 1973-2007, RSE for adult alewife numeric density averaged 22% (Figure 3a). RSE has generally increased during 1999-2007 relative to earlier years, which suggests that adult alewives are more patchily distributed in recent years than in earlier ones.

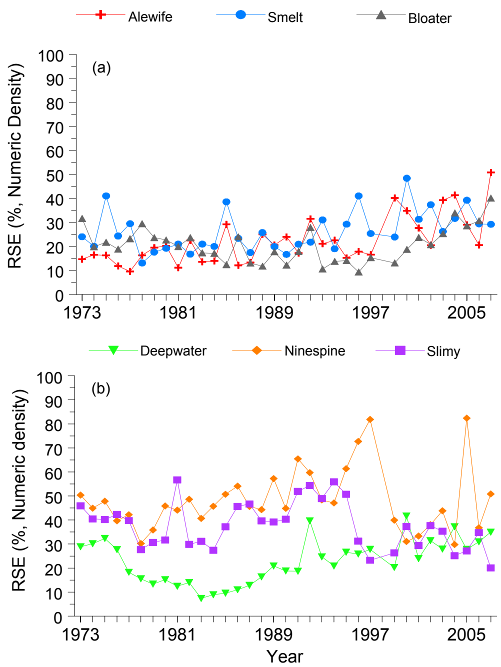

Figure 3. RSE for numeric density of Lake Michigan prey fishes, 1973-2007. Panel (a) provides estimates for adult alewife, adult rainbow smelt, and adult bloater. Panel (b) provides estimates for deepwater sculpin, slimy sculpin, and ninespine stickleback.

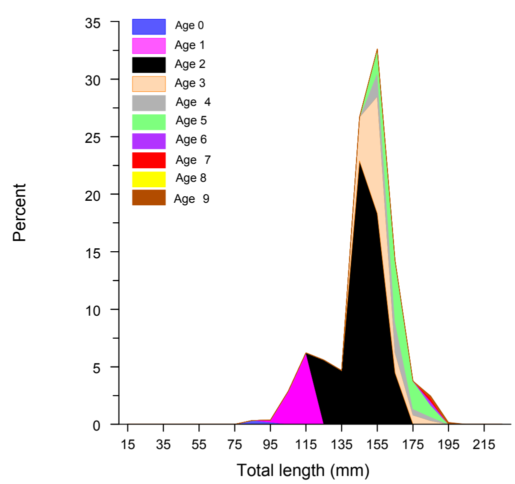

Figure 4. Age-length distribution of alewives caught in bottom trawls in Lake Michigan, 2007. Age-2 alewives belonged to the 2005 year-class.

The 2005 year-class represented more than half of the adult alewife catch in 2007, while the 2002 and 2004 year-classes comprised most of the remainder of the adult alewife catch (Figure 4). During 1999-2004, the 1998 year-class dominated the adult catch (Madenjian et al. 2005b). The 2005 year-class was estimated to be one of the strongest year-classes since 1995 by the Lake Michigan acoustic survey (Warner et al. 2006).

Bloater - Bloaters are eaten by salmonines in Lake Michigan, but are far less prevalent in salmonine diets than alewives. 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.

In 2007, adult bloater biomass density was 1.5 kg per ha, a 59% decline from 2006, and the lowest observed since 1978 (Figure 2b). Similarly, the 2007 adult bloater numeric density was 37 fish per ha, a 60% decline from 2006 (Figure 2a). RSE for adult bloater numeric density has averaged 21% from 1973-2007, but RSE for 2007 was 40% following a general trend of increasing RSE since 1999 (Figure 3a).

Overall, adult bloater numeric and biomass densities have been declining since 1989 (Figure 2). These declines were attributable to relatively poor recruitment during 1992-2003 (Madenjian et al. 2002, 2005b). Madenjian et al. (2002) proposed that the Lake Michigan bloater population may be cycling in abundance, with a period of about 30 years. Numeric density of age-0 bloaters (< 120 mm TL) was only 1.0 fish per ha in 2007, in contrast with 42.1 fish per ha observed in 2005 and 4.9 fish per ha observed in 2006 (Figure 5a). Thus, a recovery of the bloater population was not yet evident. Some fishery biologists have speculated that even if the bloater population had been exhibiting regular 30-year cycles in abundance, the dreissenid mussel invasion will prevent any future recovery of the bloater population in Lake Michigan. Continued surveillance of the bloater population over the next 3 to 5 years should allow for testing of this hypothesis.

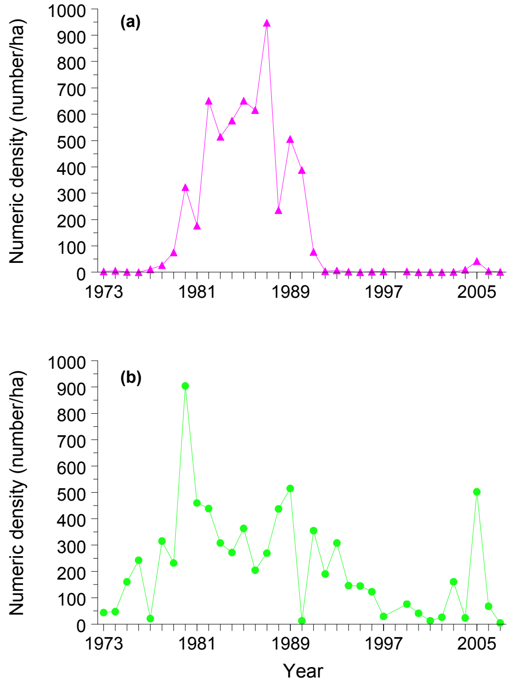

Figure 5. Numeric density of age-0 bloaters (a) and age-0 rainbow smelt (b) in Lake Michigan, 1973-2007. Time series for age-0 alewives was not included, because age-0 alewife catch was not considered a reliable indicator of alewife year-class strength (Madenjian et al. 2005a).

Rainbow smelt – 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 2007, adult rainbow smelt biomass density was at a record low level of 0.2 kg per ha (Figure 2b). Adult rainbow smelt numeric density in 2007 was 27.5 fish per ha, and only in 2002 was the adult rainbow smelt numeric density less than that observed in 2007 (Figure 2a). 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 (Figures 2, 5b). RSE for adult rainbow smelt numeric density averaged 26% from 1973-2007, and RSE for 2007 was 29% (Figure 3a).

Sculpins – From a biomass perspective, 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).

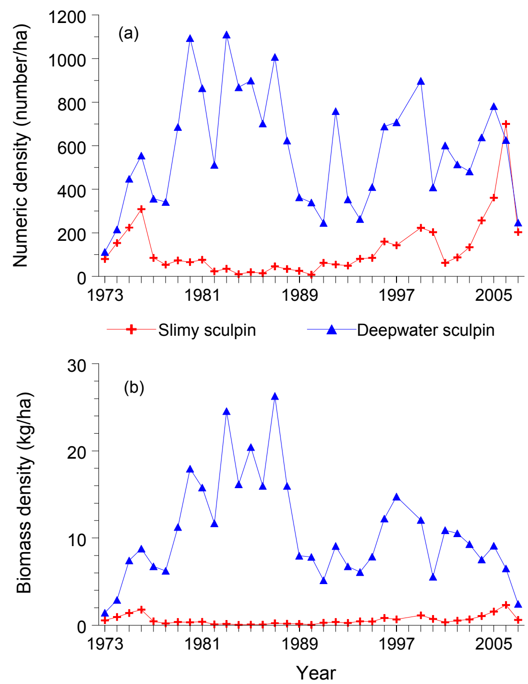

Figure 6. Density of slimy and deepwater sculpins as number (a) and mass (b) of fish per ha in Lake Michigan, 1973-2007.

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 decreased from 626 fish per ha in 2006 to 247 fish per ha in 2007 (Figure 6a). Similarly, biomass density of deepwater sculpins in Lake Michigan decreased from 6.5 kg per ha in 2006 to 2.4 kg per ha in 2007 (Figure 6b). These substantial declines may possibly have been due to the bulk of the deepwater sculpin population moving to water deeper than 110 m by 2007 (Madenjian and Bunnell 2008). Neither numeric density nor biomass density of deepwater sculpins had trended downward during 1990-2006 (Figure 6). RSE for deepwater sculpin numeric density was 35% in 2007, which follows a general trend of slightly increasing RSE since 1983 (Figure 3b).

Numeric density of slimy sculpins in Lake Michigan decreased from 701 fish per ha in 2006 to 204 fish per ha in 2007 (Figure 6a). Reasons for this substantial decrease were not clear, but similarly proportioned declines also occurred in 1977 and 2001. RSE for slimy sculpin numeric density was 20% in 2007, which was lower than its average RSE of 38% from 1973-2007 (Figure 3b). Overall, slimy sculpin numeric density showed an increasing trend from the mid 1980s to 2007. 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.

Analysis of bottom trawl survey data indicated that alewives interfering with deepwater sculpin reproduction and predation by burbot on deepwater sculpins are the most important factors affecting deepwater sculpin abundance in Lake Michigan (Madenjian et al. 2005c). The survey data provided no evidence that slimy sculpins negatively affected deepwater sculpin abundance.

<u>Ninespine stickleback</u> – Given the increasing abundance of ninespine stickleback in Lake Michigan and its occasional occurrence in the diets of salmonines and lake trout, we added this species to our annual report. Two stickleback species occur in Lake Michigan. Ninespine stickleback is native, whereas threespine stickleback 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 preyfishes, 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 7a). Densities increased dramatically in 1996-1997, and have since been highly variable. Their recent increase coincided with the expansion of dreissenid mussels in the lake, but mechanisms underlying the population increase of ninespine stickleback are unknown.

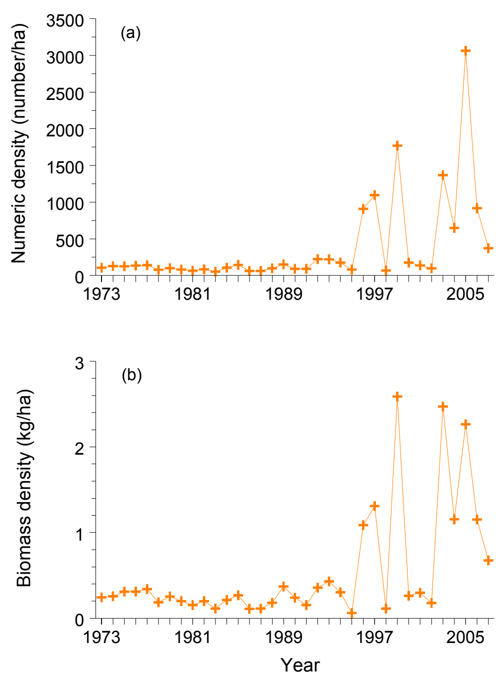

Figure 7. Density of ninespine sticklebacks as number (a) and mass (b) of fish per ha in Lake Michigan, 1973-2007.

Numerically, ninespine stickleback has been the most abundant species in the bottom trawl survey since 2003. Ninespine stickleback numeric density substantially declined between 2005 and 2007 (Figure 7a). Biomass density of ninespine stickleback decreased from 1.2 kg per ha in 2006 to 0.7 kg per ha in 2007 (Figure 7b). RSE for ninespine stickleback numeric density was 51% in 2007, which was close to the long-term average RSE of 48% from 1973-2007 (Figure 3b). RSE generally decreased in the late 1990s and early

2000s, which coincided with their increase in numeric density.

LAKE-WIDE BIOMASS

We estimated a total lake-wide biomass of prey fish available to the bottom trawl in 2007 of 31.04 kilotonnes (kt) (1 kt = 1000 metric tons) (Figure 8, Appendix 1). Total prey fish biomass was the sum of the population biomass estimates for alewife, bloater, rainbow smelt, deepwater sculpin, slimy sculpin, and ninespine stickleback. Alewives constituted 38% (11.67 kt), deepwater sculpins constituted 27% (8.53 kt), and bloaters constituted 17% (5.39 kt) of the total prey fish biomass in Lake Michigan in 2007.

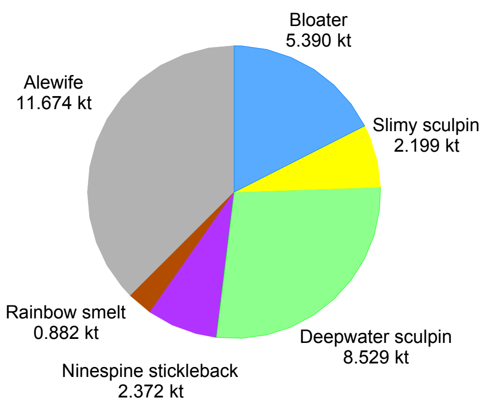

Figure 8. Estimated lake-wide biomass of prey fishes in Lake Michigan, 2007, based on the bottom trawl survey.

Total prey fish biomass in Lake Michigan has trended downward since 1989, and is largely a result of the tremendous decrease in bloater biomass (Figure 9). The current bloater biomass is about 1% of the peak value in 1989. Total prey fish biomass did increase slightly between 2000 and 2002 due to an increase in alewife biomass, in particular, the exceptionally large 1998 alewife year-class (Figure 9). The decline in total prey fish biomass between 2002 and 2005 was primarily driven by a decrease in alewife biomass. The decline between 2005 and 2007, however, was largely due to a continued decrease in lake-wide biomass of bloater and a substantial drop in deepwater sculpin lake-wide biomass between 2006 and 2007. The total lake-wide biomass of prey fish available to the bottom trawl in 2007 was the lowest biomass recorded in our time series.

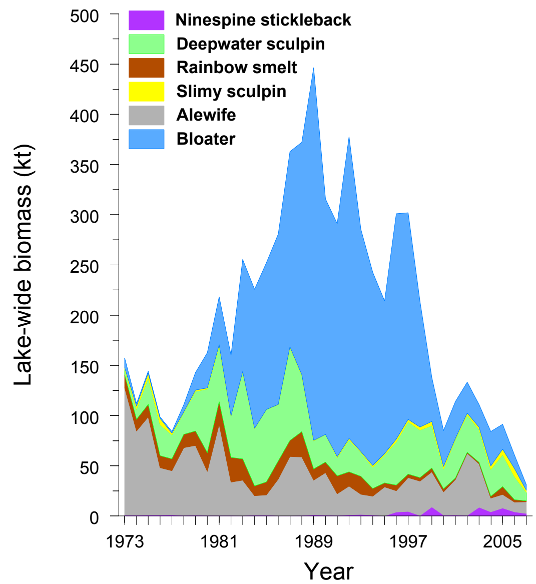

Figure 9. Estimated lake-wide biomass of prey fishes in Lake Michigan, 1973-2007, based on the bottom trawl survey.

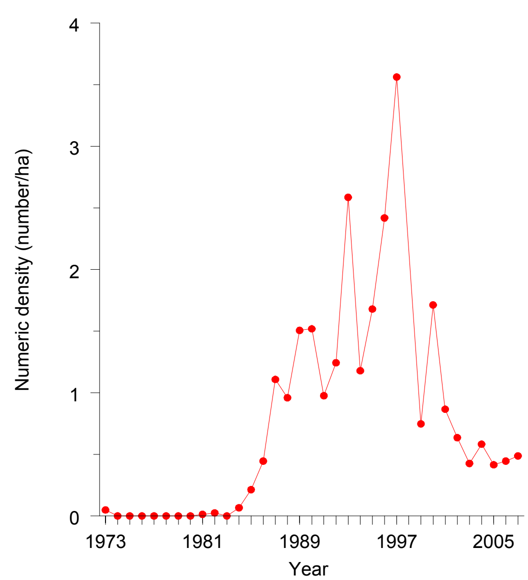

Figure 10. Numeric density of burbot in Lake Michigan, 1973-2007.

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 numeric density in 2007 (0.49 fish per ha) was similar to that of 2006 (0.44 fish per ha) (Figure 10). After a period of low numeric density in the 1970s, burbot showed a strong recovery in the 1980s. Densities increased through 1997, although we interpret the trend as a leveling off between 1990 and 2001. Since 2001, however, burbot densities decreased, perhaps partly due to increased predation by sea lampreys. Lake-wide estimates of spawning sea lampreys have generally been increasing since 2000 (D. Lavis, U. S. Fish and Wildlife Service, Ludington, MI, personal communication).

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 11). This huge year-class was likely attributable to a sufficient abundance of female spawners and favorable weather. Numeric density of the 2007 year-class was 4.7 fish per ha, which was relatively high compared with most year-classes between 1989 and 2007 (Figure 11). Most researchers believe that the poor yellow perch recruitment that occurred during 1989-2000 (Figure 11) 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).

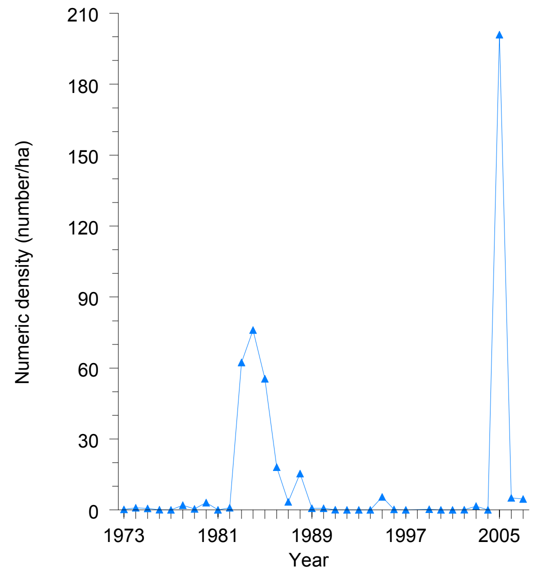

Figure 11. Numeric density of age-0 yellow perch in Lake Michigan, 1973-2007.

Round goby – 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 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 first caught in the GLSC bottom trawl survey in 2003. Round goby numeric density increased exponentially during 2003-2006, attaining a level of 27.7 fish per ha in 2006 (Figure 12a). However, numeric density suddenly dropped to 1.0 fish per ha in 2007. Round gobies have been caught at all transects except at Frankfort and at Port Washington. With additional years of continued surveillance, results from the GLSC bottom trawl survey should help detect significant effects of round gobies on the Lake Michigan fish community.

Dreissenid mussels – 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, biomass density of dreissenid mussels was highest in 2007 (Figure 12b), exhibiting a 16% increase over the 2006 level. Biomass density of dreissenid mussels increased exponentially during 2003-2006, and this increase was likely due to the greater proportion of quagga mussels in Lake Michigan (T. Nalepa, NOAA Great Lakes Environmental Research Laboratory, Ann Arbor, MI, personal communication). Relative to the zebra mussel, quagga mussels can reproduce at lower temperatures (Roe and MacIsaac 1997) and, in turn, greater depths. As a result the distribution of dreissenid mussels has increased, likely as a result of the quaggas (Bunnell et al., in review).

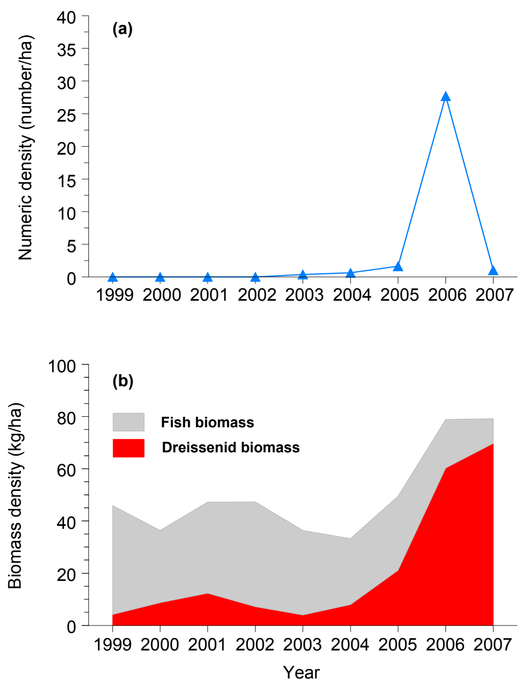

Figure 12. Estimated lake-wide numeric density of round goby (a), and total fish biomass density and dreissenid mussel biomass density (b) in Lake Michigan, 1999-2007, based on the bottom trawl survey.

Unfortunately, the increase in dreissenid mussels has 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. 2006).

The percentage of the 2007 bottom trawl catch represented by fish biomass was 12%, whereas the percentage of the 2007 bottom trawl catch represented by dreissenid mussel biomass was 88% (Figure 12b). The percentage of the Lake Michigan bottom trawl catch composed of dreissenid mussels has increased from 9% in 1999 to 88% in 2007. This increase was due to both a decrease in fish biomass and an increase in dreissenid mussel biomass over this time period. One hypothesis would be to attribute this decrease in total fish biomass during 1999-2007 to the increase in dreissenid mussel biomass. However, the explanations offered for temporal trends in fish abundance in the previous sections of this report appeared more likely. Could high densities of dreissenid mussels have caused a reduction in the catchability of benthic fishes, such as sculpins? The fact that slimy sculpin abundance showed an overall increasing trend during 1990-2007 does not support this contention. Continued surveillance of the Lake Michigan fish community over the next 3 to 5 years should provide further resolution to this issue. Should the bloater population in Lake Michigan rebound in the upcoming years, and the bottom trawl survey accurately document this recovery, then the hypothesis that the dreissenid mussel invasion was causing a collapse of the prey fish community would not appear to be valid. Finally, quagga mussels may be expected 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).

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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 2007. 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	5.28 (5.12)	0.028 (0.027)	0.099 (0.095)
adult alewife	141.54 (71.96)	3.287 (1.760)	11.575 (6.198)
age-0 bloater	1.02 (0.38)	0.009 (0.003)	0.030 (0.011)
adult bloater	37.00 (14.86)	1.522 (0.618)	5.360 (2.177)
age-0 rainbow smelt	4.49 (1.81)	0.007 (0.002)	0.024 (0.008)
adult rainbow smelt	27.46 (8.03)	0.244 (0.074)	0.858 (0.261)
deepwater sculpin	247.06 (86.38)	2.422 (0.767)	8.529 (2.702)
slimy sculpin	204.07 (40.85)	0.624 (0.122)	2.199 (0.431)
ninespine stickleback	373.66 (189.94)	0.674 (0.325)	2.372 (1.145)
burbot	0.49 (0.21)	0.541 (0.250)	1.905 (0.882)
age-0 yellow perch	4.68 (4.68)	0.002 (0.002)	0.006 (0.006)
round goby	1.02 (0.83)	0.006 (0.004)	0.022 (0.013)
dreissenid mussels	NA	69.716 (29.195)	245.515 (102.813)