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# Status and Trends of the Fish Community of Saginaw Bay, Lake Huron 2005–2011

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**Abstract.**—Saginaw Bay is a large, shallow water embayment in the Michigan waters of Lake Huron that has historically sustained a coolwater fish community that in turn supports important recreational and commercial fisheries focused primarily on percids and coregonids. The fish community has undergone enormous change and collapses of key fisheries since the mid-Twentieth Century. Between 2005 and 2011 the Saginaw Bay Walleye population continued to grow in abundance, achieving or exceeding recovery targets. Walleye growth rate has declined in response to increased abundance. Several strong Walleye cohorts have been produced but year-class strength has become more variable. Total annual mortality rate has increased during this time in spite of the increased abundance. Yellow Perch reproductive success also increased but this has not translated into recruitment to the population or fisheries. These gains in percid reproductive success are attributed to the ongoing absence of Alewives from the bay. Recruitment failures in Yellow Perch are attributed to high mortality between age-0 and age-1 life stages, primarily attributed to heavy predation by predators in the bay. Growth rate of age-0 Yellow Perch has declined but growth of yearling and older Yellow Perch has increased substantially as density has declined. Previously the bay was characterized by low predator abundance and over abundant prey species. During this reporting period, the prey base has declined and an overall more balanced predator / prey dynamic has been achieved in the Saginaw Bay fish community. Long time staples of predator diets, Alewives and Rainbow Smelt have declined or disappeared but Round Gobies have become firmly established as part of the prey fish community. While some 37 species were documented in the trawling and gill-net series, notably absent were Cisco and Lake Sturgeon, both of which were historically abundant.

## Introduction

The fish community of Lake Huron has undergone enormous change over the past decade, with profound implications for the Saginaw Bay ecosystem. The centerpiece of this change has been a decline in abundance and diversity of prey fishes. Between 1999 and 2004, offshore prey resources declined by 65% with Alewives virtually extirpated from large areas of the lake (Bence et al. 2008b). Changes in the pelagic and benthic prey fish community have been characterized by declines of nonnative species with only limited gains in native prey forms (Riley et al. 2008; Warner et al. 2009; Dunlop et al. 2010).

There has been much speculation over the forces precipitating these changes and there is ecological evidence for multiple causes. The primary competing hypotheses are a bottom-up effect stemming from changes in lower-trophic-level food resources and top-down effects from abundant predators. Hecky et al. (2004) described a fundamental shift in primary productivity from the offshore to nearshore environments and coined the term “Near shore phosphorus shunt”. This was attributed to ecosystem level reengineering by invasive dreissenids in the Great Lakes. Subsequent research has validated this concept that phosphorus is being sequestered in the nearshore environment including Saginaw Bay (Cha et al. 2011). The decline of nutrients in the offshore zone of Lake Huron had profound consequences for the zooplankton and macroinvertebrate community of the lake (Nalepa et al. 2007, 2009; Barbiero et al. 2009, 2011). Zooplankton declines were attributed to declines in offshore phytoplankton availability (Barbiero et al. 2011) and to increased planktivory stemming from the losses of the formerly abundant macroinvertebrate *Diporeia* spp. which may have served as a predation buffer when abundant (Barbiero et al. 2009). There is some suggestion that *Diporeia* spp. declines, in turn, were a result of competitive effects of invasive dreissenid mussels, particularly the deeper form, quagga mussels (common and scientific names of all aquatic organisms mentioned in this report appear in Appendix A). Collectively, these declines had direct effects on growth of Alewives and other species in Lake Huron (Pothoven and Madenjian 2008) and presumably their abundance. Despite this evidence, Bence et al. (2008a) illustrated that, while lower food-web changes were undeniable, resulting levels were not entirely out of the range observed in other lakes including the more oligotrophic Lake Superior. Bence et al. (2008a) argues that there is room for a top-down component to the explanation of food-web change where top predators such as abundant Chinook Salmon (still abundant in the early 2000s) contributed to the reshaping of the pelagic food web.

So profound were the food web changes and the subsequent consequences for the fish community that the transformation has been regarded as an entire regime shift for Lake Huron (Ridgeway 2010). These changes are the back drop to this examination of recent trends and the current status of the fish community of Saginaw Bay. Saginaw Bay’s fish community was already demonstrating the localized effects of food web change near the end of the last examination of its fish community (Fielder and Thomas 2006), with the disappearance of juvenile Alewives, which used the bay as a nursery ground. The disappearance of Alewives, which are documented to be formidable competitors and predators on newly hatched percids, has had positive effects on the reproductive success of Walleye and Yellow Perch in the bay (Fielder et al. 2007).

The objectives of this analysis are to 1) document trends in abundance, recruitment, size and age structure, condition, and growth rates for many of the Saginaw Bay fish stocks; 2) evaluate the presence of invading species; 3) quantify diet patterns for select species; and 4) archive data and analysis for future use, and thereby provide a basis for evaluating progress towards existing management goals and development of new ones.

## **Study Area**

Saginaw Bay lies entirely in Michigan’s waters of Lake Huron and spans a surface area of 2,960 km<sup>2</sup>. The inner bay is shallow, averaging 4.6 m in depth, while the outer bay depth averages 14.6 m. The inner and outer bays are defined by a line between Point Au Gres and Sand Point (Figure 1). Land use in the watershed is a mixture of industry and agriculture, but there are also large tracts of forested area (Johnson et al. 1997). There are several tributary systems to the bay, the largest being the Saginaw River. Water loosely circulates in a counterclockwise direction in the bay (Danek and Saylor 1977) and the flushing rate is approximately 186 days (Keller et al. 1987). The inner portion of the bay is generally regarded as eutrophic with productivity declining towards the outer bay region. Saginaw Bay’s limnology was further described by Beeton et al. (1967) and the bay’s water chemistry by Smith et al. (1977).

The trawling portion of the annual netting survey has been in place since 1970 and Weber (1985) summarized results through 1984. Haas and Schaeffer (1992) updated the trawling results through 1989 and Fielder et al. (2000) summarized the results through 1997. Fielder and Thomas (2006) further summarized results through 2004. The gillnetting portion of the fish community survey began in 1989 and those results (through 1997) were summarized by Fielder et al. (2000) and through 2004 by Fielder and Thomas (2006).

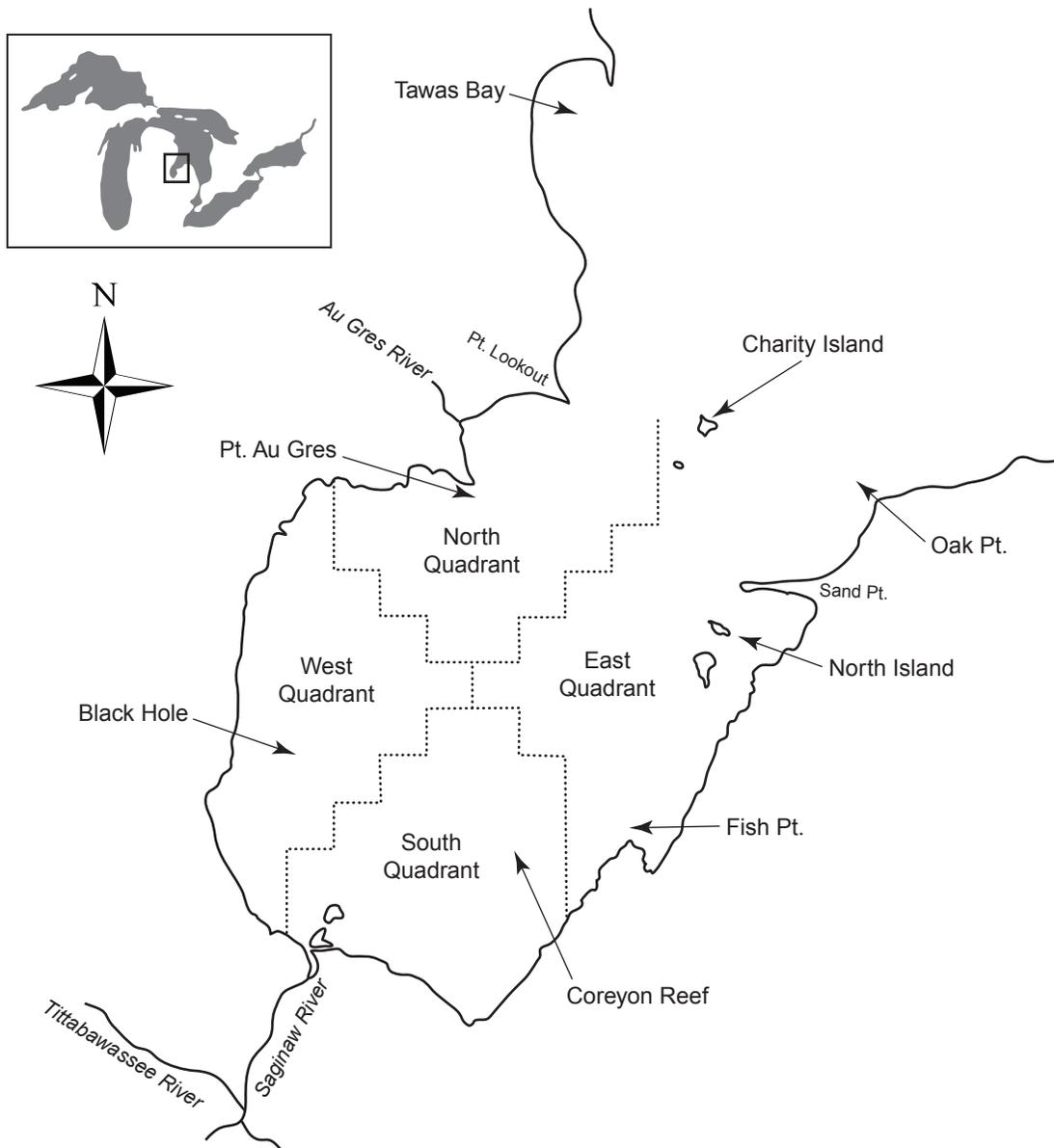


Figure 1.—Saginaw Bay gill-net sampling locations and trawling quadrants.

## Methods

### *Trawling*

Since the early 1970s, 10-m headrope bottom trawls have proven an effective gear for sampling all ages of Yellow Perch in Saginaw Bay. Trawling locations in the inner bay have been based on a 2-minute latitude x 2.8-minute longitude grid system since the 1980s. Fish samples were collected during early September of each year by the Michigan Department of Natural Resources (DNR) research vessel RV *Channel Cat* from three fixed index grids in the inner bay: Au Gres (north quadrant), Pinconning (west quadrant), and North Island (east quadrant; Figure 1). The Au Gres station was located near the city of Au Gres, and conditions there more closely resemble those of the less eutrophic outer bay. The Pinconning station was located at a bottom depression known locally as the “Black Hole.” This station, closest to the mouth of the Saginaw River, has organic sediments dominated by pollution-tolerant benthic macroinvertebrates (Nalepa et al. 2003; Schneider et al. 1969). The North Island station was located off Wildfowl Bay, a shallow sub-bay that serves as a nursery area for many fish species. In addition, fish were collected with trawls in at least one randomly selected grid from each of the four quadrants of the inner bay. Total trawl effort, while not fully uniform by year, spanned a geographically representative area (Table 1).

Table 1.—Location of trawl stations and number of tows made in Saginaw Bay, 2005–2011.

Quadrant	Site	Year						
		2005	2006	2007	2008	2009	2010	2011
East	North Island	6	6	9	9	6	6	6
South	Coreyon Reef	3	3	6	9	6	6	6
West	Black Hole	6	12	9	9	6	6	9
North	Au Gres	12	6	9	10	6	6	6
Total		27	27	33	37	24	24	27

Only those trawl tows conducted during September are discussed in this report. The gear was a 10.66-m headrope, two-seam otter trawl with 4.6-m wings and 18.9 m overall length. The trawl was constructed of 76-mm, 38-mm, and 32-mm graded stretched-measure mesh from gape to cod end, with a 9-mm stretched-mesh liner in the cod end. The net was towed by a single warp and 45.7-m bridle along the bottom for 10 minutes at a speed of approximately 2 knots. Based on trawl mensuration, the average gape width and height dimensions were 7 m x 1 m (Michigan Department of Natural Resources, unpublished data). Water temperature and Secchi disk transparency were recorded at each trawling site. Some summaries of trawling data are supplemented with results from earlier years (Weber 1985; Haas and Schaeffer 1992; Fielder et al. 2000; Fielder and Thomas 2006) to facilitate interpretation. Total weight and number for each fish species collected in each tow were recorded. Large catches (>10 kg) of forage fish were sometimes subsampled by selecting 25% to 40% of the total catch. Length-frequency distributions were recorded for at least 150 individuals of each forage species, including age-0 Yellow Perch, at each index trawl station.

Scale samples were taken from Yellow Perch for age and growth analysis. In addition, a maximum of 52 adult and 10 age-0 Yellow Perch were sampled for diet at each of the three fixed stations each year from 2005 to 2010. Yellow Perch were sampled randomly, stunned on ice, and immediately frozen with liquid nitrogen to stop digestion. These fish were kept frozen until processed in the laboratory. Finally,

up to 300 yearling and older Yellow Perch were collected from random grids, placed on ice, and then frozen for later dry weight analysis in the laboratory.

For each year, estimates of age- and sex-specific Yellow Perch total catch and catch-per-unit-effort (CPUE) were calculated. The estimation method accounted for bias inherent in subsampling for age estimation following the procedure outlined by Schneider (2000). The mean catch by age (ages 1 to 6) was used to estimate survival for ages 1 to 6 with a standard catch curve analysis (Miranda and Bettoli 2007). Age-specific sex ratios were determined by dividing the male catch by the female catch for each age, from age 1 to 6, for each year. The overall sex ratio for each year was determined by dividing the total male catch by the total female catch.

Yellow Perch were thawed in the laboratory, measured, and weighed. Fish were eviscerated, sexed, and checked for redworm, *Eustrongylides tubifex* and *Philometra cylindracea*, infestation. Previous research on Saginaw Bay found Yellow Perch were heavily parasitized by redworm, which contributed to reduced condition and energy depletion (Salz 1989). Viscera were weighed after removal and weighing of stomach contents. Somatic weight (total weight of an eviscerated individual) was also recorded. Stomach contents were preserved in ethanol. To determine somatic tissue water content, Yellow Perch and their excised viscera were dried at 90°C for 2 days in a drying oven and weighed to 0.0001 g. Percent water content was used as an indicator of fat content. Elliot (1976) found that as food ration size increased, protein and fat increased and percent water content decreased. Stomach contents of specimens were evaluated between 1998 and 2010 by counting and identifying all items to the lowest taxonomic level possible, given the stage of digestion. The diet was analyzed for frequency-of-occurrence: the percentage of fish with non-empty stomachs that contained at least one of a selected food item (Windell and Bowen 1978). Due to staffing reductions and budget constraints, perch diets were not sampled in 2011.

Dorsal spine samples were taken from all yearling-and-older Walleye for age and growth analysis. Most yearling-and-older Walleye were also examined for stomach contents on-board the survey vessel. The fish were sacrificed and the stomach was removed immediately. Stomach contents were enumerated and identified following the same method used for Yellow Perch. The diet was analyzed for frequency-of-occurrence: the percentage of fish with non-empty stomachs that contained at least one of a selected food item (Windell and Bowen 1978).

Fielder et al. (2000) investigated the effects of the zebra mussel colonization of Saginaw Bay on trawl CPUE for various species, age-specific Yellow Perch CPUE, mean total length for the major forage species, and Yellow Perch condition. They suspected that zebra mussel changes in energy cycling in the bay could be manifested in changes in abundance, growth, and survival for some fish species. We continued their approach by comparing these factors among the pre-dreissenid invasion period (1986 to 1990), the post-dreissenid invasion period (1993 to 2002), and the post-Alewife collapse period (2003–2011). The dreissenid colonization years of 1991 and 1992, considered transitional years, were excluded. In addition, we estimated Yellow Perch survival and sex ratios for the three time periods. We derived survival estimates for each time period with a standard catch curve analysis (Miranda and Bettoli 2007) of the average age-specific catch rates, for ages 1 to 6. The mean age-specific sex ratio for each time period was calculated by averaging the sex ratio for each age from 1 to 6 across the time period.

A soft-rayed forage index value was calculated for each year. The soft-rayed forage index was the sum of the mean catch-per-10-minute tow values for the most common soft-rayed forage species. The species included in the calculation of this annual index were Alewife, Gizzard Shad, Rainbow Smelt, Round Goby, Spottail Shiner, and Trout-perch.

## Gillnetting

Gillnetting of Walleyes was based on the work of Isbell and Rawson (1989), who showed that gill-net catch could be effectively used as a measure of abundance and recruitment for Walleye and other species. Gill-net sampling was performed at eight fixed stations from the Michigan DNR Research Vessel *Chinook* (Table 2, Figure 1) concurrent with the trawling in early September of each year. Beginning in 2005, the Pt. Au Gres/Au Gres River/Pt. Lookout sets were combined into a single station (hereafter known only as Pt. Au Gres) taking the local assessment from four sets to two. Two net sets were made at each sample site (Table 2, Figure 1). Gill-netting effort was divided between inner- and outer-bay environments (Table 2). Gill nets were 335 m long by 2 m deep, constructed of multifilament twine with 30.5-m panels of 38-, 51-, 57-, 64-, 70-, 76-, 83-, 89-, 102-, 114-, and 127-mm stretch nylon mesh. Gill nets were fished overnight on the bottom in depths greater than 3 m. Catch-per-unit-effort was calculated and expressed as the number of each species per 335 m of net. The 38 mm mesh was added to the study in 1993. All catch was measured for total length in mm, but Walleyes, Northern Pike, Yellow Perch, Smallmouth Bass, and Channel Catfish were also weighed in g, with sex and maturity scored and noted. Maturity was scored as either mature or immature upon internal examination of gonads according to the criteria of Goede and Barton (1990). Dorsal spines were collected for age interpretation from these same species except Channel Catfish, which were aged with pectoral spines and Northern Pike, which were aged with scales until 2011 when the cleithra bone was used. Yellow Perch and Channel Catfish were sometimes subsampled for these metrics by including specimens caught from only every other net. Diet of Walleyes was noted by examining the stomach contents and is reported as frequency-of-occurrence, which is the percentage of fish with non-empty stomachs that contained at least one of a selected food item (Windell and Bowen 1978).

Table 2.—Number of fall gill-net sets (by location) for Saginaw Bay, Lake Huron, 2005–2011.

Station	Year						
	2005	2006	2007	2008	2009	2010	2011
Inner bay							
Pt. Au Gres	2	2	2	2	2	2	2
Black Hole	2	2	2	2	2	2	2
Coreyon Reef	2	2	2	2	2	2	2
Fish Pt.	2	2	2	2	2	2	2
North Island	2	2	2	2	2	2	2
Outer bay							
Oak Pt.	2	2	2	2	2	2	2
Charity Is.	2	2	2	2	2	2	2
Tawas	2	2	2	2	2	2	2
Inner bay total	10	10	10	10	10	10	10
Outer bay total	6	6	6	6	6	6	6
Total	16	16	16	16	16	16	16

Condition was examined by calculating relative weight for Walleye (Murphy et al. 1990) and Yellow Perch (Willis et al. 1991) and expressed by stock density length indices (Gabelhouse 1984). Proportional-stock-density (PSD) and relative-stock-density (RSD) were also determined according to the size designations of Anderson and Gutreuter (1983) for Walleye and Anderson and Neumann (1996) for Yellow Perch. Growth rate was indexed as mean length-at-age at capture, and compared to the Michigan average for the same season (fall) as reported by Schneider (2000).

Analyses of some metrics from the gill net make comparisons between the reporting period of this report (2005–2011) versus the same measures from earlier years in the time series, which began in 1989 (1989–2004) so as to provide some indication of trends or noteworthy changes.

### ***Statistical Analysis***

Trawl and gill-net catches (CPUE) are often not normally distributed, with lognormal distributions common. The distribution of catch data was graphically examined (Stewart-Oaten 1995). When necessary, trawl and gill-net data were examined for normality using Lilliefors test and Bartlett's or Levene's Test to examine for homogeneity of variance, both of which are assumptions for valid applications of analysis of variance (ANOVA) procedures. When substantial deviations from normality were not detected, we used parametric ANOVA procedures, otherwise nonparametric Kruskal-Wallis (K-W) procedures were used to test for statistical differences in mean CPUE among years for both gear types. Statistical differences between individual means of some metrics of interest were determined by T-test when departures from normality were not substantial or by Mann-Whitney U test otherwise.

Analysis of variance procedures were also used to test for differences in Yellow Perch mean length-at-age among years for trawl data and for Walleye and Yellow Perch mean length-at-age from gill-net data. Some means are reported with two standard errors of the mean (SEs), which approximate 95% confidence intervals to assist in visually examining the summarized data for significant differences. For some metrics of interest, true 95% confidence intervals are reported. In some instances, means are reported with their coefficient of variation (CV) to inspect relative variability among reported groups.

Most analyses (such as means and SEs) are conducted using formulations appropriate for simple random sampling. The assumptions of such a sample design are met reasonably well for the trawl design, but recent reflection has concluded that the use of paired sets in the gill-net portion of the survey really constitutes a single stage cluster design. While the means from a cluster design are still unbiased and mathematically equivalent with those from simple random sampling formulations, the SEs are not. Standard errors of the mean for gillnetting CPUE are calculated using the standard single stage cluster design (Thompson 2002). Aside from the sample design question, both survey elements strive for a spatial spread across the expanse of the bay (via fixed site selection for the gill-net survey and the use of quadrants for the trawl survey). This approach likely magnifies catch differences especially between the inner and outer bay environments. Consequently the magnitude of variability of the data is likely exaggerated by design and resulting expression of variability (such as SEs of the means and confidence intervals) are also somewhat inflated and can be regarded in this analysis as conservative. Biological data from the gill-net catch, is not believed to be influenced by clustering as there is less or no spatial component believed to occur for such metrics within the Saginaw Bay fish populations and means and SEs are based on the simple random sampling formulations.

Total annual mortality rates for Walleye, Yellow Perch, and Channel Catfish were calculated using two methods with numbers by ages from the gill-net collected fish. The "point-in-time" catch curve method makes an assumption of equal annual recruitment. Because this is unlikely and because time series of numbers at age data were available, we also estimated total annual mortality using the "cohort" method (Ricker 1975; Miranda and Bettoli 2007). The cohort method makes the assumption of equal vulnerability of ages to the gear over time. In each case, the actual computation was based on the Robson-Chapman method of catch curve estimation of mortality (Hilborn and Walters 1992; Miranda and Bettoli 2007). The point-in-time approach to total annual mortality estimation represents the time period reflecting the ages of the fish in the collection (multiple year classes). The cohort method reflect the time period spanned by a single year class over its longevity. While similar, the two methods take a different approach to total annual mortality estimation. Given the importance of this metric, it is estimated and reported both ways allowing for a more in-depth evaluation of these rates.

Simple linear regression analysis was used to develop length/weight relationships for some species. We examined some bivariate data such as general relationships between recruitment of some species and various candidate factors using regression analysis. In some instances the independent variables were transformed with the natural log to linearize the data. The Von Bertalanffy length at age model was fit and parameters of this model are presented for some species and are calculated according to Isely and Grabowski (2007). Maturation of male and female Walleyes was defined as age at 50% maturity from gill-net data and was derived by solving for age at a maturity score of 50% between immature and mature by applying and assuming a linear relationship in maturity and age between the two age groups that bracketed the 50% maturity threshold. All statistical tests for this study were performed according to Sokal and Rohlf (1981) and conducted at a significance level of  $P = 0.05$ . SPSS computer software was used for statistical analyses (SPSS 2010).

## Results

### *Trawling*

From 2005 to 2011, a total of 199 trawl tows were made in inner Saginaw Bay during daylight hours between 7 September and 1 October (Table 1). Mean water temperatures at the trawling sites, recorded since 1987, ranged from 13.0°C to 22.1°C and exceeded the long-term mean of 17.6°C in six out of the last years of the survey (Figure 2). In general, a pattern of warmer mean water temperatures during the fall survey is evident since the early 1990s. Mean fall Secchi disk transparencies recorded at the trawling sites ranged from 0.74 m to 2.24 m, with a long-term mean of 1.33 m. While no trend in Secchi transparency was obvious for the period from 1987 to 2000, transparencies appear to have increased since then, with transparencies exceeding the long-term mean in seven of the last nine years of the survey (Figure 3).

*Species composition and catch rates.*—For the seven-year period from 2005 to 2011, a total of 279,676 fish were caught in fall survey trawls in the inner portion of Saginaw Bay. Species composition varied considerably among years (Table 3). Overall, the most abundant species were White Perch, Trout-perch, Round Goby, Yellow Perch, and Spottail Shiner. In combination, these five species accounted for at least 83% of the total catch each year, except for 2011, when Mimic Shiners accounted for an unprecedented 17% of the total catch. Round Gobies, first captured in survey trawls in Saginaw Bay in 1999, accounted for an average of over 14% of the total catch across the 2005 to 2011 period.

Catch-per-unit-effort, expressed as mean catch per 10-minute tow, also varied considerably among years (Table 4, Appendix B). A few noteworthy patterns or occurrences were apparent. Alewife CPUE has been consistently near zero since 2005, and the 2005–2011 mean value is less than the Alewife CPUE means for the 1980s and 1990s by three orders of magnitude. The 2005–2011 mean CPUE values for Channel Catfish, Johnny Darter, Rainbow Smelt, and Spottail Shiner were all less than the mean CPUE's for those species recorded during the prior 30 years. In fact, no Johnny Darters have been collected during the fall trawl survey since 2001. A single age-0 Cisco was captured in the trawl survey in 2009. Six species (Walleye, White Bass, Lake Whitefish, Logperch, Mimic Shiners, and Sand Shiners) had mean 2005–2011 CPUE values higher than the mean decadal values for the 1980s, 1990s, and 2000s. Walleye CPUE values since 2003 have been consistently higher than in any prior survey period, largely due to strong recruitment as indicated by age-0 catch rates (Table 5). Similarly for Yellow Perch, age-0 CPUEs since 2003 have generally been higher than during the period from 1992 to 2002 (Table 6). The soft-rayed forage index values for the 2005–2011 period (Table 4) were consistently lower than during the 1980s and 1990s. In fact, six of the seven lowest forage index values of the time series were recorded since 2005.

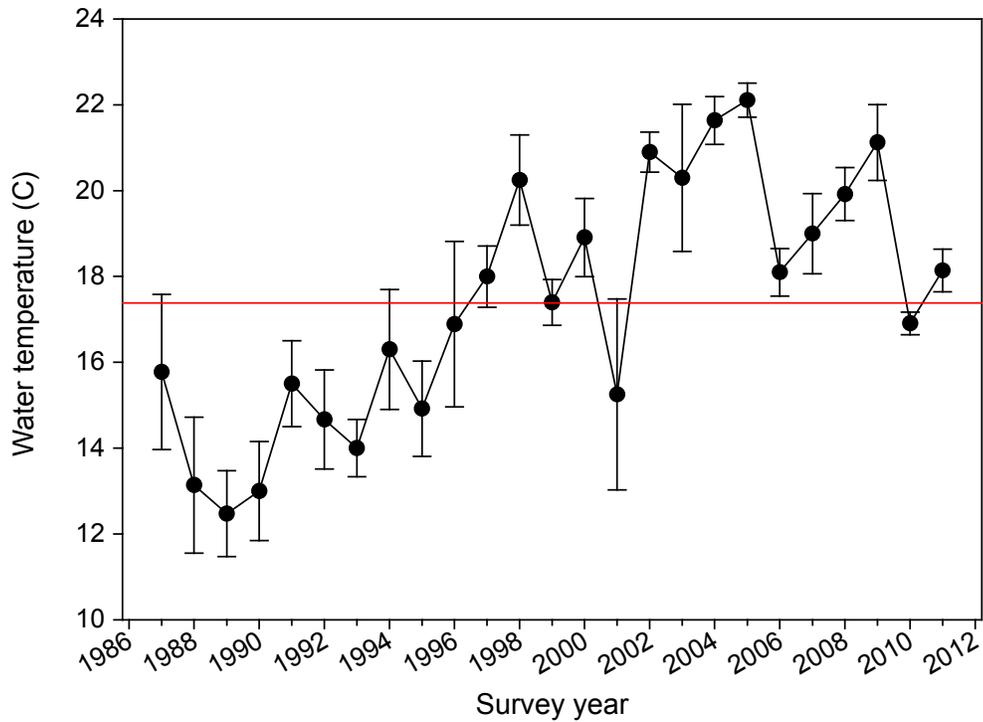


Figure 2.—Mean ( $\pm 2$  SE) water temperatures recorded during fall trawling on Saginaw Bay, 1987–2011. Horizontal line represents mean water temperature for period from 1987 to 2011.

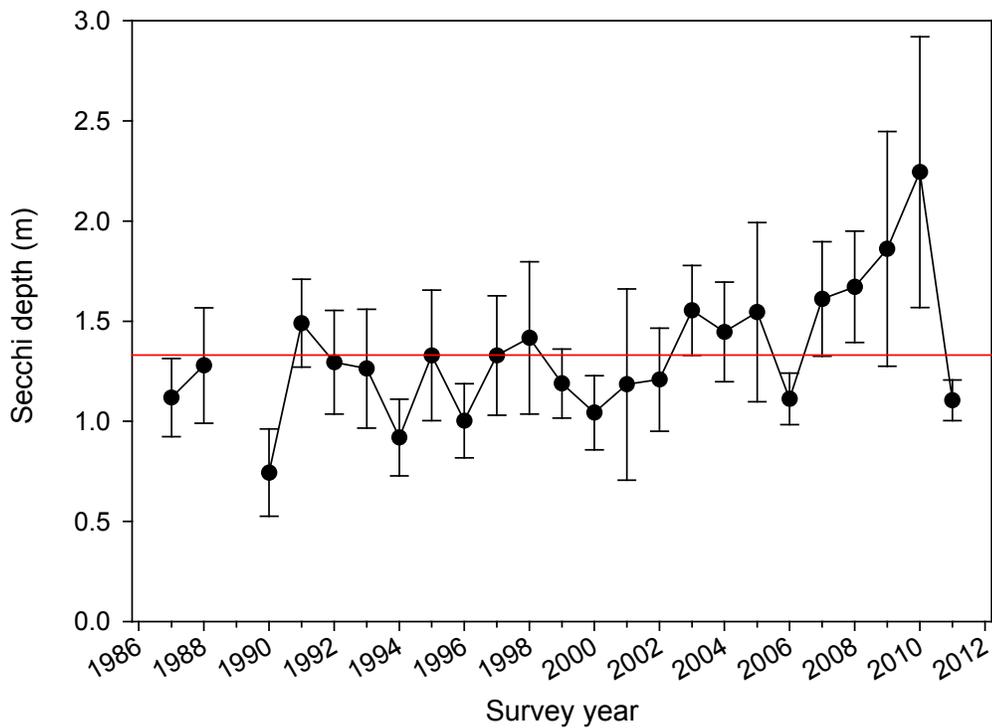


Figure 3.—Mean ( $\pm 2$  SE) Secchi disk transparency recorded during fall trawling on Saginaw Bay, 1987–2011. No secchi depth data were recorded in 1989. Horizontal line represents mean Secchi depth for period from 1987 to 2011.

Table 3.—Species composition (expressed as percentage of annual total catch by number) of Saginaw Bay fall trawl catches, 2005–2011.

Species	Survey year							Avg.
	2005	2006	2007	2008	2009	2010	2011	
Alewife	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Channel Catfish	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Common Carp	0.3	0.9	0.4	0.3	0.3	0.3	0.2	0.4
Emerald Shiner	0.6	0.6	0.4	2.0	0.2	0.0	0.5	0.6
Freshwater Drum	1.2	1.2	1.0	0.5	0.3	0.4	0.7	0.7
Gizzard Shad	0.1	0.9	0.5	1.1	1.3	0.6	0.6	0.7
Johnny Darter	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cisco	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lake Whitefish	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Logperch	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Longnose Gar	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mimic Shiner	0.0	0.0	0.0	0.0	0.0	0.0	17.0	2.4
Quillback	0.1	0.1	0.1	0.1	0.0	0.1	0.0	0.1
Rainbow Smelt	9.6	0.3	2.2	1.3	4.4	0.5	22.3	5.8
Rock Bass	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Round Goby	19.4	2.2	7.7	28.0	25.1	13.9	5.5	14.5
Sand Shiner	0.0	0.0	0.2	0.0	1.8	2.2	0.0	0.6
Silver Lamprey	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Spottail Shiner	18.8	20.8	15.6	8.0	7.2	6.6	10.8	12.6
Trout-perch	11.9	25.9	20.4	15.0	21.3	17.7	19.0	18.7
Walleye	2.5	1.1	1.0	0.6	5.5	2.6	1.6	2.1
White Bass	1.4	0.2	0.3	0.3	1.0	0.7	0.6	0.7
White Perch	15.6	38.8	44.5	30.4	5.0	35.9	11.3	25.9
White Sucker	1.5	0.7	0.4	0.2	0.5	0.4	0.5	0.6
Yellow Perch	16.9	6.2	5.2	12.2	26.0	18.0	9.2	13.4
Total catch (No.)	37,110	26,619	49,127	60,024	27,566	26,200	53,030	39,954

Table 4.—Mean CPUE (number per 10-minute tow) of fish collected by fall trawling in Saginaw Bay, 2005–2011 and decadal means. Total annual number of tows is in parentheses. AA = all ages, YOY = young of year.

Species	Year							Mean			
	2005 (27)	2006 (27)	2007 (33)	2008 (37)	2009 (24)	2010 (24)	2011 (27)	1980s	1990s	2000s	2005–11
Alewife	1.6	1.2	0.0	0.0	0.1	0.0	0.0	227.7	305.5	257.9	0.4
Channel Catfish	0.9	0.9	0.5	0.4	0.2	0.4	0.6	3.6	3.2	2.7	0.5
Cisco	0.0	0.0	0.0	0.0	<0.1	0.0	0.0	0.0	0.0	0.0	0.0
Common Carp	5.6	10.7	8.0	4.9	3.8	3.7	3.9	2.7	5.3	6.4	5.7
Emerald Shiner	8.3	9.2	10.6	34.3	1.9	0.5	10.6	46.7	8.6	6.9	11.1
Freshwater Drum	21.6	14.2	16.7	9.5	3.7	5.6	19.3	7.0	17.5	11.8	12.1
Gizzard Shad	1.9	11.7	10.5	30.6	15.6	6.6	15.3	35.9	19.8	12.4	14.2
Johnny Darter	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.3	11.5	0.5	0.0
Lake Whitefish	1.2	0.0	0.0	0.1	1.4	0.7	0.1	0.3	0.3	0.5	0.6
Logperch	0.0	0.3	0.1	1.1	0.6	0.1	0.1	0.0	0.0	0.2	0.4
Longnose Gar	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.0
Mimic Shiner	0.0	0.0	0.0	0.0	0.0	0.0	384.8	0.0	0.0	0.0	46.6
Quillback	1.2	1.1	1.5	1.5	0.4	0.7	0.9	2.4	0.7	1.7	1.0
Rainbow Smelt	131.5	5.7	65.5	26.3	50.5	5.7	500.6	264.8	269.6	188.5	102.8
Rock Bass	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.6	0.0	0.0
Round Goby	278.3	30.6	151.3	523.4	297.0	209.1	123.5	0.0	0.4	261.3	248.0
Sand Shiner	0.0	0.0	7.2	0.0	21.8	23.9	0.0	0.0	0.0	2.9	8.3
Shorthead											
Redhorse	0.0	0.1	0.0	0.1	0.1	0.0	0.1	0.0	0.0	0.1	0.1
Silver Lamprey	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Spottail Shiner	271.3	313.8	311.0	165.6	91.8	86.6	228.3	489.3	468.2	547.8	201.0
Trout-perch	187.3	304.1	425.8	268.8	263.0	297.0	383.9	145.9	475.9	397.9	302.2
Walleye AA	37.0	14.0	17.9	11.8	68.7	36.1	35.0	1.1	3.1	22.9	33.7
Walleye YOY	31.3	1.3	12.4	6.0	65.7	30.8	29.9	0.4	1.6	18.4	27.8
White Bass	21.3	2.0	6.5	7.3	14.1	12.3	13.8	4.5	2.5	10.6	11.0
White Perch	252.9	491.0	851.4	646.0	73.9	452.5	238.6	255.9	306.4	501.8	416.7
White Sucker	25.1	8.5	9.0	4.1	7.5	5.3	9.6	6.8	11.5	17.1	9.5
Yellow Perch AA	286.7	96.4	121.4	226.7	391.2	240.1	202.3	555.8	105.0	434.9	236.5
Yellow Perch YOY	251.9	87.1	111.8	207.8	363.0	205.8	143.4	188.0	48.1	411.3	209.7
Soft-rayed forage index value <sup>a</sup>	880.1	676.3	974.7	1,049.1	719.8	605.5	1,262.2	1,210.4	1,548.1	1,672.7	881.1

<sup>a</sup> Soft-rayed forage index value is the sum of catch rates for Alewife, Emerald Shiner, Gizzard Shad, Rainbow Smelt, Round Goby, Spottail Shiner, and Trout-perch.

Table 5.—Mean number, catch rate (CPUE expressed as mean catch per 10-minute tow) and mean total length of age-0 Walleyes and two standard errors of the means (2 SE) in fall trawl samples on Saginaw Bay, 1986–2011. Mean length data not available prior to 1998 or for 2001.

Year	Number of age-0 Walleyes captured	Age-0 Walleye catch rate	2 SE	Mean length (mm)	2 SE
1986	20	0.4	—	—	—
1987	34	0.5	—	—	—
1988	39	0.6	—	—	—
1989	19	1.3	—	—	—
1990	0	0.0	—	—	—
1991	28	1.9	—	—	—
1992	6	0.2	—	—	—
1993	1	0.0	—	—	—
1994	22	0.6	—	—	—
1995	14	0.4	—	—	—
1996	0	0.0	—	—	—
1997	83	2.2	(1.4)	—	—
1998	149	8.6	(7.0)	212	(2.4)
1999	20	2.0	(2.0)	200	(13.7)
2000	5	0.3	(0.3)	180	(8.6)
2001	27	0.9	(0.7)	—	—
2002	84	2.2	(1.1)	176	(7.6)
2003	1,114	40.9	(16.5)	171	(2.2)
2004	822	19.9	(4.5)	117	(1.4)
2005	812	31.3	(11.2)	119	(1.1)
2006	24	1.3	(0.8)	162	(7.5)
2007	327	12.4	(3.2)	148	(1.6)
2008	183	6.0	(1.5)	144	(2.6)
2009	942	65.7	(14.4)	105	(0.8)
2010	576	30.8	(14.1)	119	(1.7)
2011	599	29.9	(8.9)	134	(1.3)

Table 6.—Mean number of young-of-the-year Yellow Perch caught per 10-minute tow (CPUE) and their mean total length and two standard errors of the mean (2SE), Saginaw Bay, fall 1970–2011<sup>a</sup>.

Year	CPUE	Mean total length		
		2 SE	(mm)	2 SE
1970	29.5	—	96.5	—
1971	20.2	—	91.4	—
1972	13.9	—	83.8	—
1973	30.6	—	91.4	—
1974	27.9	—	88.9	—
1975	247.9	—	88.9	—
1976	11.1	—	91.4	—
1977	52.9	—	91.4	—
1978	99.8	—	86.4	—
1979	166.7	—	78.7	—
1980	39.0	—	86.4	—
1981	71.3	—	83.8	—
1982	686.7	—	76.2	—
1983	251.9	—	76.2	—
1984	171.0	—	78.7	—
1985	147.8	—	78.7	—
1986	71.4	—	73.7	—
1987	131.5	—	81.3	(0.3)
1988	56.6	—	76.2	(0.7)
1989	252.8	—	71.1	(0.3)
1990	39.0	—	79.5	(0.4)
1991	110.8	—	70.2	(0.4)
1992	7.1	—	76.2	(1.2)
1993	0.5	—	90.7	(6.5)
1994	3.9	—	85.0	(5.5)
1995	98.9	—	72.8	(0.7)
1996	37.3	—	81.9	(0.8)
1997	87.4	(30.9)	73.8	(0.6)
1998	112.5	(49.4)	76.1	(0.7)
1999	19.8	(6.9)	92.4	(0.9)
2000	7.1	(3.5)	83.2	(2.1)
2001	98.6	(40.4)	77.1	(0.6)
2002	26.4	(12.2)	76.2	(0.8)
2003	2,389.6	(943.7)	69.7	(0.7)
2004	389.9	(100.5)	64.9	(0.7)
2005	251.9	(142.0)	79.0	(1.0)
2006	87.1	(57.9)	72.8	(1.1)
2007	111.8	(48.5)	77.6	(1.0)
2008	207.8	(123.5)	78.7	(1.0)
2009	363.0	(111.8)	75.4	(0.8)
2010	205.8	(93.5)	86.2	(0.8)
2011	143.4	(41.9)	77.7	(0.7)

<sup>a</sup> Data prior to 1990 from Haas and Schaeffer (1992).

*Pre-dreissenid invasion, post-dreissenid invasion, and post-Alewife collapse periods in the trawl catch.*—Comparison of mean CPUE values between pre-dreissenid (1986–1990), post-dreissenid (1993–2002), and post-Alewife crash (2003–2011) revealed CPUE values that differed significantly (Kruskal-Wallis test) between periods for several species (Table 7). Emerald Shiner, Gizzard Shad, Rainbow Smelt, and Yellow Perch CPUE were all highest during the pre-dreissenid period. Freshwater Drum, Johnny Darter, Spottail Shiner, and Trout-perch CPUE were all highest during the post-dreissenid period. Alewife, Channel Catfish, Johnny Darter, Rainbow Smelt, and Spottail Shiner CPUE were all lowest during the post-Alewife crash period. In contrast, Round Goby, Walleye, and White Perch CPUE were significantly higher during the post-Alewife crash period. Yellow Perch CPUE was lowest for the post-dreissenid period. Mean age-specific CPUE (for ages 2 and older) of Yellow Perch (Table 8) were the lowest during the post-Alewife crash period. Age-0 CPUE of Yellow Perch was greatest during the post-Alewife crash period, but apparently low survival resulted in age-1 CPUE that was much lower than during the pre-dreissenid period and very similar to the age-1 CPUE during the post-dreissenid period when age-0 CPUE was lowest.

Table 7.—Mean CPUE for common species in Saginaw Bay fall trawl samples for pre-dreissenid invasion (1986–1990), post-dreissenid invasion (1993–2002), and post-Alewife collapse (2003–2011) time periods. Two standard errors of the mean are included (2SE). Kruskal-Wallis (denoted as K-W) test for significant differences with alpha = 0.05, ‘a’ is comparison between pre-dreissenid invasion and post-dreissenid invasion, ‘b’ is comparison between pre-dreissenid invasion and post-Alewife collapse, and ‘c’ is comparison between post-dreissenid invasion and post-Alewife collapse.

Species	Pre-dreissenid invasion		Post-dreissenid invasion		Post-Alewife collapse		K-W Sig. Diff.
	Mean catch rate	2 SE	Mean catch rate	2 SE	Mean catch rate	2 SE	
Alewife	401.8	200.1	403.6	88.3	78.3	39.6	b,c
Channel Catfish	3.8	1.4	4.0	0.7	0.9	0.2	a,b,c
Common Carp	5.2	1.2	5.8	0.7	5.6	0.7	a,b
Emerald Shiner	60.5	24.3	1.8	0.9	8.8	4.2	a,b,c
Freshwater Drum	8.1	2.7	14.9	2.6	10.9	1.8	a,b
Gizzard Shad	67.6	28.1	12.4	3.0	12.9	4.0	a,b
Johnny Darter	2.8	1.0	10.4	2.4	0.0	0.0	a,b,c
Rainbow Smelt	632.4	290.1	332.2	110.3	145.1	41.6	b,c
Round Goby	—	—	164.3	41.0	249.8	46.5	c
Spottail Shiner	532.3	123.7	704.4	179.8	303.4	59.2	b,c
Trout-perch	288.7	84.1	602.2	131.2	334.8	47.7	a
Walleye	2.0	0.5	3.1	1.0	33.1	4.1	b,c
White Perch	290.8	113.2	349.1	52.1	396.9	56.4	a,b
White Sucker	7.0	1.5	14.1	2.8	13.1	3.4	a,b
Yellow Perch	722.2	166.2	85.1	10.4	463.3	118.3	a,b,c

Table 8.—Mean CPUE (catch per 10-minute tow) by age for Yellow Perch in fall trawling in Saginaw Bay, 1986–2011 and for previous reporting periods and since Alewife collapse.

Survey year	Age											All ages	Yearling and older
	0	1	2	3	4	5	6	7	8	9	10		
1986	117.6	132.8	125.9	128.4	21.2	3.0	0.7	0.5	0.0	0.0	0.0	530.0	412.4
1987	258.0	61.0	98.6	66.8	37.6	6.6	1.8	0.4	0.0	0.0	0.0	530.9	272.9
1988	458.9	263.8	248.6	309.4	171.6	56.8	13.5	1.7	0.9	0.0	0.0	1,525.3	1,066.4
1989	280.2	168.7	180.3	128.0	81.1	33.3	12.9	4.4	0.3	0.3	0.0	889.6	609.4
1990	34.0	37.8	20.2	20.5	12.6	6.1	2.8	0.9	0.3	0.1	0.1	135.3	101.3
1991	102.6	15.6	29.3	19.2	13.5	8.6	2.5	0.4	0.0	0.0	0.0	191.8	89.1
1992	7.7	44.5	8.5	6.6	4.0	2.5	0.7	0.3	0.0	0.0	0.0	74.9	67.2
1993	0.5	2.2	20.7	7.6	4.4	1.9	0.3	0.1	0.2	0.0	0.0	37.8	37.3
1994	3.5	1.4	2.8	10.1	2.5	1.0	0.2	0.1	0.0	0.0	0.0	21.7	18.2
1995	100.6	12.0	2.6	3.5	5.2	1.1	0.6	0.1	0.1	0.0	0.0	125.8	25.2
1996	37.9	30.9	5.9	3.7	2.7	3.2	0.8	0.0	0.0	0.0	0.0	85.0	47.1
1997	89.1	11.3	16.9	2.9	0.5	0.5	0.4	0.2	0.0	0.0	0.0	122.0	32.8
1998	74.4	54.1	11.7	6.6	1.7	0.4	0.3	0.1	0.0	0.0	0.0	149.2	74.8
1999	19.5	28.1	25.3	10.7	4.7	1.2	0.2	0.2	0.0	0.0	0.0	89.7	70.3
2000	9.4	4.0	11.6	8.3	4.3	1.0	0.5	0.2	0.0	0.0	0.0	39.2	29.8
2001	134.0	3.2	3.8	11.3	4.2	0.7	0.1	0.1	0.0	0.0	0.0	157.2	23.3
2002	36.7	28.1	1.1	1.6	2.0	0.5	0.2	0.1	0.0	0.0	0.0	70.3	33.6
2003	2,450.8	4.6	11.1	1.1	0.5	0.8	0.3	0.1	0.0	0.0	0.0	2,468.7	18.4
2004	461.8	22.9	2.0	2.8	0.5	0.4	0.3	0.0	0.0	0.1	0.0	490.7	28.9
2005	233.7	20.7	5.7	0.5	0.2	0.1	0.0	0.0	0.0	0.0	0.0	260.8	27.2
2006	84.9	6.5	3.0	1.6	0.2	0.1	0.1	0.0	0.0	0.0	0.0	96.4	11.4
2007	89.8	6.1	1.5	1.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	98.9	9.1
2008	214.4	20.1	1.0	0.5	0.1	0.2	0.0	0.0	0.0	0.0	0.0	236.2	21.8
2009	313.9	25.9	1.4	0.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0	341.8	27.8
2010	203.0	30.8	1.7	0.7	0.1	0.1	0.0	0.0	0.0	0.0	0.0	236.2	33.2
2011	153.3	46.3	4.2	0.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0	204.3	51.0
Mean													
All years	229.6	41.7	32.5	29.0	14.5	5.0	1.5	0.4	0.1	0.0	0.0	354.2	124.6
2005–11	184.7	22.3	2.6	0.7	0.2	0.1	0.0	0.0	0.0	0.0	0.0	210.7	25.9
1986–90	229.7	132.8	134.7	130.6	64.8	21.2	6.3	1.6	0.3	0.1	0.0	722.2	492.5
1993–02	50.5	17.5	10.2	6.6	3.2	1.1	0.4	0.1	0.0	0.0	0.0	89.8	39.2
2003–11 <sup>a</sup>	467.2	20.4	3.5	1.0	0.2	0.2	0.1	0.0	0.0	0.0	0.0	492.7	25.4

<sup>a</sup> Post-Alewife collapse

Mean total length for the major forage species also differed between the pre-dreissenid, post-dreissenid, and post-Alewife crash periods (Table 9). Age-0 Alewives and Rainbow Smelt both had lower mean lengths in the post-dreissenid periods than during the pre-dreissenid periods, and then even lower mean lengths in the post-Alewife crash period. Three species, Gizzard Shad, Trout-perch, and White Perch, had lower mean total lengths in the post-dreissenid period, but experienced a rebound in total length in the post-Alewife crash period. Mean length for age-0 Yellow Perch differed less across the three time periods than for the other common forage species.

Table 9.—Mean total length (mm±2 SE) of common forage species in fall trawl samples of Saginaw Bay for pre-dreissenid invasion (1986–90), post-dreissenid invasion (1993–2002), and post-Alewife collapse (2003–2011) time periods. Kruskal-Wallis (denoted as K-W) test for significant differences with alpha = 0.05, a is comparison between pre-dreissenid invasion and post-dreissenid invasion, b is comparison between pre-dreissenid invasion and post-Alewife collapse, and c is comparison between post-dreissenid invasion and post-Alewife collapse. MTL = Mean total length

Species	Pre-dreissenid invasion		Post-dreissenid invasion		Post-Alewife collapse		K-W Sig. Diff.
	MTL	2 SE	MTL	2 SE	MTL	2 SE	
Alewife (age 0)	77.5	0.5	70.7	0.4	61.4	0.9	a,b,c
Gizzard Shad (age 0)	97.8	1.1	87.9	1.5	101.1	1.6	a,b
Rainbow Smelt (age 0)	55.5	0.4	49.7	0.4	44.3	0.4	a,b,c
Round Goby (all ages)			45.6	1.1	47.8	0.6	c
Spottail Shiner (all ages)	80.4	0.6	72.7	0.4	73.5	0.5	a,b
Trout-perch (all ages)	80.9	0.7	68.7	0.5	71.6	0.5	a,b,c
White Perch (age 0)	78.3	0.5	69.2	0.5	75.6	0.4	a,b,c
Yellow Perch (age 0)	75.9	0.3	76.4	0.4	75.6	0.3	b,c

*Survival, sex ratio, growth, condition, redworm incidence, and diet of Yellow Perch.*—Catch curve analysis of trawl samples for Yellow Perch ages 1–6 produced estimates for annual survival of 54% for the pre-dreissenid invasion period, 47% for the post-dreissenid invasion period, and 35% for the post-Alewife collapse period (Figure 4). The shape of the catch curves differed between the three time periods. For the pre-dreissenid invasion period, the curve was nearly flat for ages 1–3, indicating high survival, with lower survival for ages 3–6. For the post-dreissenid invasion period, the curve exhibited a more consistent descending slope across all ages, suggesting survival had declined in the post-dreissenid invasion period for ages 1–3, and producing a better linear fit for the regression ( $R^2 = 0.97$ ). For the post-Alewife collapse period, the curve descended steeply from age-1 to age-2 and continued to descend steeply through age-4, indicating declines in survival had been greatest between ages 1 and 4.

The overall male to female sex ratio for Yellow Perch (across ages 1 to 6) was near 1.0 for the 2003–2011 time period (Table 10), and less skewed than the values recorded for earlier time periods. In general, age-specific sex ratios have become less skewed towards males across the three time periods. For the two earlier time periods, the sex ratio was consistently male-skewed for all ages. However, age-specific sex ratios for the most recent time period were nearly even (1.06) for age 1, then skewed towards females for ages 2 and 3, and then heavily skewed towards males for ages 4, 5, and 6. This suggests that males and females were experiencing similar mortality rates through age-1, then mortality rates were higher for males from ages 1 to 3, while mortality rates were higher for females for ages 4 to 6.

Based on mean length-at-age, female Yellow Perch grew faster than male Yellow Perch in Saginaw Bay (Table 11). On average, for the 2005 to 2011 period, males reached a length of 200 mm by age-3, while females reached the same length by age-2. Saginaw Bay Yellow Perch growth was well above statewide average growth rates for ages 1 to 5. Saginaw Bay Yellow Perch mean length-at-age has generally maintained a trend of improved growth since the mid-1990s (Figure 5), particularly for ages 2, 3, and 4.

In general, since 1993, somatic tissue water content decreased with age for Saginaw Bay Yellow Perch, indicating older fish had higher somatic tissue energy reserves (Table 12). There was also a fairly consistent pattern of higher somatic water content prior to dreissenids for ages 4–6 for both sexes.

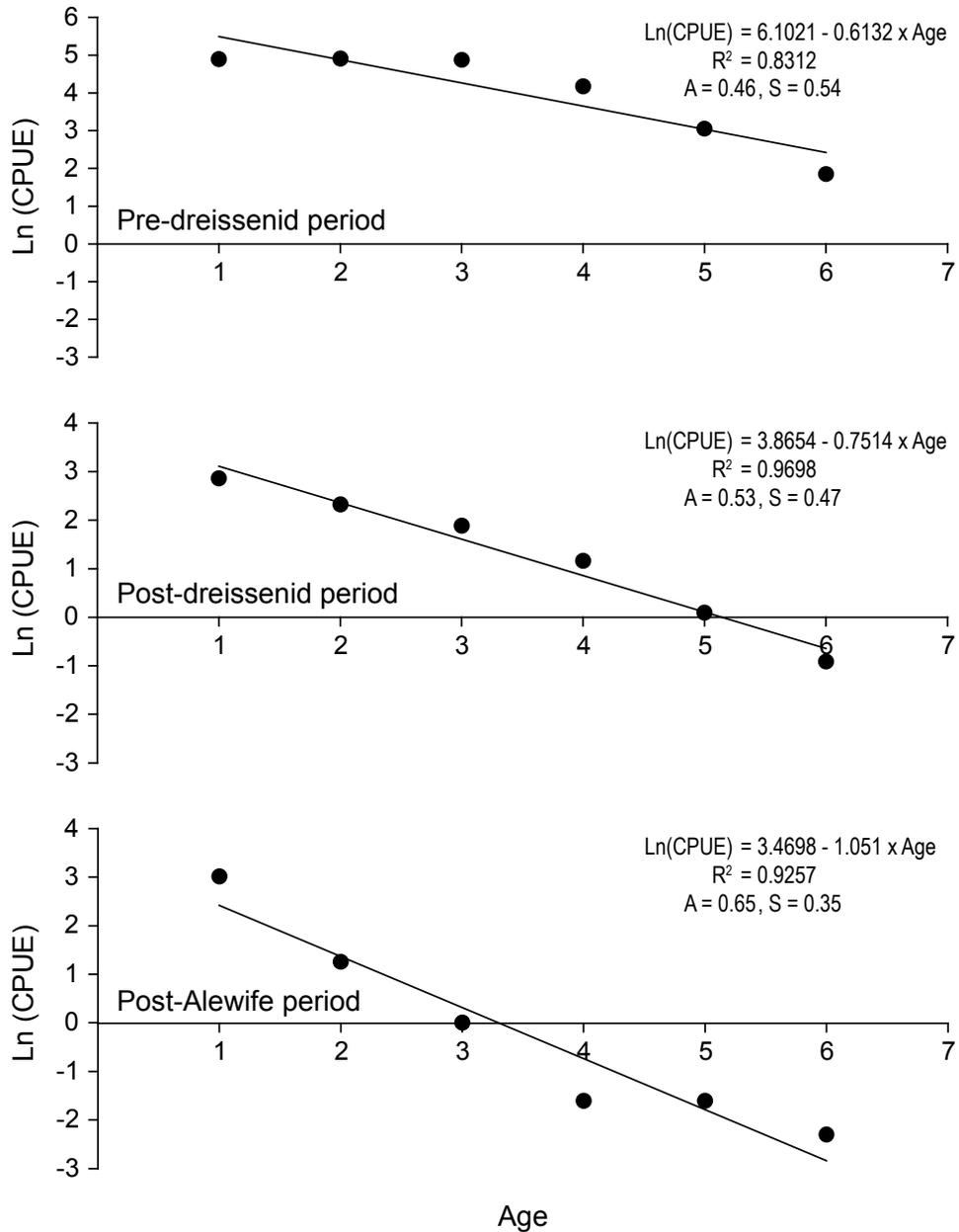


Figure 4.—Plot of observed catch [Ln(CPUE)] versus age for Yellow Perch, ages 1 to 6, from Saginaw Bay fall trawling for pre-dreissenid invasion (1986 to 1990), post-dreissenid invasion (1993 to 2002), and post-Alewife crash (2003 to 2011) periods. Line is a plot of the regression equation given.

Table 10.—Mean male to female sex ratio (M:F) for Yellow Perch in Saginaw Bay based on fall trawl samples during three time periods. CI = confidence interval; N = number of years with data available in the time period.

Age	1971–1991 <sup>a</sup>			1992–2002			2003–2011		
	M:F ratio	95% CI	N	M:F ratio	95% CI	N	M:F ratio	95% CI	N
1	1.64	1.38–1.91	20	1.14	1.01–1.27	11	1.06	0.99–1.13	9
2	2.09	1.77–2.40	20	1.56	1.06–2.05	11	0.72	0.59–0.86	9
3	3.44	2.53–4.34	20	1.45	1.13–1.78	11	0.67	0.47–0.86	9
4	3.46	2.62–4.30	20	1.56	1.04–2.08	11	2.39	1.48–3.30	6
5	2.07	1.48–2.66	14	2.61	1.47–3.76	11	3.71	1.01–6.41	4
6	1.81	0.26–3.36	10	2.44	0.58–4.30	8	4.99	–	1
All ages	2.50	2.19–2.81	20	1.26	1.09–1.43	11	1.03	0.79–1.26	9

<sup>a</sup> Data prior to 1990 from Haas and Schaeffer (1992).

Table 11.—Mean length (mm) at age for Yellow Perch from Saginaw Bay fall trawling, 2005–2011. SWA = fall statewide average (Schneider 2000).

Age	SWA	Survey year							2005–11 Mean
		2005	2006	2007	2008	2009	2010	2011	
Males									
1	–	133	135	134	140	136	132	136	135
2	–	182	186	186	189	184	199	187	188
3	–	201	213	225	239	215	232	210	219
4	–	237	222	238	239	–	–	–	234
5	–	238	252	–	264	–	267	–	255
6	–	–	257	–	–	–	–	–	–
Females									
1	–	137	142	141	150	143	138	143	142
2	–	193	199	203	211	203	201	198	201
3	–	199	223	229	250	224	254	235	231
4	–	243	232	254	282	260	291	196	251
5	–	250	–	298	288	220	–	–	264
6	–	–	–	–	–	–	–	–	–
Sexes combined									
1	127	135	139	138	144	139	135	140	139
2	160	188	192	197	204	196	201	193	196
3	183	200	218	227	247	221	249	229	227
4	208	239	227	243	254	260	291	–	252
5	234	244	252	298	276	220	267	–	260
6	257	–	257	–	–	–	–	–	–

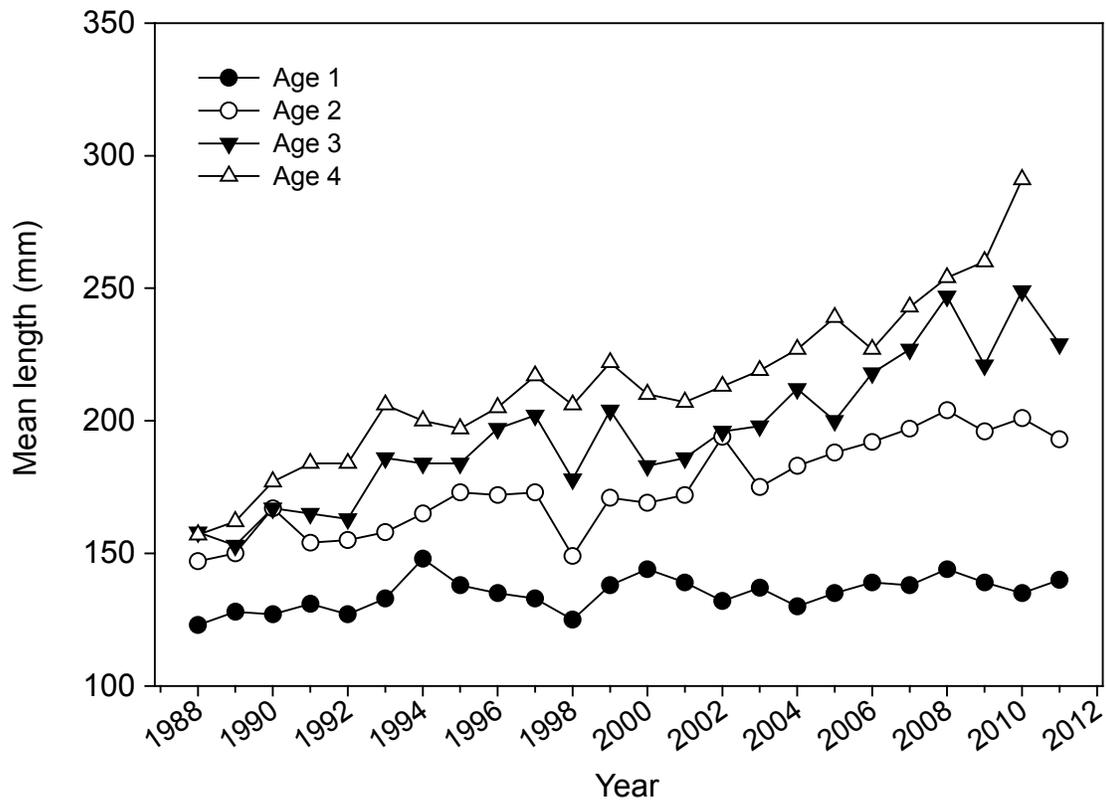


Figure 5.—Mean length-at-age for Yellow Perch from Saginaw Bay trawls, 1988 to 2011. Statewide average lengths: age 1 = 127 mm, age 2 = 160 mm, age 3 = 183 mm, age 4 = 208 mm.

Table 12.—Mean proportion of water by weight and two standard errors (2SE) in Yellow Perch collected by fall trawling in Saginaw Bay during for pre-dreissenid invasion (1986–88), post-dreissenid invasion (1993–2002), and post-Alewife collapse (2003–2010) time periods. Kruskal-Wallis (denoted as K-W) test for significant differences with alpha = 0.05, a is comparison between pre-dreissenid invasion and post-dreissenid invasion, b is comparison between pre-dreissenid invasion and post-Alewife collapse, and c is comparison between post-dreissenid invasion and post-Alewife collapse.

Age	1986–1988		1993–2002		2003–2010		K-W Sig. diff.
	Mean	2 SE	Mean	2 SE	Mean	2 SE	
<b>Males</b>							
1	0.728	0.003	0.736	0.002	0.744	0.001	a,b,c
2	0.732	0.002	0.734	0.001	0.732	0.002	—
3	0.727	0.002	0.727	0.002	0.727	0.003	—
4	0.731	0.002	0.718	0.002	0.718	0.004	a,b
5	0.728	0.003	0.717	0.004	0.723	0.005	a
6	0.733	0.006	0.719	0.006	0.724	0.004	a
<b>Females</b>							
1	0.732	0.004	0.738	0.002	0.747	0.001	b,c
2	0.739	0.002	0.735	0.002	0.735	0.001	a,b
3	0.735	0.002	0.731	0.002	0.725	0.005	a,b
4	0.736	0.004	0.727	0.004	0.726	0.009	a
5	0.734	0.005	0.729	0.006	0.707	0.024	b
6	0.734	0.010	0.724	0.009	—	—	—

Infection of Yellow Perch by redworm nematodes (likely *Eustrongylides tubifex* and *Philometra cylindracea*) varied considerably across years (Figure 6). The peak prevalence was recorded in 2000 (83%) and 1988 (77%). From 2000 to 2004, the infection rate declined steadily and then remained below 10% from 2005 to 2011. Within years, no differences were found in rates of infection between males and females.

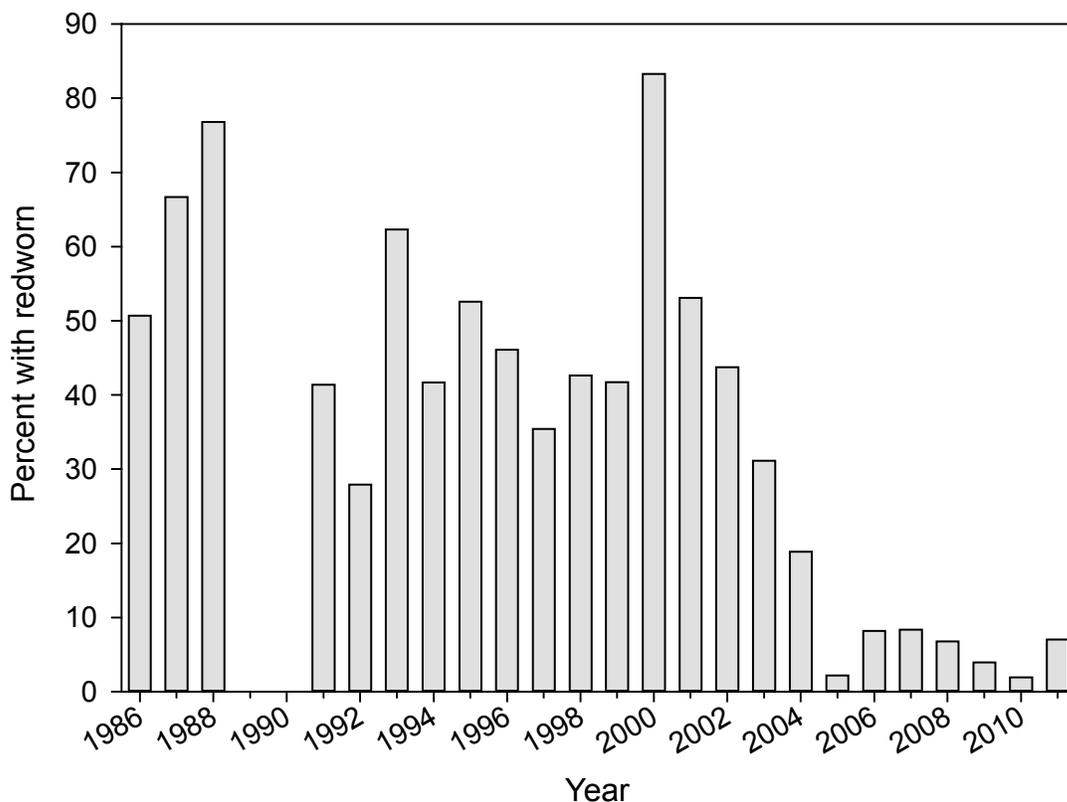


Figure 6.—Frequency of parasitic redworm (likely *Eustrongylides tubifex* and *Philometra cylindracea*) in Yellow Perch from Saginaw Bay fall trawling, 1986–2011. No data are available for 1989 and 1990.

*Diet of Yellow Perch and Walleye.*—Stomach contents were examined from 741 Yellow Perch collected by fall trawling from 2005 to 2010. We found few trends or patterns in the frequency of occurrence of diet items (Table 13). Round Gobies first appeared in Yellow Perch stomachs in 2001 and have been observed in the diet each year since. From 1986 to 1996, zooplankton were found in more than 50% of the non-empty stomachs examined each year. However, zooplankton importance in the diet declined from 1998 through 2001 and reached a record low frequency of occurrence of only 5.1%. Since 2004, zooplankton have once again become a major component of the diet, with 50% to 97% of the non-empty stomachs containing zooplankton. A similar but less prominent pattern was apparent for chironomid larvae. For seven of the nine years sampled between 1986 and 1997, chironomid larvae frequency of occurrence equaled or exceeded 60%, but from 1998 to 2002 the frequency of occurrence was less than 50% for four out of five years. Then, from 2008 to 2010, chironomid larvae frequency of occurrence exceeded 74% each year. A pattern of reduced frequency of empty Yellow Perch stomachs was noted after 2003. From 1986 to 2003, the percentage of empty stomachs in the diet samples ranged from 17.6% to 63.0%, with an overall mean of 38.6%. From 2004 to 2010, the percentage of empty stomachs in the diet samples ranged from 0.1% to 25%, with an overall mean of only 7.4%.

The stomachs of Walleyes caught in trawls were examined during each year from 1998 to 2011. Prior to 2003, Alewives were consistently the most frequently occurring prey item in non-empty Walleye stomachs (Table 14). However, in 2003–2005 Yellow Perch were found in a higher proportion of non-empty Walleye stomachs than any other taxa. Since 2005, only one Walleye stomach examined has contained an identifiable Alewife. White Perch were the most frequently occurring prey item in 2006. From 2007 to 2011, Gizzard Shad and Yellow Perch have been the primary prey items found in the stomachs of Walleye collected in the trawl survey. The diversity of prey items was highest in 2004 and 2005, with seven species identified from Walleye stomachs in each year. Round Gobies first appeared in Walleye diets in 2000 and continued to account for a small percentage of the diet in the most recent years.

### ***Gillnetting***

Twenty-five species were collected by gillnetting during 2005–2011 (Table 15). The most abundant species were Yellow Perch, Gizzard Shad, Walleye, White Perch, and White Sucker. Walleye abundance remained high during 2005–2011 (mean gill-net CPUE of 29.3; Table 15) relative to the previous reporting period of 1998–2004 (mean gill-net CPUE of 11.6; Fielder and Thomas 2006) and the beginning of the time series (1994–1997, mean CPUE of 12.8; Fielder et al. 2000). The early years (1989–1993) of the survey exhibited a very high Walleye gill-net CPUE (mean 43.7) but Fielder et al. (2000) regarded that as a period of greater vulnerability of Walleye to the gear with a subsequent decline in catchability after that time period attributed to the effects of dreissenid mussel colonization and increases in water clarity.

The gill-net CPUE of yearling Walleye, which serves as an indicator of year-class strength, was more variable since 2005 (year classes 2004–2010; CV = 1.64) than for 2001–2004 year classes (CV = 1.26), (Figure 7, Table 16). The latter represents the period of initial resurgence in Walleye reproductive success while the period since 2005 represents year-class production with the population at carrying capacity. Year-class strength (as indicated by gill-net CPUE of yearling Walleye) varied significantly among year classes 2005–2010 (K-W test;  $P < 0.001$ ), but not among 2001–2004 (K-W test;  $P = 0.141$ ).

Prior to 2003, the trawl CPUE of age-0 Walleye (Table 5) was a good predictor of year-class strength as indicated by the gill-net CPUE of yearling Walleye (Figure 7, Table 16) with the former explaining 58% of the variability of the year-class strength (linear regression for 1993–2002;  $R^2 = 0.58$ ,  $P = 0.042$ ). Beginning in 2003, after reproductive success soared in the absence of Alewives, year-class strength was less a function of the abundance of age-0 Walleye (2003–2011;  $R^2 = 0.01$ ,  $P = 0.806$ ). Likely, density mediated factors were affecting year-class strength. Cannibalism by Walleye (mostly inflicted on age-0 Walleye) became evident for the first time in 2004 (Table 17), although competition for food and habitat may have also contributed to density effects. Declines in growth rates (mean length-at-age) of increasingly abundant age-0 Walleyes (Table 5) is further evidence of density effects, and may have left young Walleye vulnerable to predation for a longer period of time and additionally may have compromised their thermal tolerance via reduced condition during their first winter. Walleye year-class strength (as indicated by gill-net mean CPUE of yearlings the next year), however, was not obviously related to Walleye age-0 mean length (linear regression  $R^2 = 0.02$ ,  $P = 0.635$ ). Various other predictor variables (independent variables) were evaluated to explain variation in year-class strength but none were found significant (age-0 Yellow Perch CPUE from trawling,  $R^2 = 0.04$ ,  $P = 0.458$ ; Gizzard Shad CPUE from trawling,  $R^2 = 0.04$ ,  $P = 0.414$ ). Similarly, percent frequency of occurrence of Walleye (after an arcsine/square root transformation) in adult Walleye diet (i.e. cannibalism) was tested against mean total length of age-0 Walleyes collected by trawling for years 1988–2011 and was found insignificant (linear regression  $R^2 = 0.21$ ,  $P = 0.115$ ). Walleye year-class strength as indicated by gill-net CPUE of age-1 Walleyes was tested against prior year age-0 Walleye mean CPUE from trawling to test when year-class strength was set. Age-0 CPUE (transformed by natural log) had a significant positive relationship with year-class strength (linear regression  $R^2 = 0.63$ ,  $P = 0.006$ ) for years 1993–2002, but the relationship did not hold up beginning in 2003 (through 2011; linear regression,  $R^2 = 0.17$ ,  $P = 0.311$ ).

Table 13.—Frequency of occurrence (expressed as % of non-empty stomachs containing selected taxa) for food items in Yellow Perch from Saginaw Bay fall trawl surveys, 1986–2010.

Taxa	Survey year										
	1986	1987	1988	1991	1992	1994	1995	1996	1997	1998	1999
Bosmina	5.5	1.6	3.4	2.7	17.6	5.8	0.8	1.7	1.2	0.8	0.0
Daphnia	1.3	0.3	0.6	0.0	2.0	0.0	0.0	0.0	0.0	0.0	1.7
Chydorid	67.1	25.5	27.2	19.1	61.8	41.8	8.0	19.0	13.9	16.2	1.1
Macrothricid	14.0	4.4	13.5	16.4	27.4	18.6	12.8	5.2	2.9	13.7	0.0
Leptodora	0.2	2.0	0.1	0.0	0.0	0.0	0.0	0.0	4.6	0.0	0.0
Copepod	37.6	51.3	45.5	57.3	46.1	39.5	41.6	53.4	30.6	28.2	0.6
Ostracod	27.4	25.6	34.4	39.1	63.7	45.3	48.8	50.9	45.7	26.1	10.8
Sida	23.3	16.5	3.2	1.8	38.2	24.4	3.2	8.6	6.4	6.6	0.0
<i>Bythotrephes cederstroemi</i>	0.0	0.0	0.0	0.0	21.6	13.9	20.8	0.0	1.2	0.0	0.0
All plankton	73.3	62.5	59.7	65.4	78.4	68.6	78.4	63.8	48.0	39.8	19.9
Ephemera	3.5	0.2	0.7	0.0	0.0	0.0	0.0	1.7	0.0	0.0	0.6
Tricoptera	5.8	1.4	0.1	0.0	4.9	7.0	8.0	29.3	11.0	1.2	1.7
Chironomid pupae	28.3	30.2	33.9	3.6	25.5	3.5	12.8	26.7	11.6	8.7	6.8
Chironomid larvae	66.7	78.4	77.4	71.8	69.6	47.7	60.0	68.1	46.8	44.4	54.5
All insects	71.1	82.3	81.3	72.7	80.4	54.6	67.2	75.0	56.1	46.1	58.5
Pelecepod	7.4	3.6	3.8	9.1	3.9	0.0	5.6	11.2	14.4	11.6	5.7
Gastropod	3.3	0.7	0.5	0.0	0.0	0.0	0.8	0.9	2.3	0.0	1.7
Zebra mussel	0.0	0.0	0.0	0.9	16.7	20.9	1.6	12.9	4.6	4.6	0.0
Isopod	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	1.2	0.0	0.0
Hydracarina	8.5	2.5	9.4	0.9	2.9	1.2	0.8	0.0	1.2	0.0	0.0
Amphipod	4.4	1.9	1.3	0.0	28.4	15.1	0.0	4.3	36.4	2.9	19.3
All other invertebrates	19.2	8.6	14.0	10.9	41.2	33.7	8.8	21.6	49.7	17.8	23.9
Round Goby	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
All fish	18.1	7.4	7.3	10.0	10.8	9.3	12.0	16.4	22.0	10.8	13.6
Percent of empty stomachs	32.7	35.4	39.2	37.9	47.8	42.1	31.0	46.8	26.1	34.4	17.6
Number of non-empty stomachs	636	945	1,009	110	102	86	125	116	173	158	145

Table 13.–Extended.

Taxa	Survey year										
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Bosmina	0.0	2.1	0.0	0.0	0.7	1.7	2.8	20.6	3.6	3.8	13.7
Daphnia	2.1	0.0	0.0	0.0	0.0	3.4	0.0	13.1	1.4	10.7	15.1
Chydorid	0.0	0.0	0.0	0.0	24.2	4.3	22.2	30.8	46.4	74.8	54.7
Macrothricid	0.0	0.0	0.0	0.0	3.8	0.0	2.8	5.6	10.7	7.5	1.4
Leptodora	0.0	0.0	0.0	0.0	0.0	30.1	13.9	16.8	35.0	20.1	16.5
Copepod	0.0	3.6	12.7	1.7	3.0	2.6	5.6	29.9	30.7	34.0	22.3
Ostracod	4.3	0.0	0.0	0.0	9.8	12.9	27.8	12.1	27.9	35.2	59.7
Sida	0.0	0.0	0.0	1.7	15.1	0.8	8.3	16.8	15.0	18.9	20.9
<i>Bythotrephes cederstroemi</i>	0.0	0.0	0.0	0.0	91.7	43.1	0.0	43.9	45.7	49.1	5.8
All plankton	6.4	5.1	12.7	1.7	93.9	80.2	50.0	81.3	83.6	96.9	82.7
Ephemera	0.7	0.0	0.0	0.0	3.0	0.8	0.0	0.0	0.7	0.0	0.7
Tricoptera	3.5	0.0	0.0	1.7	0.7	0.0	0.0	0.9	10.0	9.4	2.9
Chironomid pupae	7.8	0.7	11.3	0.0	6.0	11.2	13.9	7.5	25.7	43.4	58.3
Chironomid larvae	29.1	13.8	45.1	3.4	18.9	32.7	47.2	31.8	74.3	75.5	80.6
All insects	34.8	13.8	45.8	6.9	21.9	34.5	47.2	34.6	77.1	83.0	84.2
Pelecepod	0.7	6.5	19.0	1.7	6.8	8.6	0.0	5.6	1.4	3.8	7.2
Gastropod	2.8	0.7	0.7	0.0	0.0	0.8	2.8	0.0	2.9	0.6	0.0
Zebra mussel	2.1	0.7	0.7	0.0	0.7	0.0	0.0	0.0	0.7	5.0	0.0
Isopod	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.4	4.3
Hydracarina	0.0	0.0	0.0	0.0	7.5	1.7	0.0	2.8	4.3	3.1	0.0
Amphipod	17.0	0.7	0.7	0.0	1.5	3.4	2.8	2.8	7.1	45.9	20.9
All other invertebrates	19.1	8.0	20.4	1.7	12.9	14.6	8.3	10.3	15.7	55.3	25.2
Round Goby	0.0	3.6	7.7	10.3	2.3	1.7	25.0	16.8	3.6	3.1	4.3
All fish	12.8	18.8	22.5	94.8	9.8	14.6	41.7	24.3	11.4	8.8	15.8
Percent of empty stomachs	45.4	63.0	30.3	49.6	2.9	8.7	25	5.3	5.2	0.1	4.8
Number of non-empty stomachs	77	51	99	58	132	116	36	107	140	159	139

Table 14.–Numbers of stomachs examined, incidence of empty stomachs and frequency of occurrence (expressed as % of non-empty stomachs containing selected taxa) of food items found in stomachs of age-1 and older Walleyes collected by fall trawling in Saginaw Bay, 1998–2011.

Year	Stomachs examined	% empty	Diet item											
			Unidentified fish remains	Gizzard shad	Alewife	Yellow Perch	Spottail Shiner	White Sucker	Round Goby	White Perch	Zebra mussel	Trout-perch	Freshwater Drum	Other taxa
1998	51	27	57	0	41	14	0	0	0	3	0	0	0	0
1999	94	28	47	0	66	0	2	0	0	2	2	0	0	0
2000	43	26	59	0	44	0	6	0	3	3	0	0	0	0
2001	33	18	63	0	70	7	4	4	0	0	0	0	0	0
2002	33	27	56	4	28	4	8	0	8	4	0	0	0	0
2003	33	15	68	0	14	39	0	0	4	1	0	4	0	0
2004	176	36	63	0	1	53	5	0	7	6	0	1	0	2
2005	116	49	54	3	0	34	3	0	12	7	2	0	2	0
2006	271	37	64	16	1	13	2	0	7	24	0	1	0	0
2007	147	24	54	38	0	14	0	0	0	9	0	0	0	0
2008	182	22	59	33	0	22	1	0	7	17	1	1	0	4
2009	55	25	61	15	0	37	7	0	10	5	0	2	0	2
2010	77	22	22	33	0	42	7	0	7	3	0	2	0	2
2011	117	24	56	28	0	28	3	0	1	4	0	0	0	2

Table 15.—Mean gill-net catch-per-unit-of-effort (CPUE; number per 305 m gill net) and two standard errors of the mean (2SE) by species for Saginaw Bay, 2005–2011, at traditional netting locations (16 net sets or 5,364 m, total each year), including four net lifts from Charity Islands and Tawas Bay added in 1995. Data includes the 38mm (1½ inch) mesh catch added in 1993.

Species	Year													
	2005		2006		2007		2008		2009		2010		2011	
	Mean	2SE												
Alewife	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bigmouth Buffalo	0.0	0.0	0.2	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bowfin	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Brown Bullhead	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Brown Trout	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0
Burbot	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Carp	0.1	0.1	0.2	0.3	0.2	0.3	0.1	0.2	0.2	0.3	0.0	0.0	0.1	0.1
Channel Catfish	4.0	3.8	3.0	3.1	6.1	5.3	3.8	4.1	4.5	6.0	5.6	5.7	3.8	4.0
Chinook Salmon	0.0	0.0	0.1	0.1	0.0	0.0	0.1	0.2	0.0	0.0	0.1	0.1	0.0	0.0
Cisco	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Freshwater Drum	4.9	2.8	4.7	4.6	6.0	2.9	5.4	4.5	8.2	7.2	5.0	4.6	6.1	6.6
Gizzard Shad	50.6	36.0	21.1	20.5	34.7	36.4	9.3	8.4	5.9	6.8	69.2	97.0	50.9	39.5
Goldfish	0.0	0.0	0.0	0.0	0.2	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.1
Lake Sturgeon	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lake Trout	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0
Lake Whitefish	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Longnose Gar	2.4	4.9	0.1	1.6	3.1	5.7	0.3	0.4	0.4	0.4	0.1	0.2	1.2	2.4
Longnose Sucker	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.2	0.0	0.0	0.0	0.0	1.8	3.6
Muskellunge	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Northern Pike	0.6	0.7	0.9	0.8	1.0	0.8	0.1	0.1	0.3	0.2	0.1	0.1	0.2	0.4
Northern Redhorse	0.2	0.3	0.4	0.2	0.1	0.2	0.1	0.2	0.4	0.4	0.1	0.2	0.1	0.2
Pumpkinseed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Quillback	0.6	0.9	0.2	0.2	1.2	1.1	0.4	0.3	0.7	0.5	0.6	1.0	1.1	1.2
Rainbow Smelt	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rock Bass	0.0	0.0	0.1	0.1	0.4	0.6	0.1	0.2	0.2	0.3	0.2	0.3	0.1	0.2
Round Goby	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.4
Round Whitefish	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.3	0.0	0.0
Smallmouth Bass	0.3	0.5	0.8	1.2	0.4	0.7	0.5	0.5	0.1	0.2	0.3	0.4	0.2	0.3
Stone Cat	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Walleye	19.2	7.8	37.7	17.9	35.6	13.6	34.6	19.2	16.0	6.6	29.2	22.6	33.1	18.8
White Bass	0.3	0.2	0.9	0.6	3.1	2.3	1.4	1.7	0.6	0.6	0.5	0.7	2.9	2.4
White Perch	37.7	61.5	37.8	34.1	16.1	14.3	18.4	29.9	9.5	15.9	8.6	9.8	22.2	16.2
White Sucker	11.9	8.2	16.2	9.8	10.8	9.4	8.9	5.1	10.1	8.1	9.8	10.1	15.3	17.3
Yellow Perch	36.2	25.1	22.4	9.8	21.4	10.6	33.7	23.9	59.3	42.8	29.9	25.1	60.0	50.7

Table 16.—Catch-per-unit-of-effort (CPUE) by year class of Walleye in fall gill-net survey catches, Saginaw Bay, Lake Huron, 2005–2011. Catch-per-unit-effort is catch per 335 m, 16 net sets were made each survey year.

Year class	Survey year													
	2005		2006		2007		2008		2009		2010		2011	
	Age	CPUE	Age	CPUE	Age	CPUE	Age	CPUE	Age	CPUE	Age	CPUE	Age	CPUE
2011	–	–	–	–	–	–	–	–	–	–	–	–	0	0.1
2010	–	–	–	–	–	–	–	–	–	–	0	0.1	1	6.2
2009	–	–	–	–	–	–	–	–	0	0.1	1	1.3	2	6.5
2008	–	–	–	–	–	–	0	0.1	1	0.4	2	2.9	3	6.1
2007	–	–	–	–	0	0.4	1	8.8	2	1.4	3	7.3	4	5.9
2006	–	–	0	0.1	1	0.8	2	1.7	3	5.8	4	9.5	5	3.2
2005	0	0.1	1	12.3	2	17.1	3	12.1	4	2.8	5	2.1	6	3.6
2004	1	3.6	2	14.6	3	10.9	4	8.2	5	3.1	6	3.6	7	0.6
2003	2	12.4	3	8.8	4	4.9	5	2.7	6	1.4	7	1.6	8	0.5
2002	3	1.5	4	1.5	5	0.6	6	0.8	7	0.7	8	0.8	9	0.3
2001	4	0.6	5	0.1	6	0.3	7	0.1	8	0.2	9	0.0	10	0.1
2000	5	0.1	6	0.1	7	0.0	8	0.1	9	0.1	10	0.1	–	–
1999	6	0.3	7	0.1	8	0.1	9	0.1	–	–	–	–	–	–
1998	7	0.3	8	0.1	9	0.1	10	0.0	–	–	–	–	–	–
1997	8	0.1	9	0.1	10	0.0	11	0.1	–	–	–	–	–	–
1996	9	0.0	–	–	11	0.0	–	–	–	–	–	–	–	–
1995	10	0.1	–	–	12	0.1	–	–	–	–	–	–	–	–
1994	11	0.1	–	–	–	–	–	–	–	–	–	–	–	–
Mean age	2.2		2.0		2.7	–	3.0		3.9		4.01		3.4	
Total CPUE <sup>a</sup>		19.1		37.7		35.2		34.6		15.9		29.1		33.1

<sup>a</sup> Data based on aged sample may differ slightly from value reported in Table 15.

Table 17.—Frequency-of-occurrence of food items found in stomachs of Walleyes from fall gill nets in Saginaw Bay, 1989–2011.

Year	Stomachs examined	% empty	Unidentified fish remains	Diet item																	
				Alewife	Channel Catfish	Cisco	Crayfish spp.	Emerald Shiner	Freshwater Drum	Gizzard Shad	Ninespine Stickleback	Rainbow Smelt	Round Goby	Sand Shiner	Spottail Shiner	Trout-perch	Walleye	White Perch	White Sucker	Yellow Perch	Dreissenids
1989	257	25.7	55.0	5.8	0.0	0.0	0.0	0.0	0.0	44.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0
1990	508	37.4	42.5	0.9	0.0	0.0	0.0	0.0	0.0	57.9	0.0	0.3	0.0	0.0	0.2	0.0	0.0	0.3	0.0	0.0	0.0
1991	669	35.9	50.8	1.6	0.0	0.0	0.0	0.0	0.0	48.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.2	0.2	0.0
1992	171	55.6	61.8	7.9	0.0	0.0	0.0	0.0	0.0	1.3	0.0	5.3	0.0	0.0	2.6	0.0	0.0	0.0	1.3	1.3	0.0
1993	371	52.6	55.1	0.6	0.0	0.0	0.0	0.0	0.0	39.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.5	0.0
1994	84	52.4	52.5	0.0	0.0	0.0	0.0	0.0	0.0	47.5	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	0.0
1995	291	45.0	53.1	30.0	0.0	0.0	0.0	0.0	0.0	24.4	0.0	0.0	0.0	0.0	0.6	0.0	0.0	1.3	0.6	3.1	0.0
1996	267	34.1	23.3	0.6	0.0	0.0	0.0	0.0	0.0	7.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	1.1	0.0
1997	204	35.3	34.8	13.6	0.0	0.0	0.0	0.0	0.0	8.3	0.0	0.0	0.0	0.0	6.1	0.0	0.0	2.3	0.0	3.0	0.0
1998	234	47.4	50.4	40.7	0.0	0.0	0.0	0.8	0.0	3.3	0.0	0.0	0.0	0.0	1.6	0.0	0.0	0.0	0.0	1.6	0.0
1999	231	48.9	60.2	32.2	0.0	0.0	0.0	1.7	0.0	0.8	0.0	0.8	0.0	0.0	11.0	0.0	0.0	0.8	0.0	7.6	0.0
2000	119	47.9	72.6	33.9	0.0	0.0	0.0	0.0	0.0	8.1	0.0	0.0	1.6	0.0	3.2	0.0	0.0	11.3	0.0	4.8	0.0
2001	132	49.2	35.8	47.8	0.0	0.0	0.0	1.5	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.5	0.0	3.0	0.0
2002	129	70.5	42.1	10.5	0.0	0.0	0.0	0.0	0.0	10.5	0.0	0.0	5.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2003	401	51.9	21.2	31.1	0.0	0.0	0.0	0.0	0.0	14.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	22.8	0.0
2004	216	65.7	37.8	0.0	0.0	0.0	0.0	0.0	1.4	0.0	0.0	0.0	2.7	0.0	1.4	0.0	9.5	0.0	1.4	56.8	1.4
2005	307	59.6	25.8	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.8	1.6	0.0	0.0	0.0	0.8	0.0	0.0	40.3	0.0
2006	603	59.2	73.6	0.0	0.0	0.0	0.0	1.2	0.4	17.1	0.0	0.0	4.5	0.0	0.0	0.0	1.2	2.8	0.0	17.1	0.8
2007	570	49.1	45.5	0.0	0.0	0.0	0.0	1.4	0.3	8.3	0.0	0.0	1.7	0.0	0.0	0.0	0.7	4.8	0.0	15.2	0.0
2008	553	46.1	66.1	0.0	0.0	0.0	0.3	0.7	1.3	22.5	0.0	0.0	5.4	0.7	0.0	0.0	0.0	7.7	0.3	9.1	0.0
2009	256	57.0	80.0	0.0	0.0	0.0	0.0	1.8	0.0	0.9	0.0	0.9	9.1	0.0	0.0	0.0	2.7	2.7	0.0	19.1	1.8
2010	470	66.6	12.5	0.0	0.0	0.0	0.0	5.1	0.0	16.0	0.0	0.6	2.9	0.0	0.0	1.0	0.0	0.6	0.3	12.1	0.0
2011	530	49.4	46.6	0.0	0.0	0.0	0.0	0.4	0.0	25.0	0.0	0.4	5.2	0.0	0.0	0.0	0.0	0.7	0.0	30.2	0.0

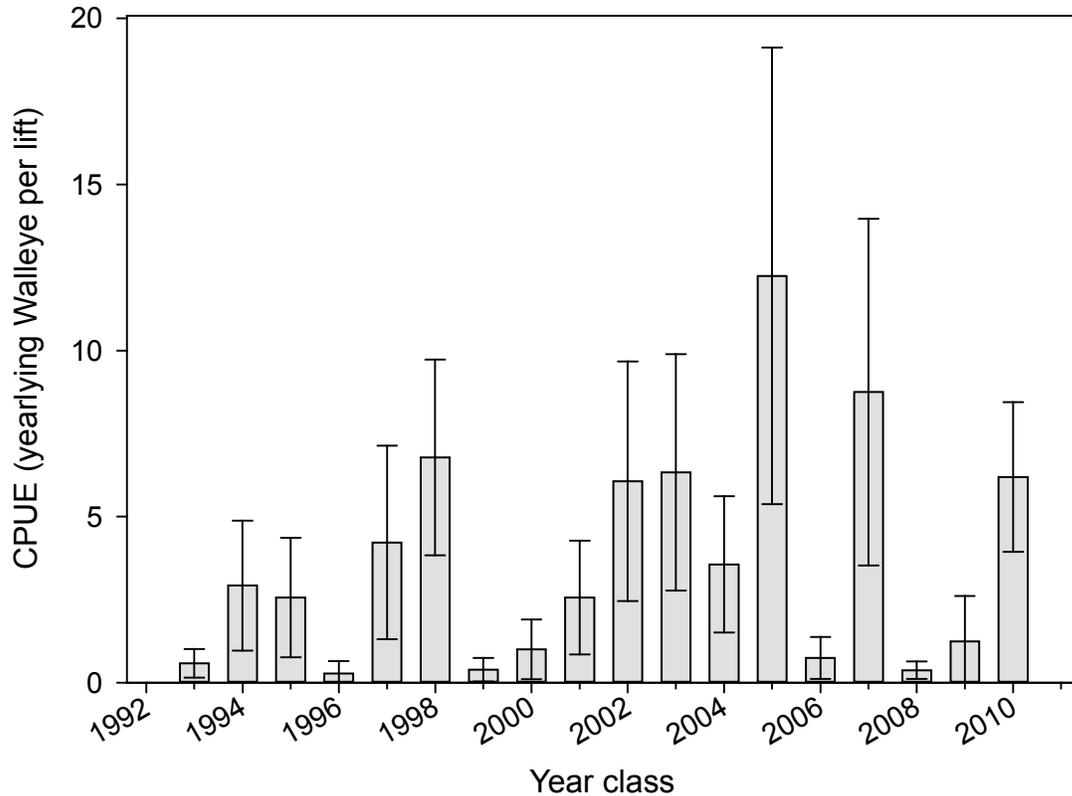


Figure 7.—Walleye year-class strength as determined by gillnet catch-per-unit-of-effort (CPUE) of yearling Walleye in Saginaw Bay for year classes 1993–2010 (catch of age-1 Walleye in survey year following these year classes). Error bars represent two standard errors of the mean. Data for year classes 1993–1996 from Fielder et al. (2000), and year classes 1997–2004 from Fielder and Thomas (2006).

Older Walleyes exhibited a decline in growth as indicated by trends in mean length-at-age (Table 18). Using age-3 as an indicator, mean length-at-age has declined to a level commensurate with the state average (Schneider 2000). The size structure of the Walleye population has become dominated by increasingly smaller individuals (Table 19) as evidenced by a lack or low proportion of Walleyes in the memorable size category. While partly a function of growth rate declines, this may also trace back to increased abundance of young, strong year classes that have not yet fully translated through to larger sizes. Declines in growth were mirrored by declines in condition. Mean relative weight declined across all categories for Walleye during the reporting period (Table 20). The age at 50% maturity increased during the reporting period (2005–2011) versus the years prior in the time series (1989–2004) for females from 2.77 to 2.96 and males from 1.51 to 2.50 (Table 21) consistent with the increase in abundance and decline in growth. Walleye stocking history and year class composition between hatchery and wild Walleyes are depicted in Appendices C and D. The Walleye length/weight relationship and Von Bertalanffy growth equations are presented in Appendix E.

Walleye total annual mortality rate (Table 22) differed significantly between the current reporting period (mean of 0.54) with that of 1989–2004 (mean of 0.43; T-test  $P = 0.012$ ). The mean Walleye total annual mortality rate from the cohort method (Table 23) was 0.56, very similar to that derived from the point-in-time catch curve method.

Table 18.—Mean length (mm)-at-age and two standard errors of the mean (2SE) for Walleyes and Yellow Perch from Saginaw Bay, Lake Huron. Data are from fall gill-net surveys for 2005–2011; Michigan average lengths are from August–September catches (Schneider 2000). Saginaw Bay historic average length-at-age for 1926–1938 is also included for Walleyes (Hile 1954). No means are included for sample sizes less than 5 specimens. Growth index (mm) is an index of overall departure from the state average based on age-specific growth rates, calculated with methodology from Schneider (2000).

Age	Year														Michigan average	Bay historic average
	2005		2006		2007		2008		2009		2010		2011			
	Mean	2SE														
<u>Walleye</u>																
0	–	–	–	–	183	9.8	–	–	–	–	–	–	–	–	180	–
1	274	6.9	281	2.7	290	8.6	298	3.0	252	7.2	276	17.3	262	4.3	250	254
2	384	2.9	373	3.2	361	2.3	368	14.8	321	17.2	309	11.3	328	7.8	338	320
3	460	20.2	441	5.8	418	4.0	424	3.3	366	3.4	388	5.5	380	8.1	386	371
4	474	57.7	479	15.8	464	9.9	450	5.3	424	8.3	432	3.8	443	9.1	437	411
5	–	–	–	–	469	19.7	498	9.9	468	10.2	457	10.1	468	12.3	472	457
6	547	36.7	–	–	534	40.7	488	14.1	478	17.8	482	7.1	488	10.3	516	483
7	573	40.2	–	–	–	–	–	–	495	29.3	492	14.4	502	26.4	541	505
8	–	–	–	–	–	–	–	–	–	–	523	21.3	495	35.9	561	533
9	–	–	–	–	–	–	–	–	–	–	–	–	487	30.6	582	582
Growth index	+40.9		+40.6		+20.0		+21.0		-19.3		-18.0		-25.5			-15.2
<u>Yellow Perch</u>																
0	–	–	–	–	–	–	–	–	–	–	–	–	–	–	84	–
1	150	2.4	153	1.9	153	2.2	158	1.4	154	1.3	159	14.5	151	1.4	127	–
2	203	2.6	210	4.8	214	3.9	215	4.7	202	3.7	221	6.8	204	5.4	160	–
3	238	11.0	238	5.5	247	6.5	252	6.3	246	7.9	249	8.5	242	10.2	183	–
4	269	15.0	265	25.2	262	10.1	273	12.5	269	12.0	278	11.9	–	–	208	–
5	–	–	–	–	–	–	280	16.9	–	–	–	–	–	–	234	–
6	–	–	–	–	–	–	–	–	–	–	–	–	–	–	257	–
7	–	–	–	–	–	–	–	–	–	–	–	–	–	–	277	–
8	–	–	–	–	–	–	–	–	–	–	–	–	–	–	292	–
9	–	–	–	–	–	–	–	–	–	–	–	–	–	–	302	–
Growth index	+45.4		+47.1		+49.5		+53.3		+48.8		+57.2		+42.3			

Table 19.—Walleye and Yellow Perch proportional stock density (PSD)<sup>a</sup> and relative stock density (RSD-P and RSD-M)<sup>b</sup> from fall gill-net data, 2005–2011 from Saginaw Bay, Lake Huron.

Species	2005	2006	2007	2008	2009	2010	2011
Walleye	57(8,1)	44(2,0)	55(4,0)	71(4,0)	59(8,0)	76(5,0)	52(6,0)
Yellow Perch	41(6,1)	42(9,1)	51(15,1)	25(8,1)	24(4,0)	35(14,1)	17(3,0)

<sup>a</sup> Stock and quality size for Walleye is 250 mm and 380 mm, respectively, Yellow Perch: 130 mm and 200 mm. Range of PSD values suggested as indicative of balance when the population supports a substantial fishery is 30–60 for Walleye and 30–50 for Yellow Perch (Gabelhouse 1984, Anderson and Weithman 1978).

<sup>b</sup> Preferred size for Walleye is 510 mm, memorable size is 630 mm. For Yellow Perch, it is 250 mm and 300 mm, respectively (Gabelhouse 1984, Anderson and Gutreuter 1983).

Table 20.—Mean relative weight by length class and all sizes combined for Walleyes and Yellow Perch collected in gill nets during fall 1993–2011 from Saginaw Bay, Lake Huron. N = sample size for that year.

Year	Length class				N
	Stock-quality	Quality-preferred	Preferred-memorable	All sizes combined	
Walleye					
1993	91	91	88	90	382
1994	88	88	90	88	155
1995	92	93	92	95	302
1996	90	92	90	90	267
1997	95	90	92	91	204
1998	91	89	88	90	231
1999	88	90	86	88	231
2000	107	90	81	88	116
2001	103	96	92	94	114
2002	87	86	88	87	127
2003	90	90	86	90	382
2004	86	86	83	86	216
2005	83	82	81	83	307
2006	83	79	78	82	603
2007	84	82	79	83	570
2008	89	83	81	85	553
2009	82	79	76	81	254
2010	91	88	88	89	465
2011	72	72	72	72	528
Yellow Perch					
1993	96	95	94	96	218
1994	99	96	92	96	203
1995	91	87	90	89	501
1996	96	93	90	95	1,658
1997	94	95	93	94	962
1998	87	85	86	86	348
1999	79	90	87	82	528
2000	90	86	90	89	358
2001	103	97	92	100	825
2002	95	101	92	96	458
2003	90	93	90	91	399
2004	101	97	88	99	380
2005	90	90	86	89	413
2006	93	91	87	92	285
2007	85	93	94	89	332
2008	97	92	92	96	428
2009	88	93	92	90	635
2010	88	90	90	90	367
2011	89	83	79	88	420

Table 21.—Walleye male and female percent mature and age at 50% maturity in Saginaw Bay, Lake Huron for the reporting period of 2005–2011 and from prior years in the gill-net collection time series (1989–2004).

Age	1989–2004				2005–2011			
	Males		Females		Males		Females	
	Number	% mature	Number	% mature	Number	% mature	Number	% mature
0	111	0.0	53	0.0	5	0.0	4	0.0
1	509	11.2	534	0.9	257	2.7	253	5.1
2	427	87.1	314	6.4	429	35.2	427	36.3
3	280	96.1	217	63.1	436	64.2	356	50.6
4	285	98.6	215	94.0	262	87.4	249	64.7
5	254	99.6	121	99.2	96	95.8	85	94.1
6	190	97.9	88	98.9	104	100.0	52	96.2
7	141	98.6	57	96.5	30	100.0	22	90.9
8	100	98.0	45	95.6	16	100.0	12	100.0
9	45	100.0	15	100.0	4	100.0	4	100.0
10	14	100.0	13	100.0	2	100.0	1	100.0
11	6	100.0	6	100.0	1	100.0	2	100.0
12	2	100.0	0	100.0	0	100.0	1	100.0
13	0	100.0	2	100.0	0	100.0	0	100.0
Age at 50% mature	1.51		2.77		2.50		2.96	

Table 22.—Total annual mortality rate (A) for Walleye, Yellow Perch, and Channel Catfish in Saginaw Bay for 1989–2011 as determined by the Robson-Chapman method of point-in-time catch curve analysis, using gill-net collection data. Vacant cells represent insufficient data for calculation.

Year	Walleye	Yellow Perch	Channel Catfish
1989	0.53	—	—
1990	0.43	0.52	—
1991	0.41	0.67	—
1992	0.32	0.57	—
1993	0.40	0.50	—
1994	0.43	0.60	—
1995	0.41	0.55	—
1996	0.31	0.41	—
1997	0.33	0.50	0.41
1998	0.35	0.47	0.74
1999	0.45	0.46	0.65
2000	0.59	0.46	0.70
2001	0.41	0.58	0.55
2002	0.43	0.73	0.62
2003	0.47	0.60	0.64
2004	0.56	0.53	0.71
2005	0.70	0.79	0.53
2006	0.65	0.58	0.35
2007	0.59	0.51	0.31
2008	0.44	0.68	0.54
2009	0.55	0.67	0.49
2010	0.51	0.61	0.48
2011	0.34	0.75	0.48

Table 23.—Total annual mortality rate (A) for Walleye, Yellow Perch, and Channel Catfish in Saginaw Bay for 1989–2009 as determined by the cohort method (applying the Robson-Chapman calculation method of catch curve analysis of year classes) using gill-net collection data. Vacant cells represent insufficient data for calculation.

Year class	Walleye			Yellow Perch			Channel Catfish		
	A	Years spanned	Ages spanned	A	Years spanned	Ages spanned	A	Years spanned	Ages spanned
1989	0.52	1990–1999	1–10	–	–	–	–	–	–
1990	0.46	1991–2001	1–11	0.46	1993–2001	3–11	–	–	–
1991	0.39	1993–2002	2–11	0.66	1996–2000	5–9	–	–	–
1992	0.26	1993–2001	1–9	0.53	1996–2000	4–8	–	–	–
1993	0.24	1994–2004	1–11	0.46	1996–2001	3–8	–	–	–
1994	0.39	1996–2004	2–10	0.59	1996–2001	2–7	–	–	–
1995	0.34	1996–2007	1–12	0.46	1997–2003	2–8	–	–	–
1996	0.16	1997–2004	1–8	0.46	1998–2004	2–8	–	–	–
1997	0.39	1998–2008	1–11	0.64	1999–2003	2–6	0.19	2001–2009	4–12
1998	0.42	1999–2007	1–9	0.53	1999–2005	1–7	0.30	2001–2011	3–13
1999	0.36	2002–2009	2–9	0.67	2001–2005	2–6	0.28	2004–2011	5–12
2000	0.44	2003–2010	3–10	0.58	2001–2007	1–7	–	–	–
2001	0.54	2003–2011	2–10	0.64	2003–2008	2–7	–	–	–
2002	0.44	2003–2011	1–9	0.73	2004–2007	2–5	0.31	2005–2011	3–9
2003	0.44	2005–2011	2–8	0.67	2005–2010	2–7	0.34	2007–2011	4–8
2004	0.45	2006–2011	2–7	0.64	2006–2010	2–6	–	–	–
2005	0.60	2007–2010	2–5	0.58	2006–2011	1–6	–	–	–
2006	0.79	2010–2011	4–5	0.56	2007–2010	1–4	0.56	2009–2011	3–5
2007	0.52	2008–2011	1–4	0.62	2008–2011	1–4	–	–	–
2008	–	–	–	0.81	2009–2011	1–3	–	–	–
2009	–	–	–	–	–	–	–	–	–

Yellow Perch abundance, as indicated by gill-net CPUE from 2005–2011, was the lowest over the time series (Table 15; mean CPUE 37.6) reflecting a significant decline from the earlier years of the survey period (K-W test  $P < 0.0001$ ). Yellow Perch abundance was greatest before zebra mussel colonization (1989–1993 mean CPUE 72.3), however, significant difference was not observed in gill-net CPUE between periods of pre- and post-dreissenid colonization (1994–2004 mean CPUE was 43.9; K-W test  $P = 0.205$ ).

Yellow Perch growth rate has continued to improve during the current reporting period (Table 18) with an average growth index of +49.0, meaning that Saginaw Bay Yellow Perch were on average exhibiting 49 mm of growth beyond the state average for the period 2001–2011, compared to +18 for 1998–2004. The increase in mean length-at-age is consistent with a decline in abundance. Despite the improvement in growth, condition as indicated by relative weight did not improve (Table 20).

The mean age of Yellow Perch collected in gill nets declined significantly during the period 2005–2011 (Table 24, mean age 1.6) when compared to 1989–2004 (mean age 3.1; K-W Test  $P < 0.0001$ ). The lack of larger, older Yellow Perch is evident in the proportional and relative stock density (Table 19). The decline in mean age is consistent with poor survival of Yellow Perch between age-0 and age-1 and lack of subsequent recruitment to the adult population. Mean age will continue to decline as adults become scarce. The poor survival of juveniles is largely attributed to predation effects (Table 17) although energetic limitations to good overwinter survival can't be ruled out either.

Total annual Yellow Perch mortality (A) as indicated by catch curve analysis was greater for the reporting period of 2005–2011 (Table 22; mean A of 0.66) than years earlier in the time series (1989–2004, mean A of 0.54) but did not test significantly different (T-test  $P = 0.667$ ). The mean total annual mortality rate of Yellow Perch as indicated by cohort analysis (Table 23) averaged 0.65 for the same time period, again greater than the cohorts spanning 1993–2005 (mean A = 0.55), but like the catch-curve method derived rates, did not differ significantly (T-test  $P = 0.592$ ). These analyses, however, began with age distributions of age-1 Yellow Perch and in some instances not until age 2 or 3, and thus beyond the early mortality period between ages 0 and 1. Also, because estimates of mortality from neighboring years overlaps in time periods, there is almost certainly autocorrelation complicating such comparisons. Therefore, the findings of no significant difference would be even greater significance given any autocorrelation. The Yellow Perch length/weight relationship and Von Bertalanffy growth equations are presented in Appendix E.

There has been no significant change in Channel Catfish abundance as indicated by gill-net CPUE from the reporting period 2005–2011 (mean CPUE of 9.0) compared to that of the earlier time series (1989–2004, mean CPUE 8.7; K-W test  $P = 0.991$ ). Mean age of Channel Catfish varied significantly between the current reporting period (Table 25; 2005–2011 mean age 5.68) and that of the earlier time series (1989–2004, mean age 4.59; K-W test,  $P < 0.0001$ ). Total annual mortality rate (A) as determined by catch curves (Table 22) was significantly less for the reporting period 2005–2011 (mean A 0.45) compared to that of the years 1997–2004 (mean A 0.63; K-W test,  $P = 0.008$ ). Sample sizes were too low to allow a consistent estimation of total mortality by the cohort method (Table 23) for Channel Catfish, but estimates were generally lower than those depicted from catch curves (Table 22). Channel Catfish continue to exhibit growth rates (as indicated by mean length-at-age) below the state average (mean growth index 2005–2011 -30; Table 26), but there was a slight improvement over the last reporting period (1998–2004, mean growth index -48). The Channel Catfish length/weight relationship and Von Bertalanffy growth equations are presented in Appendix E.

Other species have also demonstrated gains in abundance during the reporting period such as Smallmouth Bass and Freshwater Drum but did not test significant. Northern Pike gill-net CPUE tested significantly lower for the reporting period (2005–2011) compared to the earlier years of the survey (1989–2004) (K-W test,  $P = 0.017$ ).

Table 24.—Catch-per-unit-of-effort (CPUE; catch per 335 m) by year class of Yellow Perch in fall gill-net survey catches, Saginaw Bay, Lake Huron, 2005–2011.

Year class	Survey year													
	2005		2006		2007		2008		2009		2010		2011	
	Age	CPUE	Age	CPUE	Age	CPUE	Age	CPUE	Age	CPUE	Age	CPUE	Age	CPUE
2011	—	—	—	—	—	—	—	—	—	—	—	—	—	—
2010	—	—	—	—	—	—	—	—	—	—	0	0.2	1	37.8
2009	—	—	—	—	—	—	—	—	—	—	1	20.0	2	12.9
2008	—	—	—	—	—	—	0	0.1	1	48.0	2	5.6	3	1.9
2007	—	—	—	—	—	—	1	28.9	2	26.9	3	4.4	4	0.3
2006	—	—	—	—	1	12.3	2	6.9	3	4.4	4	0.9	—	—
2005	0	0.4	1	16.1	2	8.9	3	3.1	4	0.9	5	0.3	6	0.1
2004	1	17.3	2	9.1	3	4.3	4	1.1	5	0.3	6	0.1	—	—
2003	2	24.0	3	4.8	4	2.2	5	0.6	6	0.3	7	0.1	—	—
2002	3	2.3	4	0.8	5	0.3	—	—	7	—	8	—	—	—
2001	4	1.8	5	0.4	6	0.3	7	0.1	—	—	—	—	—	—
2000	5	0.2	—	—	7	0.1	—	—	—	—	—	—	—	—
1999	6	0.1	—	—	—	—	—	—	—	—	—	—	—	—
1998	7	0.1	—	—	—	—	—	—	—	—	—	—	—	—
1997	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1996	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1995	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Number aged	417		281		339		449		645		285		423	
Mean age	1.8		1.7		1.9		1.5		1.5		1.6		1.3	
Total CPUE <sup>a</sup>		46.3		31.2		28.3		40.8		80.6		31.7		52.9

<sup>a</sup> Data based on aged subsample may differ from values reported in Table 15.

Table 25.—Catch-per-unit-of-effort (CPUE; catch per 335 m) by year class of Channel Catfish in fall gill-net survey catches, Saginaw Bay, Lake Huron, 2005–2011. Number of lifts represents those with Channel Catfish age data.

Year class	Survey year													
	2005		2006		2007		2008		2009		2010		2011	
	Age	CPUE	Age	CPUE	Age	CPUE	Age	CPUE	Age	CPUE	Age	CPUE	Age	CPUE
2011	—	—	—	—	—	—	—	—	—	—	—	—	—	—
2010	—	—	—	—	—	—	—	—	—	—	—	—	1	0.50
2009	—	—	—	—	—	—	—	—	—	—	—	—	2	0.13
2008	—	—	—	—	—	—	—	—	—	—	0.43	—	3	0.25
2007	—	—	—	—	—	—	1	0.18	—	—	3	2.43	4	1.00
2006	—	—	—	—	—	—	2	0.55	3	3.75	4	3.29	5	1.25
2005	—	—	1	0.09	2	1.40	3	1.18	4	2.50	5	2.57	6	1.50
2004	—	—	2	—	3	0.20	4	0.18	5	0.13	6	0.29	7	0.88
2003	—	—	3	0.55	4	1.10	5	0.91	6	0.63	7	0.43	8	0.25
2002	3	1.33	4	0.45	5	1.90	6	0.36	7	0.50	8	0.71	9	0.50
2001	4	1.00	5	0.18	6	1.20	7	0.18	8	0.25	9	0.14	10	0.25
2000	5	0.50	6	0.09	7	0.10	8	0.18	9	0.25	10	0.29	11	0.13
1999	6	1.67	7	0.82	8	0.90	9	0.73	10	0.50	11	0.29	12	0.25
1998	7	2.00	8	0.18	9	1.40	10	0.36	11	0.13	12	0.29	13	0.13
1997	—	—	—	—	—	—	11	—	—	—	13	0.29	—	—
1996	—	—	—	—	—	—	12	—	—	—	14	0.14	—	—
1995	—	—	—	—	—	—	13	—	—	—	15	—	—	—
1994	—	—	—	—	—	—	14	—	—	—	16	0.29	—	—
1993	—	—	—	—	—	—	15	—	—	—	17	—	—	—
1992	—	—	—	—	—	—	16	0.09	—	—	18	—	—	—
1991	—	—	—	—	—	—	—	—	—	—	19	0.14	—	—
Number aged	44		31		93		56		70		84		56	
Mean age	5.8		5.9		6.1		5.6		4.7		5.7		6.0	
Total CPUE <sup>a</sup>		7.33		2.82		9.30		5.09		8.75		12.00		7.00

<sup>a</sup> Data based on aged sample may differ from value reported in Table 15.



survey began in 1989. This is a value lower than that exhibited historically in the bay (-15.2, Table 18). Asymptotic length attained by Walleye did not change appreciably between the period 1998–2004 and the current reporting period (since 2005; Appendix E), however to fully assess time-varying growth requires analysis beyond that attempted here (He and Bence 2007).

Maturation schedule of female Walleye, however did change substantially. Age at 50% maturity of female Walleyes increased to 2.96 during the reporting period compared to 2.77 previously in the time series (Table 21). Wang et al. (2009) documented a comparable increase for Saginaw Bay female Walleyes for similar time periods (3.6 years old for the years 2007–2010, compared to 2.5 years old for years 1989–2006). The age differences between Wang et al. (2009) and this analysis may be more a product of methodologies, however, than due to time periods. Many of the fish scoring mature in our fall collections were likely first-time spawners the following spring. Such declines in growth and maturity during the recovery process also took place in Lake Erie (Muth and Wolfert 1986) and can stem from density-mediated effects. Likely this value will fluctuate as Saginaw Bay's Walleye population and prey base fully come to some new equilibrium.

Overall abundance of adult Walleyes peaked and leveled off in 2006 (Table 15). Year-class strength was consistently strong from 2002 through 2005 (Figure 7). Strong consecutive or frequent Walleye year classes are not the norm for Walleye populations (Nate et al. 2011), but may be seen in cases of initial recovery after being released from recruitment limitations as seen in Lake Erie's recovery (Hatch et al. 1987). Angler harvest and catch rate in the bay followed a similar trajectory of increase beginning in 2006, with the recruitment to the fishery of the strong 2003 year class (Fielder et al. 2014). Walleye year-class strength has become more variable since about 2005, possibly reflecting the onset of more density-dependent recruitment effects. Such effects can include competition for food resources and even cannibalism (Forney 1976; Nate et al. 2011).

Ivan et al. (2011) described a strong predicative relationship between age-0 Walleye abundance and older Walleyes (age-1 and -2) in the Saginaw Bay trawl, CPUE data series and concluded that catch rates of age-0 Walleye for years 1980–2008 (year classes 1980 to 2005) are suitable indicators of year-class strength. Our analysis demonstrated a similar predictive relationship between age-0 Walleyes (Table 5) for year-class strength (as indicated by mean CPUE of age-1 Walleyes in the gill-net series; Figure 7, Table 16) until 2003. After that year, year-class strength indexed at age-1 in gill net or by trawling was not predictable from age-0 abundance (1993-2002;  $R^2 = 0.93$ ,  $P < 0.0001$  vs. 2003-2011  $R^2 = 0.25$ ,  $P = 0.097$ ).

The lack of a significant relationship between mean length of age-0 Walleye and year-class strength also suggests that survival of age-0 Walleyes may be environmentally or ecologically mediated. Madenjian et al. (1996) documented a similar lack of relationship between growth of age-0 Walleyes and subsequent year-class strength of older Walleyes in Lake Erie and attributed it to a low incidence of cannibalism which appears to be the regulating mechanism in lakes that do exhibit such a relationship, based on the premise that slower-growing age-0 Walleyes should be vulnerable to predation for a longer period of time. Cannibalism was initially documented in Saginaw Bay in 2004 but has occurred in varying levels since. Some studies have found positive relationships between Walleye year-class strength and available prey. Madenjian et al. (1996) concluded that abundance of age-0 Gizzard Shad was an important determinant of Walleye year-class strength in Lake Erie, hypothesizing that the lipid-rich diet promoted more productive spawning by adult females. We found no evidence of such a correlation for Gizzard Shad or age-0 Yellow Perch in Saginaw Bay.

Emerging from this is an indication that there are two periods of recruitment to the population; first that of age-0 Walleyes in the fall (as measured by trawling) and secondly, recruitment of age-1 Walleyes in the fall the following year (after the first overwinter mortality period) as indicated by mean CPUE in gill nets. Fielder et al. (2007) established that trends in Alewife abundance had the greatest explanatory effect for the subsequent abundance of age-0 Walleyes. Ivan et al. (2011) demonstrated that age-0 Walleye mean trawl CPUE was a good indicator of year-class strength when comparing to

age-1 or age-2 Walleye mean CPUE also from the trawl series, by examining data up through 2008. This analysis began in 2003 using age-1 mean CPUE from the gill nets as the dependent variable and indicated that such a relationship is no longer the case. That connection held as it did for Ivan et al. 2011 until 2003, but not after. We suspect forces that are affecting year-class strength (age-1 abundance) have changed since the profound food web changes that began in 2003.

The disparity between fall abundance of age-0 Walleye and abundance of yearling Walleye the following fall are evident by such contrasts as the record-high yearling gill-net CPUE being documented in 2006 (2005 year class) when the same year class showed as only the third highest as age-0 the year before. The greatest age-0 Walleye CPUE from the trawl series occurred in 2009 but yielded the seventh lowest age-1 CPUE the following year (2010). What exactly is regulating recruitment of age-1 Walleyes in Saginaw Bay is now unclear. It is clear, however, that Alewives were a determinant of “reproductive success” as measured by trawl catch at age-0, but final year-class strength is being determined sometime between the first fall of life and the second fall of life (as age-1). It is not clear if this is the same source of mortality limiting Yellow Perch or something else. A more thorough investigation of the stock-recruitment relationship for Walleyes in Saginaw Bay is called for and it may necessitate additional years of data in this new paradigm before it is fully evident.

Trends in total annual mortality of Walleye are not immediately evident. Results of catch curve analyses (Table 22) suggest relatively low rates of ‘A’ before the year 2000, but the age structure was highly variable in those years and often did not conform to the typical structure of a catch curve with a declining age progression. Equal annual recruitment is an assumption of point-in-time catch curve methods and is not typically realistic for Saginaw Bay Walleyes. The cohort method of total annual mortality rate seeks to overcome that limitation, at the expense of being influenced by any temporal changes in catchability. Neither method results in true annual values but can depict large long-term changes. Both methods (Tables 22 and 23) hint at an increasing total annual mortality rate since 2004 with rates as great as 0.79. If correct, this suggests that, despite the increase in abundance, collective mortality forces have kept pace with the population expansion and perhaps have surpassed it. Fielder et al. (2014) identifies multiple fisheries that exploit the Saginaw Bay stock of Walleyes including commercial fisheries in Ontario waters of southern Lake Huron, tribal fisheries in northern Lake Huron, as well as recreational harvest in the main basin of the lake. MacMillan (2012) also demonstrated that commercial bycatch mortality of Walleyes in Saginaw Bay is substantial at certain times of the year.

## **Yellow Perch**

The Yellow Perch population in Saginaw Bay was characterized by high abundance, slow growth, and poor condition in the 1980s (Salz 1989; Haas and Schaeffer 1992). Fielder et al. (2000) reported that Yellow Perch abundance declined drastically after 1989 and was characterized by lower abundance and improved growth and condition through the late 1990s. At the same time, redworm (likely *Eustrongylides tubifex* and *Philometra cylindracea*) prevalence declined, and perch over 200 mm long became more common in trawl catches. Fielder and Thomas (2006) reported that Yellow Perch abundance remained relatively low through 2004, while growth generally improved, redworm infection rate declined, and consumption of zooplankton declined.

For the period from 2005 to 2011, Yellow Perch in Saginaw Bay have been characterized by strong age-0 cohorts but poor survival to ages 1 and older. As a result, abundance of age-1 and older Yellow Perch remains low compared with the 1970s and 1980s. Growth rates have continued to improve, particularly for ages 2 through 4, but no trend in condition has been apparent. The diet of Yellow Perch collected during the fall survey has shifted back to zooplankton and chironomid larvae.

Historically, Yellow Perch have been a major contributor to the recreational and commercial fisheries on Saginaw Bay. Over the past 25 years, the open-water sport fishery for Yellow Perch has changed

dramatically. From 1986 to 1995, anglers extracted from 1 million to over 5 million Yellow Perch from the Bay each year (Fielder et al. 2014). As recently as 1999, angler harvest exceeded a million Yellow Perch, but annual harvest declined thereafter. In fact, total harvest for anglers from 2007 to 2010 was less than 1 million Yellow Perch for all four years combined. Over the same 25-year period, the mean age of perch in the harvest declined from values greater than 4 years old, to recent values as low as 2.3 years. The commercial fishery harvest of Yellow Perch also has reached new lows in recent years, as five of the lowest annual yields have been recorded since 2005 (Fielder et al. 2014). The changes observed in the recreational and commercial fisheries since the mid-1980s align with our survey trends of lower adult Yellow Perch abundance and improved Yellow Perch growth in recent years.

Why has Yellow Perch abundance remained low since 1990? First, age-0 production was poor in many years from 1990 to 2002, resulting in low numbers of age-1 and older fish in the population. Since 2003, age-0 production has been strong, but our results suggest that survival beyond age 0 has declined dramatically in the post-Alewife collapse period. Smaller Yellow Perch have been observed to experience lower overwinter survival due to increased predation and lower energy reserves (Post and Prankevicius 1987; Post and Evans 1989). Mean length of age 0 Yellow Perch in the post-Alewife collapse period was significantly lower than during the post-dreissenid invasion period but not different from the pre-dreissenid invasion period. For some post-Alewife collapse period cohorts, such as in 2003 and 2004, we believe survival was reduced by the unusually small size of the fish. We view the strong Walleye cohort produced since 2003, in combination with a pronounced Walleye diet shift from Alewife to Yellow Perch, as strong circumstantial evidence that Walleye predation has become a controlling factor in Yellow Perch survival beyond age 0. Similarly, based on dynamic factor analysis and correlation analysis of our Saginaw Bay Walleye and Yellow Perch trawl catch data, Ivan et al. (2011) speculated that increases in both Walleye predation and Yellow Perch overwinter mortality have likely contributed to reduced abundance of adult Yellow Perch in the Bay.

The estimate of mean annual Yellow Perch survival in Saginaw Bay during the post-Alewife collapse period (0.35, Figure 4) was on the low end of the range of those reported from other areas of the Great Lakes. Yellow Perch in the Les Cheneaux Islands (northern Lake Huron) experienced a survival rate ranging from a high of 0.68 in 1989 to a low of 0.15 in 2000 (Fielder 2010). Zorn and Schneeberger (2011) estimated mean annual survival for Little Bay De Noc Yellow Perch at 0.45 for 1988 through 2005. Thomas and Haas (2005) reported annual survival for Yellow Perch in the western basin of Lake Erie at 0.57 based on catch-age model estimates. Our survival estimates, based on catch curve analyses, suggest that survival of Yellow Perch from ages 1 through 6 declined during the post-dreissenid invasion period and then declined even further after the Alewife collapse in 2003, especially for ages 1 through 4. Sex ratio data indicated female Yellow Perch experienced higher mortality rates than males for ages 2 through 5 during the post-dreissenid invasion period. However, after 2003, males have experienced higher mortality rates than females for ages 2 and 3, then lower mortality rates than females for ages 4 and 5. Female Saginaw Bay Yellow Perch exhibit faster growth than males for a given age. A pattern of increased mortality on faster growing fish is well known in exploited fish populations (Ricker 1969; Parma and Deriso 1990; Machiels and Wijsman 1996; Sinclair et al. 2002) including Yellow Perch (Wilberg et al. 2005). We suspect that fishing (both recreational and commercial) could be a factor in the skewed male to female sex ratio for ages 4 and older. However, Walleye predation may be the principal factor in the higher mortality rate for slower growing males at ages 2 and 3.

### ***Channel Catfish***

Catch rates of Channel Catfish in the current time series as indicated by gill-net CPUE (Table 15) have trended significantly lower (Mean CPUE of 4.9) than those reported for 1998–2004 (Mean CPUE of 10.4; Mann-Whitney U,  $P < 0.0001$ ). This lower abundance level, however, was not unprecedented as they were similarly less abundant during the early 1990s (Fielder et al. 2000). The period of greater

Channel Catfish abundance of the late 1980s and early 1990s that prompted commercial fishermen to seek an expansion in their harvest (Haak 1987) appears to be over. Changes in market demand for Saginaw Bay Channel Catfish in concert with lower abundances has led to lower harvest levels (Fielder et al. 2014). Lower abundance of catfish has not expressed itself as improved growth rates (Table 26) as this species continues to grow below the state average. Rates of total annual mortality of Channel Catfish (Tables 22 and 23) exhibit little change compared to rates reported in the 1980s, which ranged from 0.35 to 0.48 (Haak 1987), although the lower abundance in recent years has resulted in too few specimens to estimate mortality rates with sufficient confidence especially for the cohort method (Table 23).

### ***Smallmouth Bass***

Abundance of Smallmouth Bass is difficult to fully assess with gill-net or trawl gear. Consequently their exact trends in Saginaw Bay are unknown. Mean gill-net CPUE increased significantly from 1998–2004 (mean 0.09) to 2005–2011 (mean 0.35; Mann-Whitney U;  $P = 0.049$ ). Sample sizes are too low to permit additional analyses but it appears this species may be one benefitting from the recent paradigm shift in the food web of Lake Huron.

### ***Prey Fish Base***

From 2005 to 2011, Saginaw Bay continued to support a diverse and abundant assortment of native and invasive fish species that served as potential prey for piscine and avian predators. However, the mix of forage species available for predators has changed in recent years. Since 2004, Alewives have been essentially extirpated in Saginaw Bay. The invasive Round Goby has become an established component of the prey base with Walleyes, Freshwater Drum, Channel Catfish, and Yellow Perch all using Round Gobies in their diets (Fielder and Thomas, 2006). Rainbow Smelt, another long-established naturalized species, has declined in abundance since the Alewife collapse. Similarly, the native Spottail Shiners and Trout-perch have also declined in abundance during the post-Alewife collapse period. These declines may be attributed to increased predation from the larger Walleye population in the bay, although Trout-perch have been very rarely observed in any Saginaw Bay predator stomachs. Increased mean total length noted for Gizzard Shad, Trout-perch, and White Perch in the post-Alewife crash period may be an artifact of increased size-selective predation by Walleye and Yellow Perch. Gizzard Shad and Emerald Shiners, were much less abundant in the trawl catches than the benthic forage species, likely in part because they were underrepresented by bottom trawls and probably make up a significant fraction of the available pelagic prey base. Spiny-rayed forage was also well represented by age-0 White Perch and age-0 Yellow Perch in most years. The Saginaw Bay prey base was underused from the 1970s through the 1990s and Walleye restoration has been a tool to improve the predator-prey balance of the fish community (Keller et al. 1987; Haas and Schaeffer 1992; Fielder and Baker 2004). Our survey results suggest that the prey fish component of the Saginaw Bay fish community remains diverse, but overall abundance has declined since 2003. We submit that the decreased growth rates observed for Walleye are a function of an improved predator/prey balance in Saginaw Bay.

### ***Ecological and Food-web Changes in Saginaw Bay***

It is difficult to determine from these fish community data if the description of a nearshore productivity shunt (Hecky et al. 2004) has played out to the benefit of Saginaw Bay fish species. What is clear is that certain species are benefitting from the ecological changes that have characterized Lake Huron since 2003. Most notable of these are percids with their increased reproductive success. The failure of this rise in reproduction to translate to strong Yellow Perch year classes is curious, however. It

is not unusual for Walleye to feed upon Yellow Perch (Chipps and Graeb 2011), but historically Saginaw Bay sustained abundant, viable fisheries for both Walleye and Yellow Perch (Baldwin and Saalfeld 1962). Although poor Yellow Perch recruitment may trace to more than just Walleye predation, the current dilemma points to some other ecological dysfunction that persists in Saginaw Bay, something independent of reproduction.

A predator can be sustained by both primary and secondary prey resources such that the abundance of a predator may be decoupled from the density of the secondary prey. In such cases, more typical functional predator-prey responses between the two may not be reflected. The phenomenon might be where a predator's abundance is tied to a primary prey but also feeds on a secondary prey at certain times of year. The predator can then drive the secondary prey to extremely low levels without any negative effect on their own abundance as long as the primary prey source persists. This is described as compensatory mortality by Hilborn and Walters (1992) and might account for how predation by Walleye and other species can drive Yellow Perch to low abundance without any consequences for the predator populations. Walleye predation has been identified as an impediment to Yellow Perch recruitment in other locations too (Johnson et al. 1992).

What is most striking about the new paradigm and food web in Lake Huron is the decline, of pelagic production in the form of prey fishes (Bence et al. 2008b). For Saginaw Bay, this has mostly manifested itself in the loss of pelagic prey fishes using the bay for spawning and nursery grounds. It is apparent that juvenile Alewives used to be an important dietary component for Walleye (Fielder et al. 2000; Fielder and Thomas 2006). Before Alewives, Cisco likely played the same ecological role, drawing productivity from the main basin and infusing that in Saginaw Bay in the form of juveniles using the bay as nursery grounds. It may be that these species formed important predation buffers on bay resident species such as Yellow Perch, and that to have good Yellow Perch recruitment in the face of a large Walleye population, that this linkage of the bay's food web to the main basin's pelagic zone needs to be intact. In the face of a broken linkage between the main basin and the bay, Yellow Perch have become a dietary staple for Walleye and perch recruitment failures may be the resulting consequence. This scenario is offered here as a speculative but useful working hypothesis. It stands to reason that the historic fish communities of the nearshore zone (locations like Saginaw Bay) and the main basin of the lake evolved with a sympatric relationship or mutual dependence. An extension of this concept says that the ongoing extirpation of Cisco in Saginaw Bay and most of the rest of Lake Huron, doesn't just express itself in the form of lost fishing opportunity, but in an ecological break down with consequences for other species. It remains unclear if other newer invasive species such as gobies might provide the same buffer, but given that they appear to have not achieved that status since 2003, it seems unlikely that they will in the future.

## Recommendations

1. We urge managers and researchers to work together to take steps to establish fishery and population goals for Yellow Perch in Saginaw Bay and strategies to achieve them. Abundance of harvestable-size Yellow Perch in the Bay has been low for more than 20 years and corresponding recreational and commercial harvests have similarly plummeted. Declining recruitment and failure of the perch population to realize any improvements as a result of strong age-0 production nearly every year since 2003, suggest adult abundance will remain low. Specific information needs and further investigations might take the form of:
  - a. Biological data collection on the commercial catch of Yellow Perch on an annual basis to better characterize that fishery and enable modeling.
  - b. Better define stock status including mortality sources via a stock assessment model for Yellow Perch in Saginaw Bay.

2. Develop and implement recovery plans for Cisco and Lake Sturgeon for Saginaw Bay to restore these historically important species and the ecological processes that may depend on them.
3. Conduct a formal analysis of the stock-recruitment relationship for age-1 Walleyes as the indicator of year-class strength. Fielder et al. (2007) established the stock-recruitment relationship for age-0 Walleyes, but it now appears that year-class strength isn't established until sometime after their first fall of life.
4. Annually model the variation of von Bertalanffy growth parameters for Walleye and relate those to potential management actions. Walleye growth continues to change and additional detailed analyses to improve management decisions are needed.
5. Discontinue aging Channel Catfish for this survey series. The collection of spines and subsequent age determination yields little management information given the declining sample size (lower abundance of Channel Catfish) and the declining interest by commercial fishermen. Field and lab resources are better applied to other endeavors.
6. Continue the fall gill-net and trawl surveys to facilitate science-based management of the Saginaw Bay fish community.

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Appendix A.—Common and scientific names of fishes and other aquatic organisms mentioned in this report.

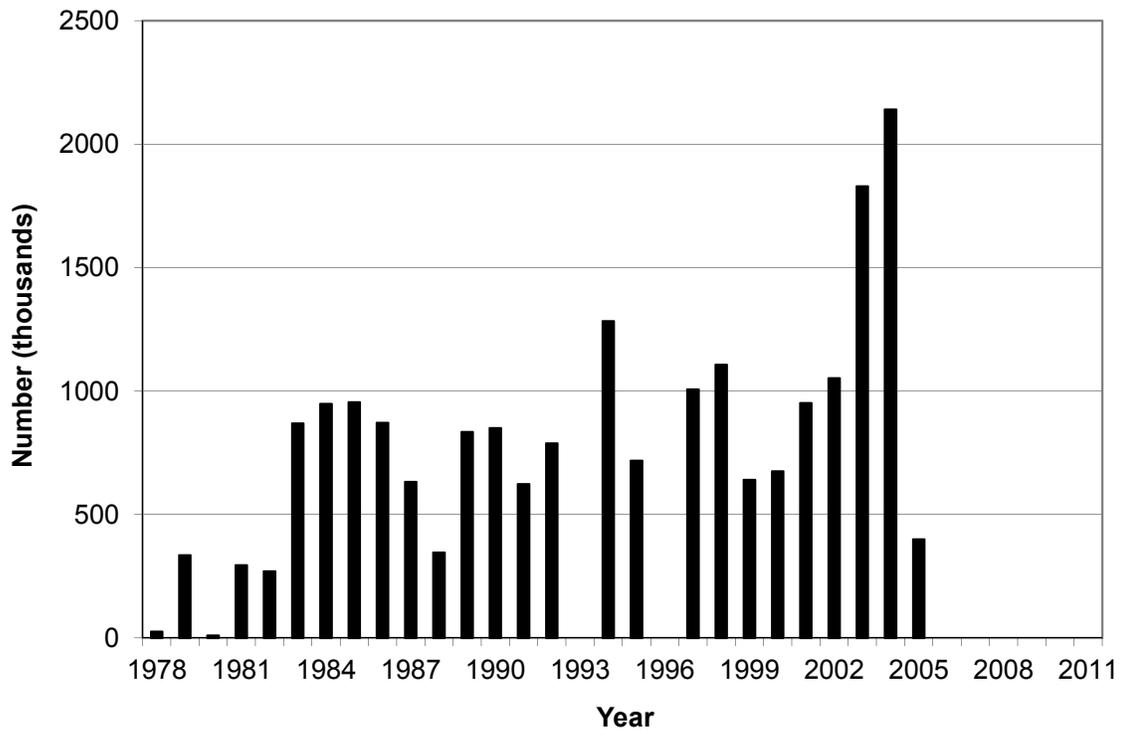
Common name	Scientific name
Alewife	<i>Alosa pseudoharengus</i>
Black Crappie	<i>Pomoxis nigromaculatus</i>
Bloater	<i>Coregonus hoyi</i>
Bowfin	<i>Amia calva</i>
Brook Trout	<i>Salvelinus fontinalis</i>
Brown Bullhead	<i>Ameiurus nebulosus</i>
Brown Trout	<i>Salmo trutta</i>
Burbot	<i>Lota lota</i>
Carp	<i>Cyprinus carpio</i>
Channel Catfish	<i>Ictalurus punctatus</i>
Chinook Salmon	<i>Oncorhynchus tshawytscha</i>
Cisco	<i>Coregonus artedi</i>
Coho Salmon	<i>Oncorhynchus kisutch</i>
Freshwater Drum	<i>Aplodinotus grunniens</i>
Gizzard Shad	<i>Dorosoma cepedianum</i>
Lake Trout	<i>Salvelinus namaycush</i>
Lake Whitefish	<i>Coregonus clupeaformis</i>
Longnose Dace	<i>Rhinichthys cataractae</i>
Longnose Gar	<i>Lepisosteus osseus</i>
Longnose Sucker	<i>Catostomus catostomus</i>
Menominee	<i>Prosopium cylindraceum</i>
Muskellunge	<i>Esox masquinongy</i>
Northern Pike	<i>Esox lucius</i>
Pink Salmon	<i>Oncorhynchus gorbuscha</i>
Quagga mussels	<i>Dreissena bugensis</i>
Rainbow Smelt	<i>Osmerus mordax</i>
Rainbow Trout	<i>Oncorhynchus mykiss</i>
Redhorse spp.	<i>Moxostoma</i> spp.
Rock Bass	<i>Ambloplites rupestris</i>
Round Goby	<i>Neogobius melanostomus</i>
Sculpin	<i>Cottus bairdi</i>
Smallmouth Bass	<i>Micropterus dolomieu</i>
Splake	<i>S. fontinalis</i> x <i>S. namaycush</i>
Spottail Shiner	<i>Notropis hudsonius</i>
Stickleback spp.	<i>Pungitius</i> or <i>Gasterosteus</i> spp.
Sunfish spp.	<i>Lepomis</i> spp.
Trout-perch	<i>Percopsis omiscomaycus</i>
Walleye	<i>Sander vitreus</i>
White Perch	<i>Morone americana</i>
White Sucker	<i>Catostomus commersonii</i>
Yellow Perch	<i>Perca flavescens</i>
Zebra mussels	<i>Dreissena polymorpha</i>

Appendix B.—Mean CPUE (number of fish per 10-minute sample) for common species collected during fall bottom trawling in Saginaw Bay, 1971–2011, including data previously reported by Weber (1985), Haas and Schaeffer (1992), Fielder et al. (2000). NA = data not available for that year.

Survey year	Species																					
	Alewife	Channel Catfish	Common Carp	Emerald Shiner	Freshwater Drum	Gizzard Shad	Johnny Darter	Lake Whitefish	Quillback	Rainbow Smelt	Rock Bass	Round Goby	Shorthead Redhorse	Spottail Shiner	Trout-perch	Walleye	White Bass	White Perch	White Sucker	Yellow Perch	Number of tows	
1971	126	1	2	4	0	3	NA	NA	NA	392	NA	0	NA	94	45	0	0	0	1	196	30	
1972	109	1	4	3	0	1	NA	NA	NA	375	NA	0	NA	419	100	0	0	0	1	151	15	
1973	3	3	2	0	0	2	NA	NA	NA	287	NA	0	NA	16	11	0	0	0	1	104	17	
1974	8	14	9	1	0	22	NA	NA	NA	139	NA	0	NA	192	120	0	0	0	1	256	30	
1975	22	17	2	1	1	17	NA	NA	NA	220	NA	0	NA	435	47	0	0	0	1	573	20	
1976	41	1	1	0	0	370	NA	NA	NA	780	NA	0	NA	94	9	0	0	0	0	272	20	
1977	13	1	2	19	1	4	NA	NA	NA	65	NA	0	NA	449	28	0	0	0	9	392	21	
1978	72	1	1	0	0	147	NA	NA	NA	499	NA	0	NA	563	25	0	0	0	5	286	18	
1979	353	4	3	1	1	5	NA	NA	NA	337	NA	0	NA	712	177	0	0	0	9	661	18	
1980	84	11	1	0	1	48	NA	NA	NA	802	NA	0	NA	442	45	0	0	0	1	703	20	
1981	289	5	3	0	0	3	NA	NA	NA	98	NA	0	NA	849	56	0	0	0	5	393	17	
1982	127	1	0	3	4	2	NA	NA	NA	266	NA	0	NA	212	30	1	3	0	15	1,319	13	
1983	1,030	1	1	54	11	39	NA	NA	NA	58	NA	0	NA	1,237	255	0	0	0	7	384	17	
1984	58	3	1	3	8	7	NA	NA	NA	250	NA	0	NA	787	148	0	10	0	14	444	12	
1985	18	3	1	11	15	11	NA	NA	NA	202	NA	0	NA	165	315	2	4	1	6	362	24	
1986	304	3	6	242	17	11	3	0	0	366	0	0	0	285	157	1	13	11	6	420	46	
1987	57	4	3	42	4	29	3	0	2	210	0	0	0	470	167	1	1	58	6	476	67	
1988	86	4	5	55	1	41	3	0	7	176	0	0	0	107	54	3	10	168	4	258	38	
1989	226	2	6	57	9	169	0	0	1	221	0	0	0	340	232	3	3	2,321	3	799	15	
1990	16	5	5	45	23	46	1	0	0	48	0	0	0	198	135	2	4	682	11	151	16	
1991	81	0	3	15	25	49	1	0	0	44	0	0	0	124	166	6	6	412	12	192	16	
1992	302	0	3	9	3	0	11	0	0	280	0	0	0	182	200	1	0	92	8	75	36	
1993	226	1	3	1	10	20	11	0	1	562	0	0	0	101	438	1	2	30	11	41	37	
1994	48	6	9	0	28	9	11	0	1	58	0	0	0	203	513	2	6	183	10	24	32	
1995	307	3	7	0	28	7	29	1	1	22	0	0	0	373	513	1	1	528	7	125	33	
1996	99	6	4	1	16	23	21	0	1	15	0	0	0	209	474	1	0	277	8	85	30	

Appendix B.—Continued.

Survey year	Species																				
	Alewife	Channel Catfish	Common Carp	Emerald Shiner	Freshwater Drum	Gizzard Shad	Johnny Darter	Lake Whitefish	Quillback	Rainbow Smelt	Rock Bass	Round Goby	Shorthead Redhorse	Spottail Shiner	Trout-perch	Walleye	White Bass	White Perch	White Sucker	Yellow Perch	Number of tows
1997	301	2	4	13	5	18	20	1	0	1,585	0	0	0	808	741	3	4	416	28	122	31
1998	1,592	3	8	2	28	23	5	0	0	50	0	0	0	549	1,175	7	2	303	11	149	27
1999	82	5	6	1	9	3	6	0	4	32	5	4	0	1,935	406	7	0	141	10	87	27
2000	363	7	6	1	18	3	4	0	1	433	0	137	0	1,019	685	2	0	984	7	39	30
2001	1,101	8	8	1	10	10	1	0	4	349	0	306	0	691	411	2	0	600	22	157	25
2002	369	5	6	1	12	20	0	1	2	161	0	368	0	1,036	439	4	0	330	28	70	35
2003	733	3	5	1	10	18	0	0	4	449	0	156	0	1,367	545	44	14	502	42	2,471	27
2004	9	1	6	2	7	2	0	1	1	213	0	365	0	213	450	28	40	287	19	490	36
2005	1.6	0.9	5.6	8.3	21.6	1.9	0	1.2	1.2	131.5	0	278.3	0	271.3	187.3	37	21.3	252.9	25.1	286.7	27
2006	1.2	0.9	10.7	9.2	14.2	11.7	0	0	1.1	5.7	0	30.6	0.1	313.8	304.1	14	2	491	8.5	96.4	27
2007	0	0.5	8	10.6	16.7	10.5	0	0	1.5	65.5	0	151.3	0	311	425.8	17.9	6.5	851.4	9	121.4	33
2008	0	0.4	4.9	34.3	9.5	30.6	0	0.1	1.5	26.3	0.1	523.4	0.1	165.6	268.8	11.8	7.3	646	4.1	226.7	37
2009	0.1	0.2	3.8	1.9	3.7	15.6	0	1.4	0.4	50.5	0	297	0.1	91.8	263	68.7	14.1	73.9	7.5	391.2	24
2010	0	0.4	3.7	0.5	5.6	6.6	0	0.7	0.7	5.7	0	209.1	0	86.6	297	36.1	12.3	452.5	5.3	240.1	24
2011	0	0.6	3.9	10.6	19.3	15.3	0	0.1	0.9	500.6	0.1	123.5	0.1	228.3	383.9	35	13.8	238.6	9.6	202.3	27



Appendix C.—Walleye fingerling stocking in Saginaw Bay by the Michigan Department of Natural Resources 1978–2011. Fingerlings were pond-reared “spring fingerlings” approximately 42 mm in total length. Stocking was discontinued in 2006.

Appendix D.—Year class composition (percent identified as hatchery fish as opposed to wild fish) of Walleye from Saginaw Bay for year classes 1997–2011 as determined by oxytetracycline mark detection analysis for two ages of juveniles. Stocking was discontinued in 2006.

Year class	Age-0	Age-1	Composite
1997	81	50	69
1998	81	83	82
1999	85	84	85
2000	96	94	95
2001	61	61	61
2002	85	91	88
2003	28	21	24
2004	19	17	18
2005	8	—	8
2006	0	0	0
2007	0	0	0
2008	0	0	0
2009	0	0	0
2010	0	0	0
2011	0	0	0

Appendix E.—Length-weight regression equations and von Bertalanffy growth equations for select species. Length/weight equations are based on data pooled for 2005–2011 from the fall gill-net collections in Saginaw Bay, Lake Huron. Length/weight equation Logs are base 10, weight (wt) is in grams, and length (len) is in mm. Von Bertalanffy equations are based on mean length-at-age data from the fall gill-net collections 2005-2011 (pooled data) where ‘t’ is age in years.

Species	Length/Weight Equation	Len/Wt R <sup>2</sup>	Von Bertalanffy Equation	K	L <sub>∞</sub>	t <sub>0</sub>
Walleye	log(wt)=3.104 log(len)-5.334	0.98	L <sub>t</sub> =638[1-e <sup>-0.2056(t+0.09)</sup> ]	0.2056	638	-0.09
Yellow Perch	log(wt)=3.119 log(len)-5.184	0.91	L <sub>t</sub> =291[1-e <sup>-0.5325(t+0.73)</sup> ]	0.5325	291	-0.73
Channel Catfish	log(wt)=3.031 log(len)-5.131	0.91	L <sub>t</sub> =588[1-e <sup>-0.2045(t+0.79)</sup> ]	0.2045	588	-0.79