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Status and Trends of the Fish Community of Saginaw Bay, Lake Huron 2018–2022

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Status and Trends of the Fish Community of Saginaw Bay, Lake Huron 2018–2022

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ABSTRACT

Bottom trawling and gillnetting are used to gauge the status of various fish populations that comprise the Saginaw Bay fish community in this survey series dating back to 1971. Reproductive success of Walleye *Sander vitreus* and Yellow Perch *Perca flavescens* has remained strong during 2018–2022 and is attributed to the ongoing absence of the invasive Alewife *Alosa pseudoharengus*. The reproductive success of Walleye is driving high abundance of that species, but age-0 Yellow Perch are not surviving to age-1 in sufficient numbers to sustain its fishery. Interannual mortality rates between age-0 and age-1 for Yellow Perch have averaged 85% since 2003, attributed principally to predation by Walleye and other predators. Walleye continue to grow slightly faster than the state average rate and close to the management target set for age-3 Walleyes. Total annual mortality rate of Walleye ranged from 0.43 to 0.49 for the reporting period. Total annual mortality rate of adult Yellow Perch ranged from 0.58 to 0.60. Walleye year class strength continues to be set at age-2. The age of 50% maturity for female Walleyes is approximately 2.9 years. Onset of maturity has become later as the population has expanded and growth rates slowed. The forage fish index increased over 2012–2017, but gains were driven by increases in single species in most years. Cisco restoration efforts are underway in Saginaw Bay, but none have been encountered in this survey series. Three Lake Sturgeon were captured during this reporting period, the first since the survey series began in 1971.

INTRODUCTION

Saginaw Bay is a distinctive feature of Lake Huron, located entirely in the Michigan waters of the lake. The bay spans a surface area of 2,960 km^2 and reflects a 14,000 km^2 watershed spanning 22 counties, the largest drainage basin in Michigan (Selzer et al. 2014). The inner and outer bays are defined by a line between Point Au Gres and Sand Point (Figure 1) and the bay roughly corresponds to Michigan Department of Natural Resources (MDNR's) Lake Huron management unit 'MH4'. Land use in the watershed is a mixture of industry and agriculture, but there are also large tracts of forested areas (Johnson et al. 1997). There are several tributary systems to the bay, the largest being the Saginaw River collection of tributaries. Water in Saginaw Bay loosely circulates in a counterclockwise direction (Beeton et al. 1967; Danek and Saylor 1977) and the flushing rate is approximately once every 186 days (Beeton et al. 1967; Keller et al. 1987).

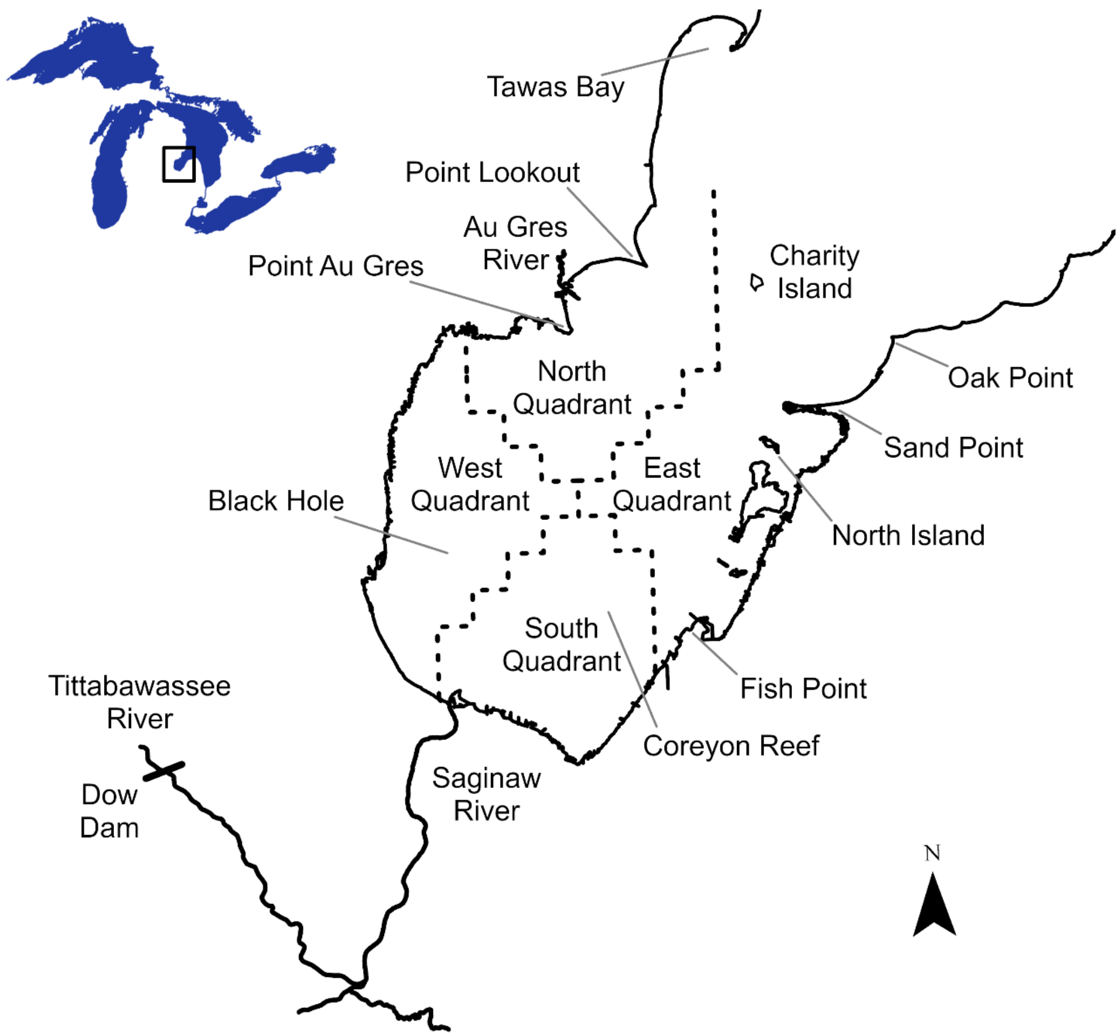

FIGURE 1. Saginaw Bay gillnet sampling stations and trawling quadrants. Gillnet stations are listed by name and include Black Hole, Coreyon Reef, Fish Point, North Island, Oak Point, Charity Island, Point Au Gres, and Tawas Bay.

The inner portion of Saginaw Bay is generally regarded as eutrophic with productivity declining towards the outer bay region (Beeton et al. 1967; Johengen et al. 2000; Smith et al. 1977). The inner bay is shallow, averaging 4.6 m in depth, while the outer bay depth averages 14.6 m. The bay is shallower and more productive than the main basin of Lake Huron (Beeton et al. 1999; Nicholls et al. 2001) therefore, it is typically warmer and thus hosts a fish community that is very different from the rest of the lake. Saginaw Bay principally reflects a cool- to warm-water fish community while the main basin is more typically known for its cold-water habitat (Dobiesz et al. 2005).

The first use of Saginaw Bay's fisheries resources was undoubtedly by Native Americans who inhabited the region for millennia. After European colonization (Lanman 1839; Bogue 2000) a commercial fishery emerged in the early 1800s and harvest records from that period constitute some of the first records of the fish community. Walleye have been central to the fish community of Saginaw Bay (see Appendix 1 for a complete list of common and scientific names of fishes mentioned in this report) as the apex predator (Schneider and Leach 1977; Keller et al. 1987; Fielder and Thomas 2014). Historically, the Walleye commercial fishery that existed in the bay was second in the Great Lakes to only that of Lake Erie, averaging more than 495 metric tons in yield per year (Schneider and Leach 1977; Baldwin et al. 2009). Other key fisheries included those for main basin species such as Cisco, Lake Whitefish and Lake Trout that used Saginaw Bay seasonally as a spawning and nursery ground (Baldwin et al. 2009; Goodyear et al. 1982; Organ et al. 1979).

The Saginaw Bay Walleye commercial fishery collapsed in the mid-1940s stemming from a series of year class failures attributed to degraded spawning reef habitat, and the construction of dams. Dams impede the migration of some spawning fishes (Hayes 2013); 300 dams are still present in the watershed today (Fielder and Baker 2004). The bay also experienced the effects of invasive species during this time (U.S. Fish and Wildlife Service 1969, cited by Schneider and Leach 1977), especially the invasive Alewife which are predators and competitors on newly hatched Walleye and Yellow Perch fry (Brooking et al 1998; Kohler and Ney 1980; Brandt et al. 1987). Another factor driving or hastening the collapse of Walleye was relatively intensive commercial exploitation. Other notable fisheries, including Cisco, also collapsed during this time. Yellow Perch, another important species with commercial harvest averaging 887 metric tons per year (1891–1970) greatly declined but did not fully disappear (Baldwin et al. 2009). These fisheries remained collapsed or depressed for decades. The commercial fishery for Walleye was formally closed in 1970 due to concerns over mercury toxicity but the fishery had already been functionally nonexistent for the previous 25 years. The second half of the twentieth century was marked by further environmental degradation in Saginaw Bay, particularly water pollution (Dempsey 2001).

Improvement and the foundation for recovery began with the passage of the Clean Water Act of 1972 and the Great Lakes Water Quality Agreement of 1978 (Haas and Schaeffer 1992; Fielder and Baker 2004). While Walleye fry stocking had been attempted for many decades, it wasn't until the MDNR began to achieve success with pond rearing of small spring fingerlings that stocking had a beneficial effect (Haas and Schaeffer 1992). A recreational fishery for

Walleye emerged in the early 1980s as a result (Ryckman 1986; Fielder et al. 2014). Marking of stocked fish with Oxytetracycline hydrochloride demonstrated that on average, 80% of year classes were fish of hatchery origin between 1997 and 2003 (Fielder 2002; Fielder and Thomas 2006).

The Saginaw Bay recreational fishery averaged an annual year-round harvest of 79,567 Walleye between 1986 and 2002. Recreational harvest of Yellow Perch averaged 1,626,501 during the same period (Fielder et al. 2014). Commercial Yellow Perch yield was 87.5 metric tons per year on average for the same time period. A Walleye recovery plan that laid out strategies and measurable metrics to define recovery was developed in the 1990s and formally adopted in the early 2000s (Fielder and Baker 2004). Despite early gains and planning efforts, Walleye recovery didn't occur until profound food web changes emerged in Lake Huron in 2003 (Riley et al. 2008; Riley and Roseman 2013). Within a single year, the invasive Alewife, which has been the backbone of the lakes prey base for more than 70 years, collapsed. The disappearance was attributed to a combination of bottom-up forces stemming from the effects of invasive dreissenid mussels and the loss of macroinvertebrates (Barbiero et al. 2011) and top-down effects of excessive predation by piscivorous fish (He et al. 2015). The absence of Alewives and substantial declines in Rainbow Smelt allowed reproduction of several key native species to explode, apparently due to their release from the deleterious effects of these invasive species (Fielder et al. 2007). Walleye natural reproduction soared and stocking was discontinued in 2006. The recreational harvest and harvest rate of anglers increased 238% and 387%, respectively. Formal recovery targets were met in 2009 and population estimates of the Saginaw Bay stock of Walleye exceeded 10 million age-2+ fish in 2023 (MDNR unpublished data). The stunning recovery is one of the great fisheries recovery stories of the Great Lakes (Fielder and Baker 2019).

The success of Walleye in Saginaw Bay was not mirrored by Yellow Perch, however. Yellow Perch exhibited a similar surge in reproductive success, but it didn't translate into recruitment. Poor recruitment of Yellow Perch was attributed to high mortality between age-0 and age-1 due to heavy predation (Fielder et al. 2022). In 2015, in an effort to reduce predation on juvenile Yellow Perch, the MDNR instituted liberalized recreational harvest regulations for Walleye fishing in Saginaw Bay. This included an increased daily possession limit from 5 to 8 Walleye and a reduction in the minimum length limit from 381 to 330 mm. By 2023, those efforts to increase survival of juvenile Yellow Perch had not been realized despite some increased Walleye harvest. As the Walleye stock size decreased, large year classes were produced which kept overall abundance high. In light of this, a new recreational management plan for Walleye and Yellow Perch was developed with a new vision and goals that emphasize the sustainability of Walleye and no longer recommended the use of Walleye management to decrease predation on Yellow Perch (Jolley et al. 2024).

Other recent fishery management efforts in and around Saginaw Bay have included a Lake Sturgeon stocking program in the Saginaw River system of tributaries with a target of 2,000 fingerlings released each year since 2018 (ECCC and USEPA 2022). An interagency initiative has also been underway since 2018 to reintroduce Cisco to central Lake Huron using Saginaw Bay as a stocking site. The target is to release 1 million Cisco fingerlings reared by the U.S. Fish and Wildlife Service (USFWS) into Saginaw Bay each year for 10 years (LHTC 2007). Lastly, a recent fishery assessment has highlighted the importance of Saginaw Bay as a production source for Lake Whitefish in Lake Huron possibly constituting the principal source of recruitment for much of the main basin (Ebener et al. 2021).

Regular fishery assessment of the Saginaw Bay fish community is fundamental to informing efforts to develop management initiatives and gauge their progress. Recurring measurements of trends in abundance are needed across most species, including recreationally and commercially important species, the forage base, and nongame species as well. Such a fishery-independent survey provides important information on the status and trends in the fish community as well as a different perspective than those of fishery-related assessments such as the recreational creel survey and commercial harvest reporting, both of which take place in Saginaw Bay annually. These data (both from the fishery and the fish community) enable mathematical modeling of fish populations and their fisheries to generate important metrics and measurements associated with their status that inform management decision making.

The fishery-independent assessment of the Saginaw Bay fish community began in 1971 with a bottom trawling survey. Recognizing that trawling omitted some of the larger members and species of the fish community, a variable mesh gillnetting component was added in 1989. The objectives of this survey and the report herein 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 the development of new ones. Although the Saginaw Bay fish community assessment dates to 1971, this report focuses primarily on the more contemporary survey results. Summarized results from additional survey years are provided in the supplementary material. To accommodate readers viewing a printed version of this article, the URL for the supplementary material is https://www2.dnr.state.mi.us/publications/pdfs/DNRFishLibrary/FisheriesReports/FR045_supp_material.xlsx.

It is recognized that the greatest ability to characterize the status and trends of the Saginaw Bay fish community and its fisheries comes through integration of information sources including other surveys, reporting, and modeling efforts. It is necessary, however, to periodically report on the findings of individual components of the various surveys by condensing the data into the most useful summaries and archiving them for use by others. This report is that effort and some of the summaries include time series from earlier years of the survey work, which in turn trace to past publications such as Weber 1985 (summary of trawling results through 1984), Haas and Schaeffer 1992 (updated trawling results through 1989), Fielder et al. 2000, Fielder and Thomas 2006, and Fielder and Thomas 2014 (trawling and gillnetting results through 2011), and Fielder et al. 2022 (most recent survey results through 2017).

METHODS

Trawling

Bottom trawls have proven to be an effective gear for sampling prey species and all ages of Yellow Perch in Saginaw Bay since the first trawl survey was completed in 1971. Since the 1980s, trawling locations in the inner bay have been based on a 2-minute latitude x 2.8-minute longitude grid system. Fish samples were collected during daylight hours between September 6th and 25th of each year by the MDNR Research Vessel *Channel Cat* from four fixed index grids in the inner bay: Au Gres (north quadrant), Pinconning (west quadrant), North Island (east quadrant), and Coreyon Reef (south quadrant) (Figure 1). The Au Gres index grid is located near the city of Au Gres, and conditions there more closely resemble those of the less eutrophic outer bay. The Pinconning index grid is located at a bottom depression known locally as the "Black Hole." This grid, 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 index grid is located off Wildfowl Bay, a shallow sub-bay that serves as a nursery area for many fish species. The Coreyon Reef index grid is located on a sandy flat that was once an important spawning area and is now in proximity to a restored portion of the reef. Prior to 2016, three replicate trawl tows were conducted at each of the fixed stations and three more replicates at an additional randomly selected grid in each quadrant for a total of 24 tows each year. Beginning in 2016, six separate grids per quadrant were sampled with a single trawl tow. One of which was completed at the index grid in each quadrant. The other five grids in each quadrant were randomly selected. This resulted in equal effort each year (24 trawl tows), better spatial representation, and avoidance of unintended cluster designs, which in turn led to improvements to the analytical methods. In 2020, a reduced-effort survey was completed due to COVID-19 limitations. Only 8 trawl tows were completed with each index being sampled along with a randomly selected grid from each quadrant.

The two-seam otter trawl used for all tows had a 10.66-m headrope with 4.6-m wings and 18.9 m overall length. It was constructed of 76-, 38-, 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 along the bottom for 10 minutes by a single warp and 45.7-m bridle at a speed of approximately 2 knots. Based on trawl mensuration, the average gape width and height dimensions with this gear configuration were 7 m x 1 m (MDNR unpublished data). Water temperature and Secchi disk transparency were recorded at each grid and total weight and number of each fish species collected were recorded in each trawl tow. Beginning in 2019, turbidity was measured with an electronic meter instead of Secchi disk depth. A relationship between turbidity and Secchi disk depth was developed by MDNR and used to convert turbidity to Secchi disk depth using the equation:

$$\text{Secchi depth} = 4.89267 * \text{turbidity}^{-0.67425}$$

Large catches (>10 kg) of forage fish were sometimes subsampled by selecting 25% to 40% of the total catch. Total length in millimeters was recorded for up to 150 individuals of each forage species at each index grid, including age-0 Yellow Perch. All age-1 and older Walleye and Yellow Perch captured in the trawl were weighed to the nearest 0.01 kg and measured.

Immediately after capture, most age-1 and older Walleye were sacrificed, their stomachs were removed and the contents examined on-board the survey vessel. The prey fish contained in the stomachs were counted and, if possible, identified to species. Prey fish that were unidentifiable were classified as unidentifiable fish remains and counted. Beginning in 2022, age-1 and older Walleye were no longer sacrificed for stomach contents examination to increase trawl survey efficiency as the gillnet survey already provides these data.

Scale or dorsal spine samples for age and growth analysis were taken from a maximum of 25 age-1 and older Yellow Perch and 10 age-1 and older Walleye per 25 mm size group. For each year total trawl catch and catch-per-unit-effort (CPUE, as number of fish per 10-min tow) of Yellow Perch was estimated by age and sex. Estimates were weighted to account for bias inherent in stratified random subsampling for age estimation following the procedure outlined by Schneider (2000). The mean catch by age was used to estimate survival for ages 1 to 6 with a standard catch curve analysis (Miranda and Bettoli 2007). Overall and age-specific (ages1 to 6) sex ratios were determined by dividing the male catch by the female catch for each year and denoted as 'M/F'. Beginning in 2022, age-1 and older Walleye were no longer aged to increase trawl survey efficiency since the gill net survey already provided these data. However, Walleye viewed as being borderline age-0 or age-1 were still aged to ensure accurate age-0 Walleye catch rate calculations during the trawl survey.

Trends in forage base are reported two ways; mean CPUE and as a forage index value calculated by summing the mean total weight in kilograms per 10-min tow for the most common forage species, including Alewife, Emerald Shiner, Gizzard Shad, Mimic Shiner, Rainbow Smelt, Round Goby, Spottail Shiner, Trout-Perch, age-0 White Perch, and age-0 Yellow Perch. Some analyses were delineated by the years after the collapse of Alewives (2003 to 2022) to allow for comparisons before and after this event.

Gillnetting

Gillnetting was based on the work of Isbell and Rawson (1989), who showed that gillnet catch could be effectively used as a measure of relative abundance and recruitment for Walleye and other species. Gillnet sampling consisted of 16 sets with the set locations being selected using a combination of fixed and stratified-random sites. Half of the net sets (eight) were at fixed stations (Figure 1) and half were at randomly assigned stations. The randomly assigned stations were stratified between inner bay (five stations) and outer bay (three stations). This design was new beginning in 2018; previously it was a fixed cluster design where pairs of nets were fished at the eight fixed sites. The redesign was formulated to provide more representative sampling, eliminate the cluster design element, improve statistical power, and to more closely align with the trawling sampling design (Fielder and Hayes 2014). Gillnetting was performed by the Research Vessel *Tanner* concurrent with the trawling in early September of each year.

Gillnets 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; the 38-mm mesh was added in 1993. Overnight, bottom net sets were made in depths greater than 3 m at each sample site. All catch was measured for total length in mm. Walleye, Northern Pike, Yellow Perch, and Smallmouth Bass were also weighed in grams with sex and maturity scored by internal examination of gonads according to the criteria of Goede and Barton (1990). Dorsal spines or fin rays were collected for age interpretation from these same species. Yellow Perch were subsampled for these metrics by including specimens caught from every other net. Walleye diet was noted by examining the stomach contents and 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).

Gillnet CPUE was calculated as the number of each species per 335-m net lift. Condition was examined by calculating *Wr* 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), an index of the size structure of the population, 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 fall season as reported by Schneider (2000).

Statistical Analysis

Analysis of variance was used to test for differences in trawl and gillnet catch rates among years and time periods. Analysis of variance was 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 gillnet data. Trawl and gillnet CPUE often have a lognormal distribution therefore, distributions of CPUE values were graphically examined (Stewart-Oaten 1995). Trawl and gillnet data were examined for normality using Lilliefors Test and for homogeneity of variance using Bartlett's or Levene's Test. When substantial deviations from normality were observed, nonparametric Kruskal-Wallis (KW) procedures with post-hoc multiple comparisons were used to test for statistical differences in mean CPUE among and between years or time periods for both gear types. Statistical differences between individual means of some metrics of interest were determined by a *t*-test when departures from normality were not observed or by a Mann-Whitney U (MW-U) test otherwise. Some means are reported with two standard errors of the mean (2SE) 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. Calculations of mean and SE for trawling and gillnetting catch rate data were conducted using equations for simple random sampling. The assumptions of such a sample design are suitably met for the trawl and gillnet designs. Both survey elements strive for broad spatial coverage across the expanse of the bay via the use of a combination of fixed and stratified-random site designs.

Total annual mortality rates for Walleye and Yellow Perch were calculated using two methods with numbers by ages from the gillnet-collected fish. The point-in-time catch curve method assumes equal annual recruitment. Given that equal annual recruitment 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 assumes 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 reflects 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 was used to examine predictive abilities of various ages of Walleye on subsequent ages in an examination of when year class strength is established. Simple linear regression was also used to develop length/weight relationships for some species based on natural log transformed data and linear regression. A Von Bertalanffy length-at-age model was fit for Walleye and Yellow Perch using individual data (from the gillnet collection) rather than means, with model parameters calculated according to Isely and Grabowski (2007). Maturation of male and female Walleyes was defined as age at 50% maturity from gillnet 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. The same method was used for Yellow Perch from the trawl collection, except for males which is reported as a straight percent mature at age-1. Age at 50% maturity has been determined to be the optimal method for expression of the onset of maturity for Saginaw Bay Walleyes (Wang et al. 2009). All statistical tests for this study were performed according to Sokal and Rohlf (1981) and conducted at a significance level of $P = 0.05$ based on two-tailed hypothesis testing unless otherwise stated. SPSS computer software or R statistical software were used for statistical analyses (IBM 2020; R Core Team 2021).

RESULTS

Trawling

A total of 104 trawl tows were completed during the trawling portion of the fish community survey from 2018–2022. Mean annual water temperature at trawling sites during this period ranged from 16.6 to 21.3°C, exceeding the mean of 18.1°C since 1985 in four of the five years (Figure 2). Over the entire time series since 1970, the mean surface water temperature has been getting warmer and the slope of a linear regression of mean temperature versus year was positive and statistically significant from zero ($F = 53.861$, df = 47, $P < 0.0001$). Mean annual Secchi depth at trawling sites during this period ranged from 0.6–2.0 m, exceeding the long-term mean of 1.4 m in four of the five years (Appendix 2). Water clarity as indicated by Secchi disk depth is increasing as indicated by a statistically significant increasing regression line ($F = 11.972$, df = 34, $P = 0.002$) although it may be leveling off in recent years.

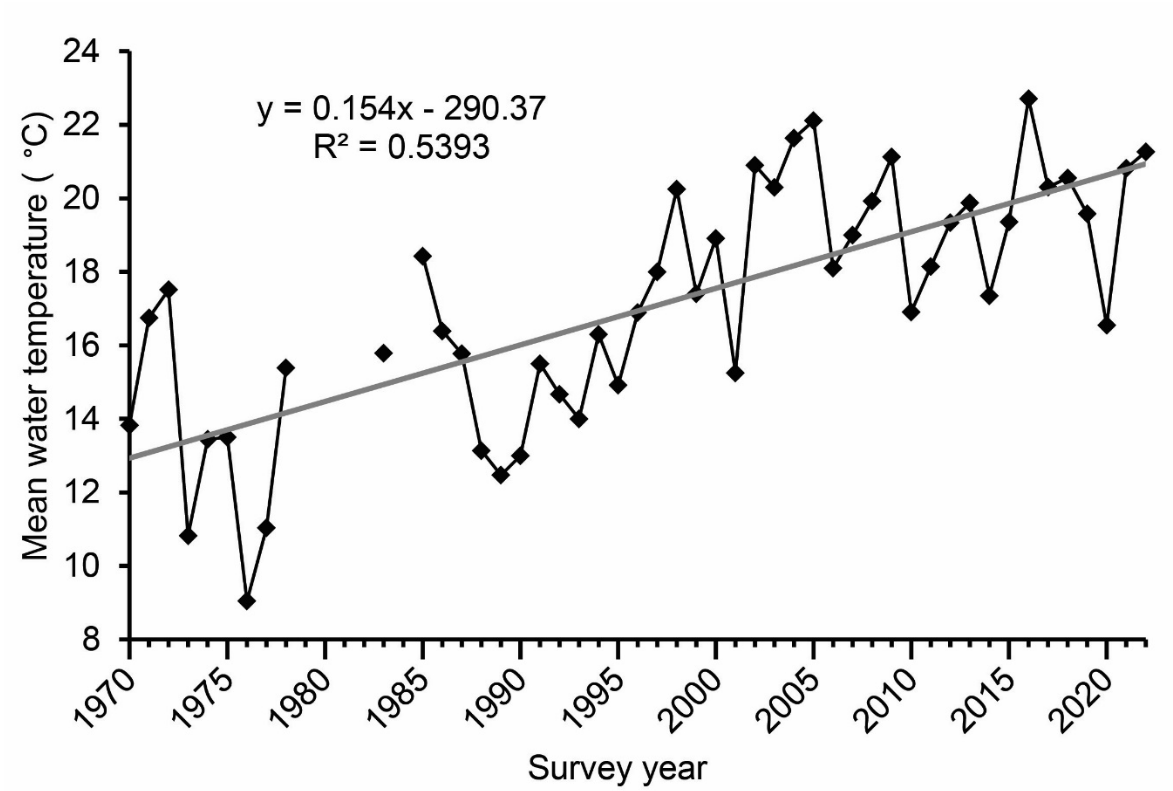

FIGURE 2. Mean water temperatures recorded during fall trawling on Saginaw Bay, 1970–2022. Gray line represents fitted linear regression line.

Species composition and catch rates

The trawling portion of the fish community survey resulted in 124,979 total fish being caught representing 32 species during 2018–2022. Species composition varied among years, although the most common species were generally similar from year-to-year (Table 1; Appendix 3). The most common species by number during this period were Mimic Shiner, White Perch, Trout-Perch, Yellow Perch, and Round Goby. These species accounted for 81–96% of total fish caught during the trawl survey across years (mean = 89%) and are the same most common species from the previous reporting period (2012–2017). Forage index values have varied among time periods (Figure 3; KW test, $H = 31.36$, df = 6, $P < 0.001$) but the 2018–2022 survey period was not statistically different from the 1970s (KW post hoc test, $H = -11.13$, df = 1, $P = 1.000$), 1980s (KW post hoc test, $H = 5.60$, df = 1, $P = 1.000$), 1990s (KW post hoc test, $H = 17.90$, df = 1, $P = 1.000$), 2000s (KW post hoc test, $H = -23.90$, df = 1, $P = 0.180$), or 2010s (KW post hoc test, $H = 4.80$, df = 1, $P = 1.000$). Cisco and Lake Sturgeon, species of conservation need, were absent from the trawl catch.

TABLE 1. Mean catch-per-unit-effort (CPUE) and forage CPUE value (number of fish per 10-min tow) for species collected from fall trawl samples in Saginaw Bay, 2018–2022, and decadal means. Forage CPUE reflects Alewife, Emerald Shiner, Gizzard Shad, Mimic Shiner, Rainbow Smelt, Round Goby, Spottail Shiner, Trout-Perch, age-0 White Bass, age-0 White Perch, and age-0 Yellow Perch. Twenty-four trawl tows were completed each year. AA = all ages, YOY = young of year. Measures of variability are omitted for clarity.

Species	Survey Year 2018	Survey Year 2019	Survey Year 2020	Survey Year 2021	Survey Year 2022	Survey Year(s) 2018–22	Survey Decade 1980s	Survey Decade 1990s	Survey Decade 2000s	Survey Decade 2010s	Survey Decade 2020s
Mimic Shiner	240.5	185.4	452.8	666.0	246.5	358.2	0.0	4.7	13.7	384.6	455.1
White Perch	73.3	96.4	772.9	354.2	210.8	301.5	255.9	310.7	482.0	171.9	446.0
Trout-Perch	203.6	206.8	134.4	376.1	274.4	239.0	145.9	530.7	385.3	316.6	261.6
Yellow Perch AA	172.2	97.9	434.3	287.2	103.3	219.0	555.8	110.0	417.5	163.1	274.9
Yellow Perch YOY	163.7	82.1	385.6	260.0	80.8	194.5	188.0	48.6	395.2	133.7	242.1
Round Goby	27.4	125.9	98.7	214.1	110.0	115.2	0.0	0.4	269.8	148.7	140.9
Walleye AA	32.6	32.8	16.8	42.8	49.9	35.0	1.1	3.4	22.8	29.3	36.5
Walleye YOY	28.3	27.6	8.0	36.9	44.4	29.0	0.4	1.6	18.7	23.4	29.8
Rainbow Smelt	27.6	67.4	11.7	27.8	2.2	27.4	264.8	271.6	195.4	78.6	13.9
Gizzard Shad	8.9	14.1	29.6	31.1	8.4	18.4	35.9	19.8	12.2	22.4	23.0
Spottail Shiner	10.5	8.2	7.6	20.5	31.7	15.7	489.3	479.8	560.7	63.6	19.9
White Bass	9.7	10.4	1.6	2.7	11.9	7.3	4.5	2.5	10.4	9.5	5.4
Freshwater Drum	4.8	10.8	7.5	5.8	5.4	6.8	7.0	17.3	11.6	17.2	6.2
White Sucker	4.1	3.7	2.7	2.0	2.2	2.9	6.8	11.7	16.5	4.7	2.3
Logperch	2.0	8.0	0.3	<0.1	0.2	2.1	<0.1	0.1	0.2	1.3	0.2
Emerald Shiner	4.1	0.4	2.3	0.8	2.2	2.0	46.7	8.6	7.0	9.0	1.7
Common Carp	1.6	1.7	0.8	1.1	0.8	1.2	2.7	5.3	6.4	2.6	0.9
Alewife	0.0	4.2	0.0	0.0	0.0	1.0	227.7	305.3	274.1	0.4	0.0
Channel Catfish	0.5	0.5	0.3	0.5	0.5	0.5	3.6	3.2	2.5	0.8	0.4
Quillback	0.1	0.4	0.1	0.3	0.4	0.3	2.4	0.7	1.6	0.4	0.3
Lake Whitefish	0.0	0.1	0.0	<0.1	0.0	<0.1	0.3	0.3	0.5	0.1	<0.1
Cisco	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lake Sturgeon	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Forage-CPUE value[a]	769.2	798.9	1897.2	1821.2	709.8	1199.3	1658.7	1982.6	2605.8	1477.6	1476.1

[a]Forage CPUE value is the sum of catch rates for Alewife, Emerald Shiner, Gizzard Shad, Mimic Shiner, Rainbow Smelt, Round Goby, Spottail Shiner, Trout-Perch, age-0 White Bass, age-0 White Perch, and age-0 Yellow Perch.

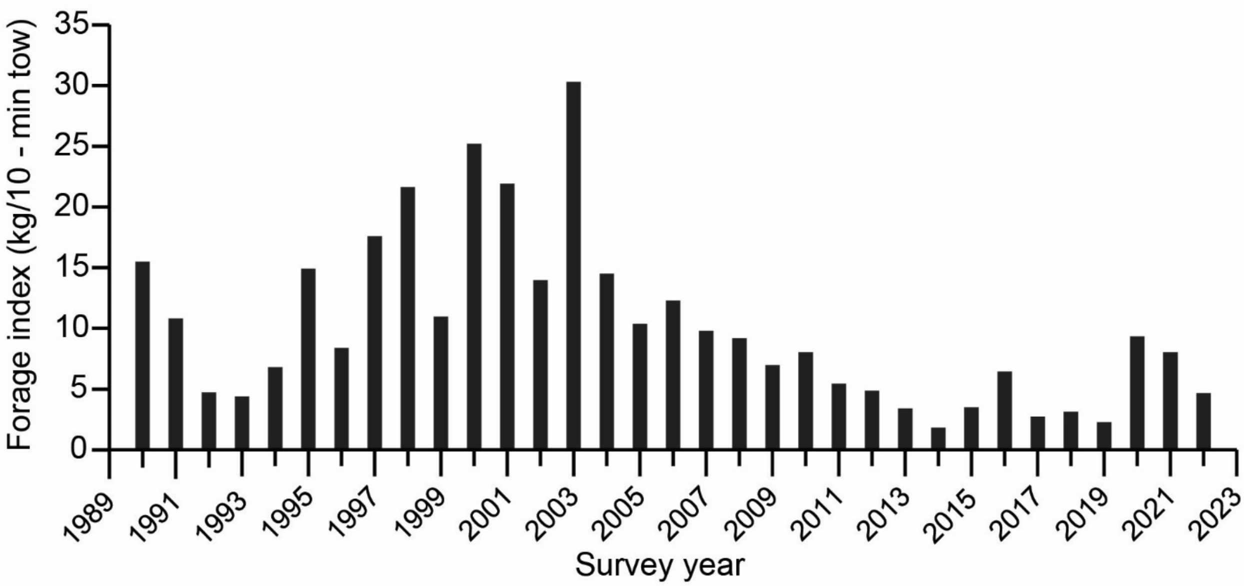

FIGURE 3. Trends in Saginaw Bay prey fish abundance (forage index) expressed as mean kilograms per 10-min tow. Prey fish composition for this index includes: Alewife, Emerald Shiner, Gizzard Shad, Rainbow Smelt, Spottail Shiner, Round Goby, Trout-Perch, age-0 White Bass, age-0 White Perch, age-0 Yellow Perch, and Mimic Shiner.

Invasive species have been large components of the species composition during the trawling portion of the survey for several time periods, including the most recent survey period. Round Goby, which first appeared in survey trawls in 1999 made up a mean of 9% of the total catch during the period. Mean annual Round Goby CPUE has not differed among time periods since the 2000s (KW test, $H = 6.79$, df = 3, $P = 0.079$). Alewife were once a large component of the species composition but collapsed after 2003 and have been largely absent since 2005. During the 2018–2022 period, Alewife were only caught in survey trawls in 2019. Mean Alewife CPUE has varied among time periods (KW test, $H = 29.21$, df = 5, $P < 0.001$) and the 2018–2022 time period was significantly less than the 1980s (KW post hoc test, $H = 23.15$, df = 1, $P = 0.031$) and 1990s (KW post hoc test, $H = 23.95$, df = 1, $P = 0.022$). White Perch first appeared in survey trawls in 1984 and have been a large component of the catch in the decades that followed. White Perch catch can vary greatly from year to year (often driving the forage index and CPUE up or down), representing between 9 and 39% of the total catch from 2018–2022 (mean = 19%). The mean annual CPUE of White Perch has varied some among time periods (KW test, $H = 18.49$, df = 5, $P = 0.002$) with the 2000s having higher CPUE than the 1980s (KW post hoc test, $H = 24.50$, df = 1, $P = 0.001$) but no statistical differences between other time periods.

Walleye and Yellow Perch catches in survey trawls have varied over time, likely related to trends in recruitment. Since 2003, Walleye CPUE in the trawl survey has been higher than previous survey periods, a result of strong reproductive success as indicated by age-0 catch rates (Figure 4, Appendix 4). The 2018–2022 period had the second highest mean annual CPUE of age-0 Walleye (29.5 fish per 10-min tow) of any 5-year time period since the trawl survey began (33.1 fish per 10-min tow from 2009–2013). Yellow Perch age-0 CPUE has been very high since 2003 compared to the previous period (Table 2), but those high CPUEs failed to translate into increases in yearling and older (age-1+) age classes (Table 3, Figure 5).

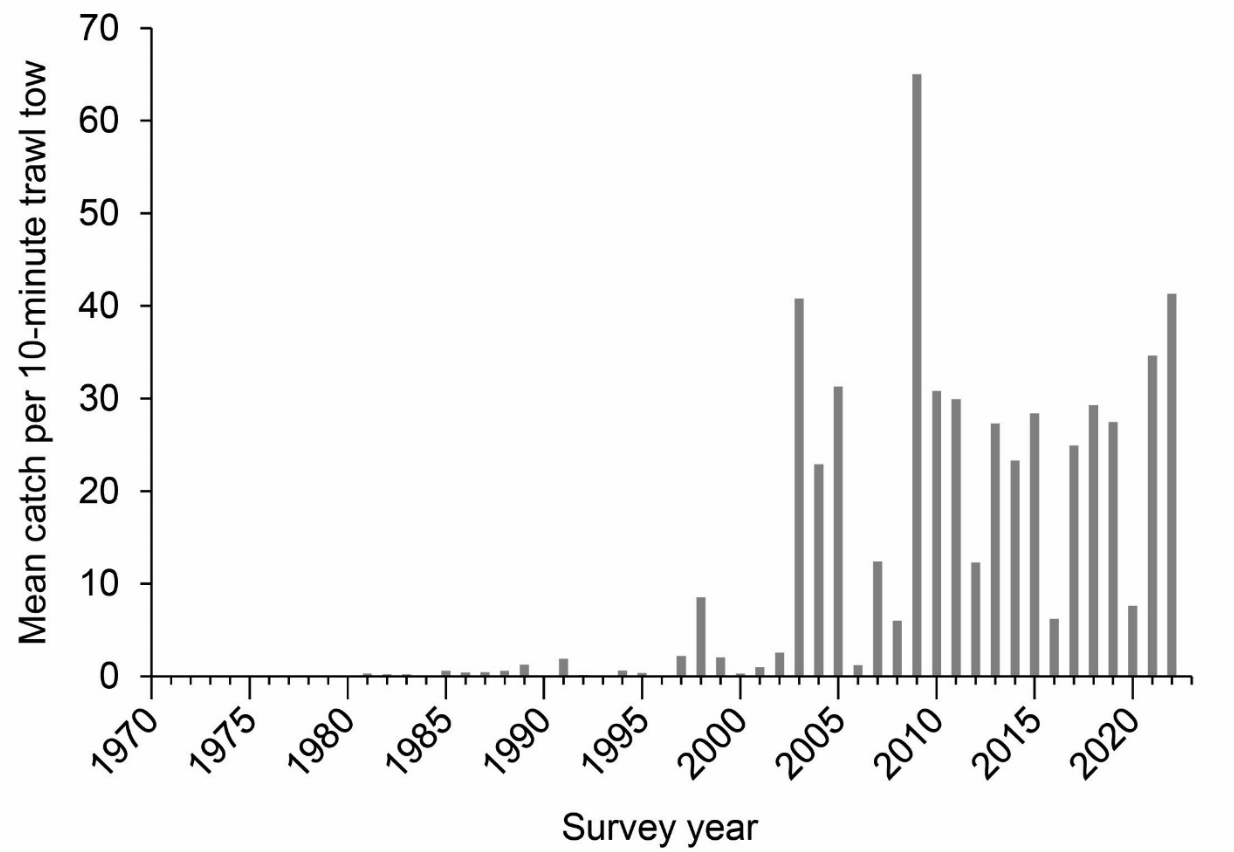

FIGURE 4. Mean catch per 10-min tow of age-0 Walleyes in trawls from 1971 to 2022.

TABLE 2. Mean catch-per-unit-effort (CPUE, number per 10-min tow) and mean total length (mm) of age-0 Yellow Perch collected from fall trawl samples in Saginaw Bay, 2003–2022. 2SE = two standard errors of the mean. Data prior to 1990 from Haas and Schaeffer (1992). See supplementary material for results from additional survey years.

Survey year	CPUE	2SE	Mean total length (mm)	2SE
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
2012	115.3	35.2	87.4	1.0
2013	149.8	84.3	77.7	1.4
2014	45.3	24.5	81.0	0.5
2015	154.7	67.8	77.1	1.1
2016	115.2	59.9	81.2	1.0
2017	158.3	108.0	74.4	1.0
2018	156.8	80.2	79.2	1.0
2019	77.1	33.4	77.7	1.2
2020	379.6	633.0	79.4	0.6
2021	243.8	105.2	72.2	1.2
2022	75.8	38.8	81.2	1.6

TABLE 3. Mean catch-per-unit-effort (CPUE, number per 10-min tow), by age, of Yellow Perch collected from fall trawl samples in Saginaw Bay, 2003–2022. Grand means are provided for the entire time series, the current reporting period (2018–2022) and the post-Alewife collapse period (2003–2022). See supplementary material for results from additional survey years.

Survey Year	Age-0	Age-1	Age-2	Age-3	Age-4	Age-5	Age-6	Age-7	Age-8	Age-9	Age-10	All ages	Age-1 and older
2003	2450.3	4.6	11.1	1.1	0.5	0.8	0.3	0.1	0.0	0.0	0.0	2468.7	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
2012	118.0	17.5	6.7	0.7	0.2	0.0	0.0	0.0	0.0	0.0	0.0	143.0	25.0
2013	155.0	7.5	1.5	0.7	0.1	0.1	0.0	0.0	0.0	0.0	0.0	164.9	9.9
2014	50.8	20.1	2.0	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	73.3	22.5
2015	160.5	33.7	2.1	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	196.8	36.3
2016	116.4	28.0	5.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	149.7	33.3
2017	158.2	19.3	8.5	1.7	0.2	0.0	0.0	0.0	0.0	0.0	0.0	187.9	29.7
2018	163.7	5.0	1.7	1.7	0.1	0.0	0.0	0.0	0.0	0.0	0.0	172.2	8.5
2019	82.1	11.3	2.2	1.2	0.9	0.0	0.0	0.0	0.0	0.0	0.0	97.9	15.8
2020	406.4	25.9	1.5	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	434.3	27.9
2021	260.0	20.2	6.0	0.8	0.1	0.0	0.0	0.0	0.0	0.0	0.0	287.2	27.2
2022	82.7	16.2	4.3	2.0	0.2	0.1	0.0	0.1	0.0	0.0	0.0	105.6	23.0

Grand Mean

Survey Years	Age-0	Age-1	Age-2	Age-3	Age-4	Age-5	Age-6	Age-7	Age-8	Age-9	Age-10	All ages	Age-1 and older
All years	197.1	27.5	16.8	12.2	6.0	2.1	0.7	0.2	0.0	0.0	0.0	262.7	65.6
2018–2022	199.0	15.7	3.1	1.2	0.3	0.0	0.0	0.0	0.0	0.0	0.0	219.4	20.5
2003–2022	297.9	19.4	3.7	1.0	0.2	0.1	0.0	0.0	0.0	0.0	0.0	322.3	24.4

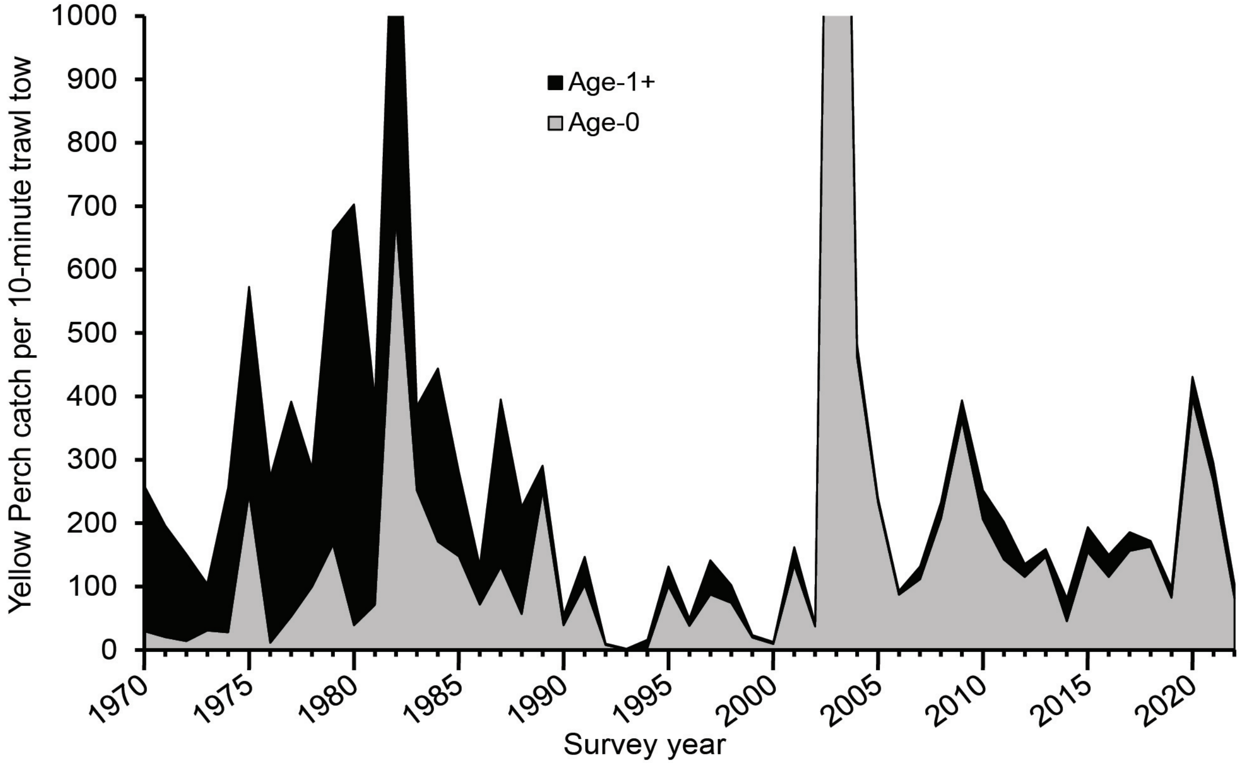

FIGURE 5. Mean catch per 10-min tow of age-0 and age-1+ Yellow Perch in Saginaw Bay from 1970–2022. 2003 age-0 mean catch was 2451 per tow and total catch in 1982 was 1319 perch per tow.

CPUE, survival, sex ratio, growth, and maturity of Yellow Perch

Mean age-specific CPUEs for age-1 and older Yellow Perch have been low since the Alewife collapse in 2003 (Table 3; Figure 5). Age-0 CPUE of Yellow Perch has been greatest since the Alewife collapse, but low survival has resulted in lower age-1 Yellow Perch CPUE compared to other time periods. Catch curve analysis of trawl samples for Yellow Perch ages 1–6 produced an estimate of total annual mortality of 74% since the Alewife collapse in 2003, compared to 47% before. Total annual mortality for the 2018–2022 period was estimated at 79% for Yellow Perch ages 1–5. The interannual mortality rate for Yellow Perch between age-0 and age-1 (same cohort the following year) has increased significantly since 2003, increasing from 67% prior to 2003 to 85% after (Figure 6; *t*-test, df = 30, $P = 0.006$).

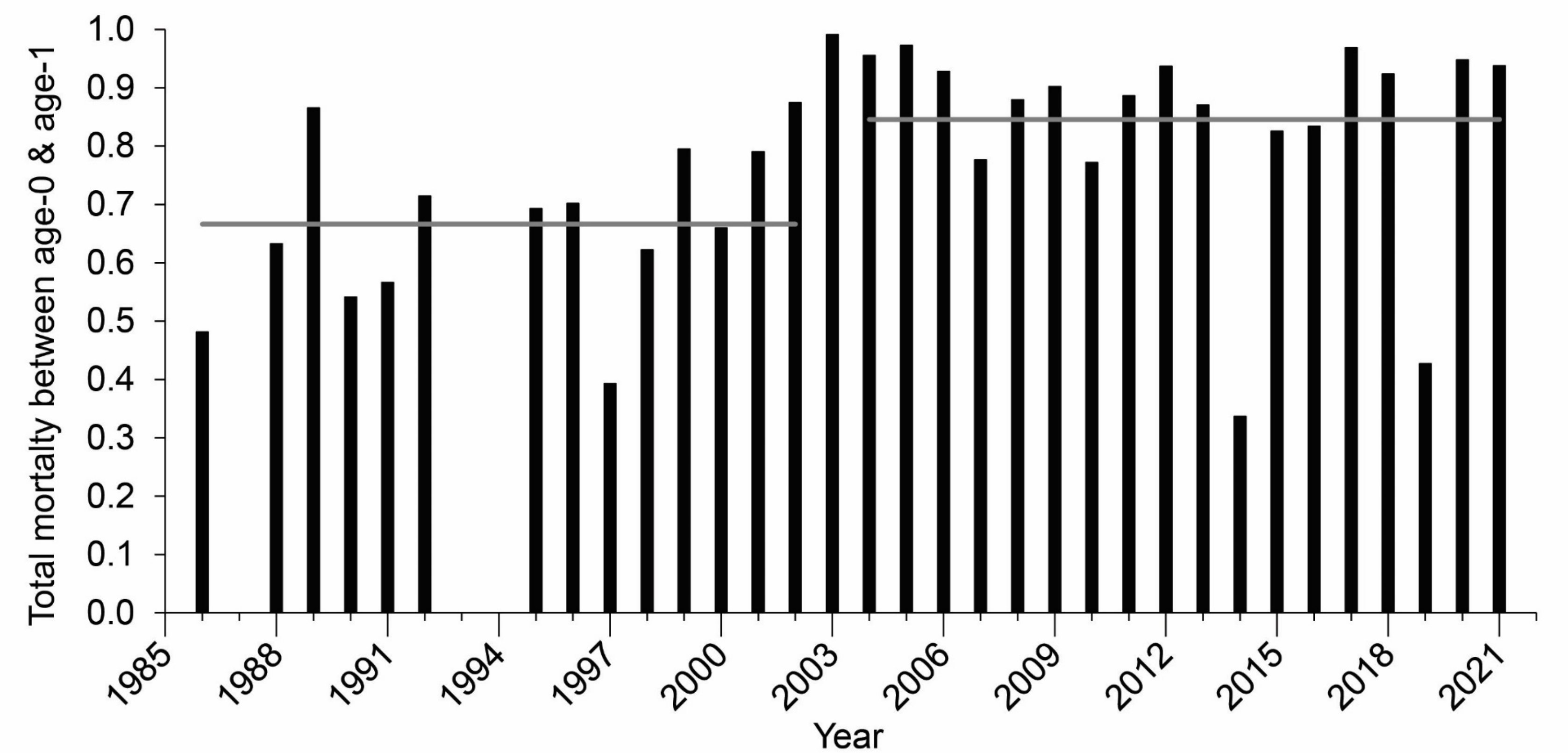

FIGURE 6. Total mortality rate of Yellow Perch between age-0 (fall young-of-the-year) as collected by trawling in the fall of each year and age-1 (yearling) for the same year class as collected the following fall by the same trawling. Gray lines are series averages before and after 2003. Reflects data through 2022, 2021 is last year estimable. See supplementary material for results from additional survey years.

For Yellow Perch, age-specific sex ratios during the post-Alewife time period were nearly even for age-1 (M/F: 1.06), then skewed towards females for ages 2 and 3, and then heavily skewed towards males for ages 4, 5, and 6 (Appendix 5). During the 2018–2022 reporting period, the sex ratio mirrored the trend of the post-Alewife period, aside from age-4 being nearly even (M/F: 0.97; not enough fish to evaluate age-5+). Pooled by age (1–6) since 2003, however, the overall sex ratio was near 1.0

Based on mean length-at-age at time of capture, female Yellow Perch grew faster than male Yellow Perch in Saginaw Bay (Appendix 6). On average, for the 2018–2022 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 1–5. Saginaw Bay Yellow Perch mean length-at-age has generally maintained a trend of faster growth since the mid-1990s (Appendix 7), particularly for ages 2, 3, and 4. However, during the 2018–2022 period and roughly the last 10 years, growth has remained relatively consistent.

During 2018-2022, female Yellow Perch reached 50% maturity by age-1, similar to the previous reporting period. Maturity of male Yellow Perch occurs as early as fall for age-0 fish in some instances (77% for this reporting period). Combining all sexes, an annual mean of 68% of Yellow Perch caught during survey fall trawls between 2018–2022 were mature at age-1. This represents a decline from 2012–2017, which had an annual mean of 81%. During the current reporting period the annual mean of Yellow Perch that were mature at age-1 during fall trawls were 90% and 47% for males and females, respectively. These both represent declines from the previous reporting period when 97% of males and 66% of females were mature at age-1.

Diet of Walleye

Prior to 2003, Alewives were consistently the most frequently occurring prey item in non-empty Walleye stomachs from the fall trawl survey (Table 4). However, from 2003–2005 Yellow Perch were found in a higher proportion than any other taxa. Since 2005, only one Walleye stomach examined contained an identifiable Alewife. White Perch were the most frequently occurring prey item in 2006. From 2007–2021, Gizzard Shad and Yellow Perch have been the primary prey items found in the stomachs of Walleye collected in the trawl survey, except for 2020 when more White Perch were found than Yellow Perch and Round Goby equaled Yellow Perch. The diversity of prey items was highest in 2014 with ten species identified from Walleye stomachs. During 2018–2022 the mean annual number of taxa present in Walleye diets was 4.3, less than the mean since the Alewife collapse (6.1) and less than the previous reporting period (6.3). Round Gobies first appeared in Walleye diets in the 2000 fall trawl survey and have continued to represent a small proportion of the diet in most years, although in the current reporting period Round Goby were only noted in Walleye diets in 2020.

TABLE 4. Number of stomachs examined, incidence of empty stomachs, and frequency of occurrence (% of non-empty stomachs containing selected taxa) of food items found in age-1 and older Walleyes collected from fall trawl samples in Saginaw Bay, 2003–2021. Walleye stomachs were no longer examined during the trawl survey starting in 2022. See supplementary material for results from additional survey years.

Survey year	Stomachs examined	% empty	Unidentified fish remains	Gizzard Shad	Alewife	Yellow Perch	Spottail Shiner	Round Goby	White Perch	Zebra Mussel	Trout-Perch	Freshwater Drum	Other taxa
2003	33	15	68	0	14	39	0	4	0	0	4	0	0
2004	176	36	63	0	1	53	5	7	6	0	1	0	2
2005	116	49	54	3	0	34	3	12	7	2	0	2	0
2006	271	37	64	16	1	13	0	7	24	0	1	0	1
2007	147	24	54	38	0	14	0	0	9	0	1	0	1
2008	182	22	59	33	0	22	0	7	17	1	1	0	4
2009	55	25	61	15	0	37	0	10	5	0	2	0	2
2010	77	22	22	33	0	42	7	7	3	0	2	0	2
2011	117	24	56	28	0	28	3	1	4	0	0	0	2
2012	169	41	45	49	0	13	5	4	1	1	2	0	1
2013	94	44	38	42	0	13	0	15	0	0	2	0	0
2014	207	26	53	42	0	3	1	3	3	1	1	0	11
2015	53	36	59	38	0	18	0	0	0	0	0	0	6
2016	122	37	48	44	0	12	1	5	6	0	1	0	3
2017	124	48	47	22	0	9	0	2	0	0	0	0	3
2018	99	58	55	10	0	29	0	0	0	0	0	0	0
2019	116	46	35	30	0	10	0	0	0	0	0	0	3
2020	86	37	46	30	0	4	0	4	6	0	0	0	11
2021	131	53	34	48	0	18	0	0	8	0	0	0	3

Gillnetting

The gillnet portion of the fish community survey collected a total of 12,204 specimens spanning 38 different species between 2018 and 2022, for an average of about 2,441 fish per year. The most abundant species were Yellow Perch, Walleye, White Perch, Gizzard Shad, and Freshwater Drum (Table 5). Notably absent from the gillnet collections were Cisco which were historically abundant (Baldwin et al. 2009) and are now designated as state-threatened species (Latta 2005). Lake Sturgeon were encountered for the first time in this time series since the gillnetting portion of the survey began in 1989. Catch rates for commonly encountered species were mostly similar within the current time period. The mean CPUE of Walleye ranged from 32.0 fish/net lift in 2019 to 41.5 fish/net lift in 2018, but did not differ significantly among those years (KW test, $H = 0.627$, df = 4, $P = 0.960$). Walleye catch rates remain high compared to earlier reporting periods. While there was no significant difference for the Walleye gillnet catch rate between the current reporting period (2018–2022) and the last period (2012–2017; MW-U, $H = 0.006$, df = 1, $P = 0.940$), there was a significant difference between mean CPUE during the post recovery period of 2009–2022 (34.6 fish/net lift) and the earlier period of 1989–2008 (20.5 fish/net lift; MW-U, $H = 36.508$, df = 1, $P < 0.001$).

TABLE 5. Mean gillnet catch-per-unit-effort (number per 335-m gillnet lift) and two standard errors of the mean (2SE) by species for Saginaw Bay, 2018–2022, representing 16 net sets or 5,364 m, total each year. Values include catch from the 38-mm (1.5 inch) mesh catch added to the survey series in 1993. Unid = Unidentified. See supplementary material for results from additional survey years.

Species	2018 Mean	2018 2SE	2019 Mean	2019 2SE	2020 Mean	2020 2SE	2021 Mean	2021 2SE	2022 Mean	2022 2SE	5-year Mean	5-year 2SE
Yellow Perch	33.38	17.69	60.19	33.83	40.63	17.00	63.38	34.00	33.50	17.86	46.21	11.44
Walleye	41.50	18.21	32.00	12.52	34.69	16.60	37.69	17.04	36.63	13.20	36.50	6.87
White Perch	30.44	24.39	22.31	18.81	6.31	3.47	18.88	17.92	25.44	18.50	20.68	8.06
Gizzard Shad	50.50	32.08	4.56	3.55	9.44	6.33	17.00	18.01	11.56	10.57	18.61	8.45
Freshwater Drum	7.38	2.93	11.50	6.45	6.81	4.77	11.81	7.83	8.75	4.67	9.25	2.48
White Sucker	10.25	4.76	8.13	4.50	8.69	4.21	6.38	4.51	6.19	3.51	7.93	1.91
Channel Catfish	4.75	3.00	6.81	4.80	3.94	2.89	5.94	3.23	9.50	4.63	6.19	1.71
White Bass	3.44	2.82	0.5	0.48	1.19	1.04	1.19	1.25	2.31	2.47	1.73	0.84
Longnose Gar	1.06	1.41	0.75	1.24	0.56	1.00	1.25	2.00	4.94	9.61	1.71	1.99
Quillback	0.25	0.29	0.06	0.13	1.38	1.75	0.19	0.2	1.19	1.86	0.61	0.52
Northern Pike	1.06	0.64	0.25	0.22	0.19	0.20	0.25	0.29	0.31	0.24	0.41	0.17
Brown Bullhead	0.06	0.13	0.19	0.27	0.25	0.50	0.81	1.25	0.38	0.63	0.34	0.3
Smallmouth Bass	0.13	0.25	0.06	0.13	0.06	0.13	0.81	1.63	0.63	0.87	0.34	0.37
Rock Bass	0.00	0.00	0.63	0.81	0.00	0.00	0.50	0.77	0.25	0.29	0.28	0.23
Round Whitefish	0.06	0.13	0.31	0.63	0.06	0.13	0.06	0.13	0.75	1.50	0.25	0.33
Lake Whitefish	0.25	0.29	0.13	0.25	0.44	0.75	0.13	0.25	0.00	0.00	0.19	0.17
Unid. Redhorse sp.	0.19	0.20	0.63	0.4	0.38	0.4	0.38	0.36	0.13	0.17	0.18	0.12
Bowfin	0.06	0.13	0.13	0.25	0.13	0.17	0.06	0.13	0.31	0.40	0.14	0.11
Burbot	0.00	0.00	0.38	0.63	0.06	0.13	0.06	0.13	0.00	0.00	0.10	0.13
Round Goby	0.00	0.00	0.06	0.13	0.00	0.00	0.19	0.20	0.25	0.50	0.10	0.11
Lake Sturgeon	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.25	0.06	0.13	0.04	0.06
Alewife	0.00	0.00	0.00	0.00	0.13	0.25	0.00	0.00	0.00	0.00	0.03	0.05
Cisco	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Walleye collected in gillnets during 2018–2022 were age-0 to age-16 from the 2022- to 2005-year classes (Appendix 8). Walleye year class strength, as indicated by yearling Walleye gillnet CPUE, averaged 4.1 Walleyes per lift since 2018 which exceeded the longer-term average of 3.6 Walleyes per lift since recovery in 2009 (Appendix 9). This increase occurred despite the absent 2020-year class indicated by yearling Walleye gillnet collections.

The relationship between age-0 catch rate in the trawls (Appendix 4) was regressed as a predictor against age-1 catch rate in the gillnet collection (Appendix 8) to examine when year class strength is first established for Walleye. After the resurgence in Walleye natural reproduction in 2003, there was no relationship (slope = -0.0095) compared to pre-recovery where a significant positive relationship existed (slope = 0.7463). The equation was statistically significant $P = 0.002$ ($F = 16.995$, total df = 11) prior to recovery but not post-recovery $P = 0.8580$ ($F = 0.033$, total df = 19), (Figure 7). To further test when year class strength is set in the post-recovery period (using 2003 as a break point for the onset of reproductive success), the CPUE of Walleye by age was regressed as a predictor of the next age (Figure 8). From this, we see that age-2 Walleye has the strongest predictive relationship with an R^2 of 0.5239.

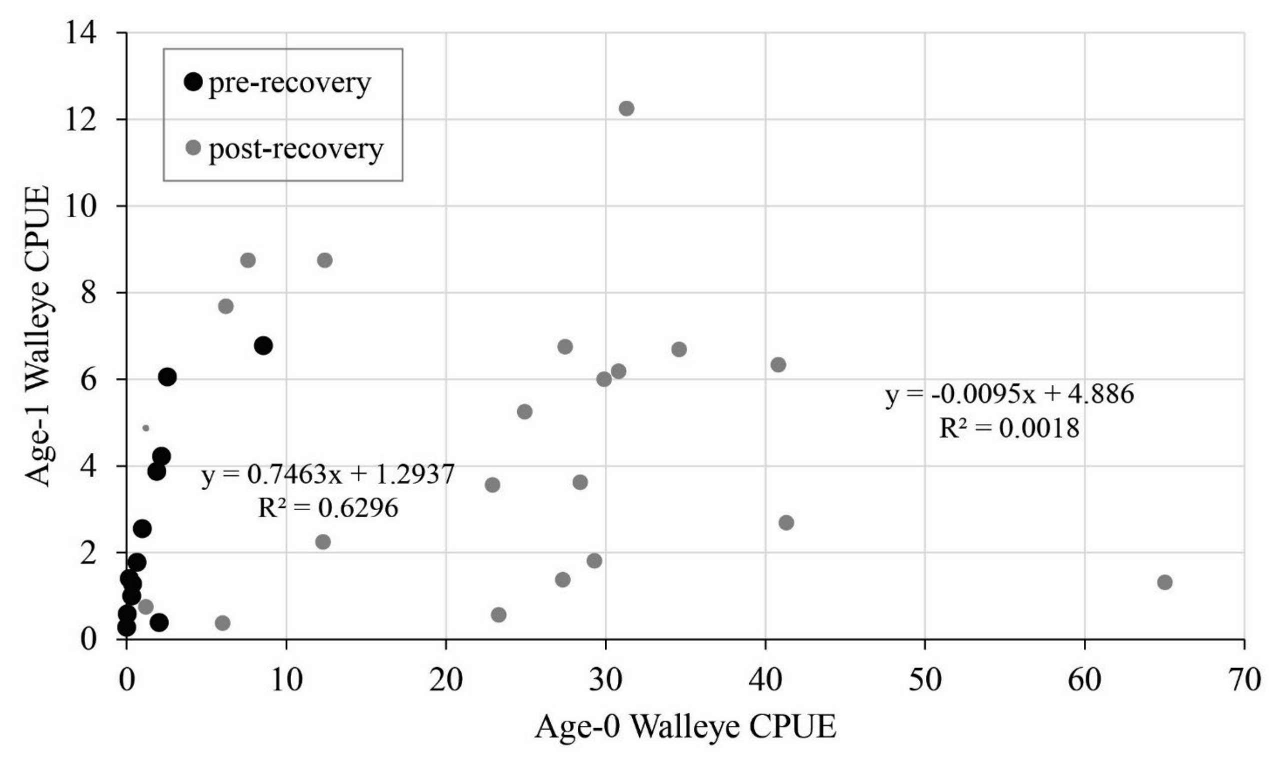

FIGURE 7. Relationship between age-0 Walleye catch-per-unit-effort (CPUE) from trawling and age-1 CPUE from the gillnet collection in Saginaw Bay, pre- and post-recovery applying 2003 as the breakpoint. Linear regression equations and coefficient of determination (R^2) for each line are included.

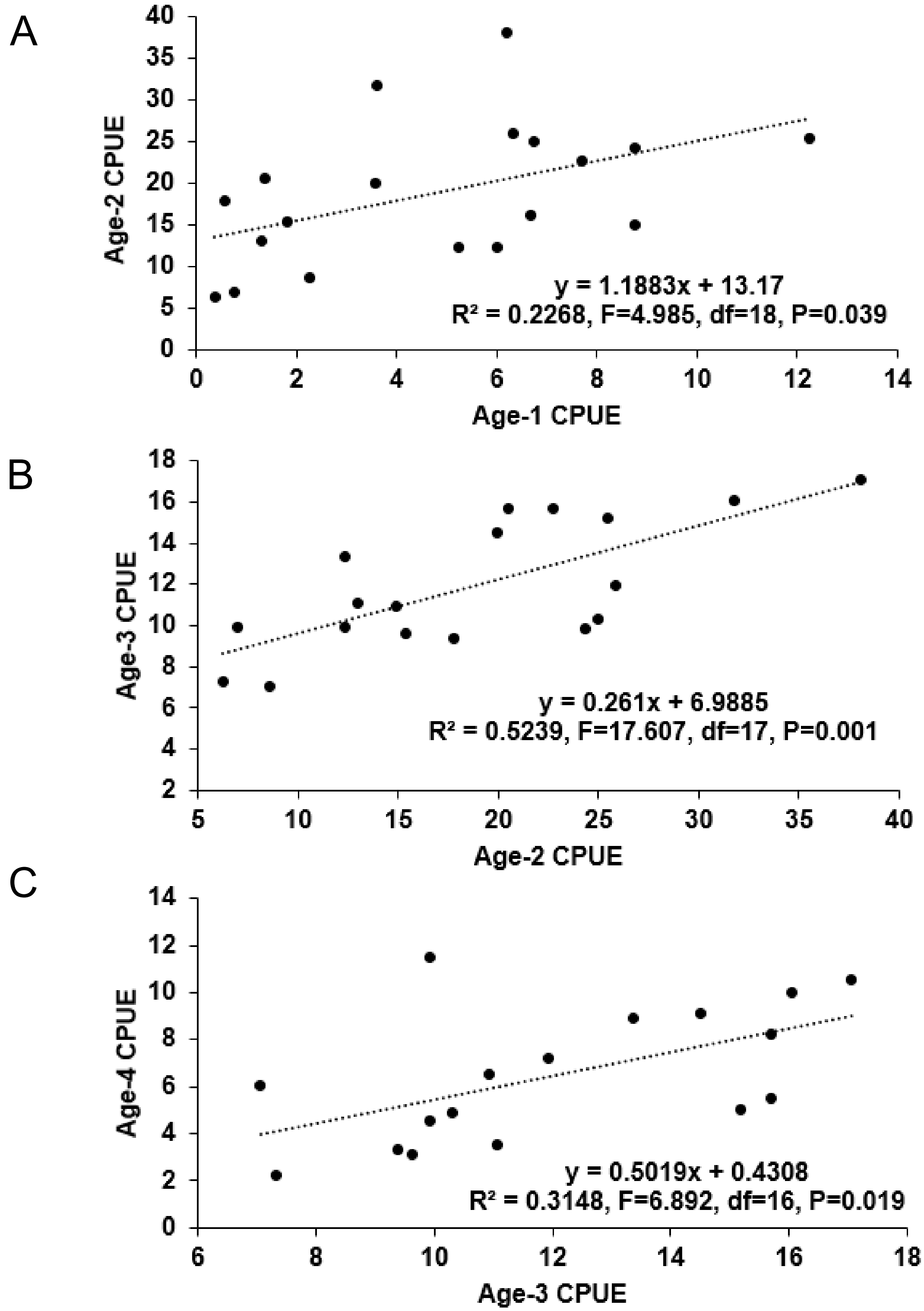

FIGURE 8. Examination of what age Saginaw Bay Walleye year-class strength is set. Regression of three ages as predictors of the next age based on catch-per-unit-effort (CPUE) of Walleyes from the gillnet survey post recovery of reproductive success (after 2003). A; Age-1 as a predictor of Age-2, B; Age-2 as a predictor of Age-3, and C; Age-3 as a predictor of Age-4. Linear regression equation and coefficient of determination (R^2) included.

Diet of Walleye in early September, during the annual gillnet survey, was again dominated by Yellow Perch and Gizzard Shad with mean frequency of occurrences of 25.08 and17.82, respectively (Table 6). This continues a trend of increased importance of Yellow Perch since 2003 when Alewives became scarce. Alewives were evident in the Walleye diet at trace amounts in 2019 and 2020 but were pervasive in the diet prior to 2003. Other notable dietary items since 2018 are Round Gobies and White Perch.

TABLE 6. Number of stomachs examined, incidence of empty stomachs, and frequency of occurrence (% of non-empty stomachs containing selected taxa) of diet items found in Walleyes collected from fall gillnet samples in Saginaw Bay, 2009–2022.

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Stomachs examined	256.0	470.0	530.0	700.0	537.0	472.0	341.0	734.0	792.0	664.0	512.0	555.0	603.0	586.0
% empty	57.0	66.6	49.4	62.0	55.1	83.9	71.3	63.1	61.1	54.1	54.2	35.3	63.2	72.9
Unidentified fish remains	80.0	12.5	46.6	43.9	64.7	40.8	51.0	66.0	55.8	45.9	62.8	42.9	61.3	63.5
Alewife	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.4	2.2	0.0	0.0
Burbot	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.3	0.0	0.0
Channel Catfish	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	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	0.0	0.0	0.0	0.0	0.0	0.0
Crayfish spp.	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
Emerald Shiner	1.8	5.1	0.4	0.8	0.0	3.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5
Freshwater Drum	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.3	0.4	0.3	0.4	0.0
Gizzard Shad	0.9	16.0	25.0	33.1	19.5	42.1	6.1	24.0	26.3	12.4	9.8	45.1	11.7	10.1
Mimic Shiner	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rainbow Smelt	0.9	0.6	0.4	0.0	0.0	0.0	1.0	0.7	0.0	0.0	0.0	2.2	0.9	1.9
Round Goby	9.1	2.9	5.2	3.4	2.1	0.0	2.0	3.4	1.9	1.3	3.4	1.1	3.6	13.8
Sand Shiner	0.0	0.0	0.0	0.0	2.1	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0
Spottail Shiner	0.0	0.0	0.0	0.0	0.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2
Trout-Perch	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Walleye	2.7	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
White Bass	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0
White Perch	2.7	0.6	0.7	1.5	3.7	1.3	0.0	3.4	0.0	1.6	5.5	4.7	0.4	0.0
White Sucker	0.0	0.3	0.0	0.0	0.8	0.0	1.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0
Yellow Perch	19.1	12.1	30.2	11.3	11.2	5.3	50.0	10.0	22.4	46.2	24.4	21.2	24.8	8.8
Dreissenid	1.8	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Walleyes in Saginaw Bay grow slightly faster than the state average and faster than they did historically (Table 7). The trend in mean total length at capture for age-3 Walleyes (sexes combined) has been an important indicator for gauging where the Walleye population is at relative to the capacity of the habitat and prey base (Fielder and Baker 2004). The growth rate is deemed density-dependent such that slower rates indicate more complete use of the carrying capacity of the bay and an overall larger Walleye population. A recovery threshold of a 425 mm, which is 110% of the state average mean total length for age-3 Walleyes, in the first 3 out of 5 years was established as a criterion for declaring recovery in the bay (Fielder and Baker 2004). That threshold was first formally met in 2009. The rate has held steady since 2018 at 422 mm (Figure 9).

TABLE 7. Mean length-at-age (mm) and two standard errors of the mean (2SE) for Walleyes and Yellow Perch (both sexes combined) collected from fall gillnet samples in Saginaw Bay, 2018–2022. Statewide average lengths are from August–September (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 calculated with methodology from Schneider (2000). See supplementary material for results from additional survey years.

Walleye

Age	2018 Mean	2018 2SE	2019 Mean	2019 2SE	2020 Mean	2020 2SE	2021 Mean	2021 2SE	2022 Mean	20222 SE	State wide mean	Saginaw Bay historic mean
0	187	2	—	—	180	13		—	—	—	180	—
1	285	3	264	3	275	2	289	2	269	2	250	254
2	374	2	355	3	371	3	372	2	365	2	338	320
3	417	2	422	2	423	2	431	3	419	3	386	371
4	459	7	452	3	461	2	471	4	455	6	437	411
5	467	7	491	9	487	4	490	5	490	6	472	457
6	516	10	502	8	496	10	506	7	511	7	516	483
7	503	12	520	15	519	11	541	8	519	7	541	505
8	511	7	525	13	528	10	515	18	—	—	561	533
9	—	—	534	9	569	16	—	—	529	18	582	582
10	—	—	—	—	529	12	535	18	540	21		
11	—	—	—	—	—	—	528	9	—	—		
Growth index	4.1		-2.0		4.7		14.5		4.4			-15.2

Yellow Perch

Age	2018 Mean	2018 2SE	2019 Mean	2019 2SE	2020 Mean	2020 2SE	2021 Mean	2021 2SE	2022 Mean	2022 2SE	State wide mean	Saginaw Bay Historic mean
0	—	—	—	—	—	—	—	—	—	—	84	—
1	155	1	154	1	153	1	163	1	158	1	127	—
2	220	2	218	2	211	2	222	1	212	2	160	—
3	263	2	263	3	271	2	251	3	255	3	183	—
4	275	6	292	2	292	6	279	9	276	6	208	—
5	305	18	296	6	303	4	306	7	—	—	234	—
6	—	—	—	—	—	—	—	—	—	—	257	—
Growth index	61.2		62.1		63.6		61.9		55.6			

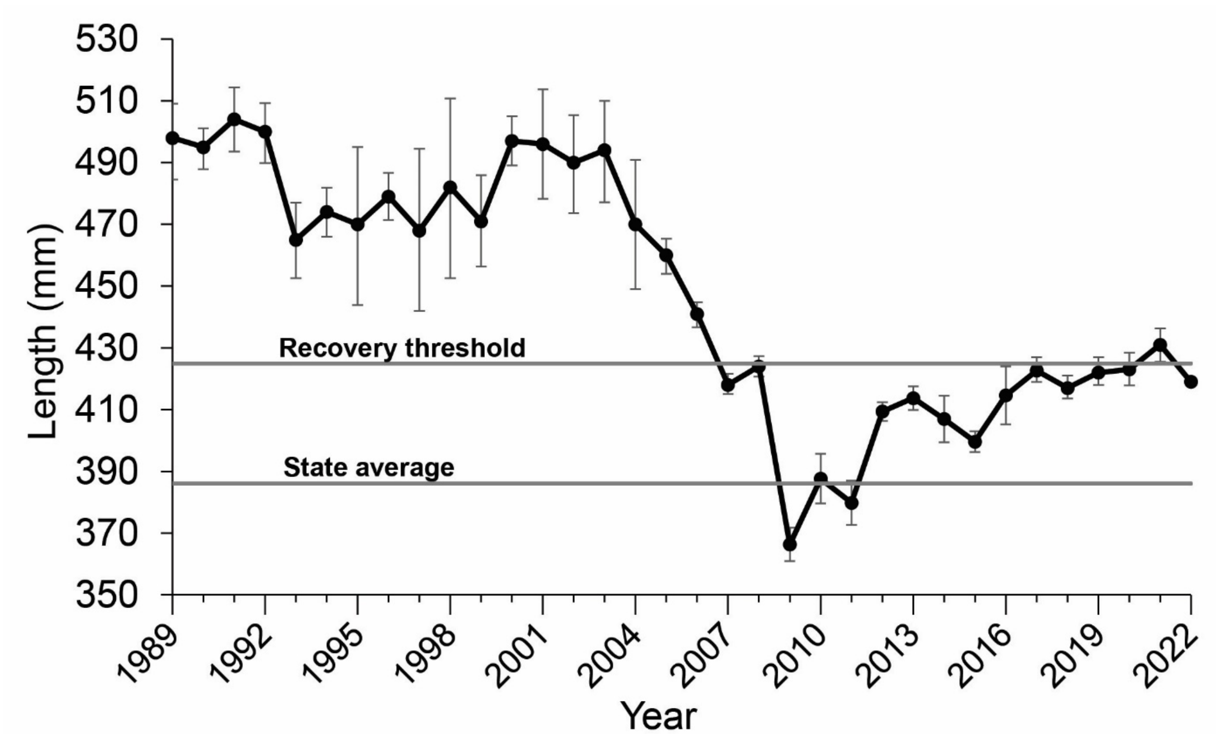

FIGURE 9. Trends in mean length of age-3 Walleyes (sexes combined) at September capture and their 95% confidence intervals. State average rate from Schneider (2000) and recovery threshold from Fielder and Baker (2004) are indicated by the gray lines.

Walleye condition, as indicated by *Wr*, has declined from when the gillnet time series began in 1989 (Figure 10). Although the trend over time is weak ($R^2 = 0.3792$), the negative slope differed from zero in a statistically significant manner ($F = 20.163$, total df = 34, $P < 0.0001$). Little trend is discernable in condition of Walleye since 2005 by length class with *Wr* typically ranging from 79 to 94 for the years of the reporting period (Appendix 10). Saginaw Bay's Walleye population is dominated by stock size individuals (250–380 mm) with PSD values ranging from 62 to 76%. Preferred size Walleyes (510–630 mm) ranged from 6 to 15% and memorable size fish (630–760 mm) were scarce (Appendix 11). These larger size classes along with trophy sized Walleyes are less than 0.2% of the population and may not be detected in the gillnet collection which is usually about 500 fish each year. Memorable and trophy sized Walleyes are observed in the annual spawning run in tributaries within the bay's watershed such as the Tittabawassee River (Fielder 2014). Prior to the surge in reproductive success in 2003, the RSD of preferred sized Walleyes averaged 38.8% compared to 7.3% since (Fielder et al. 2000; Fielder and Thomas 2006; Fielder and Thomas 2014; Fielder et al. 2022).

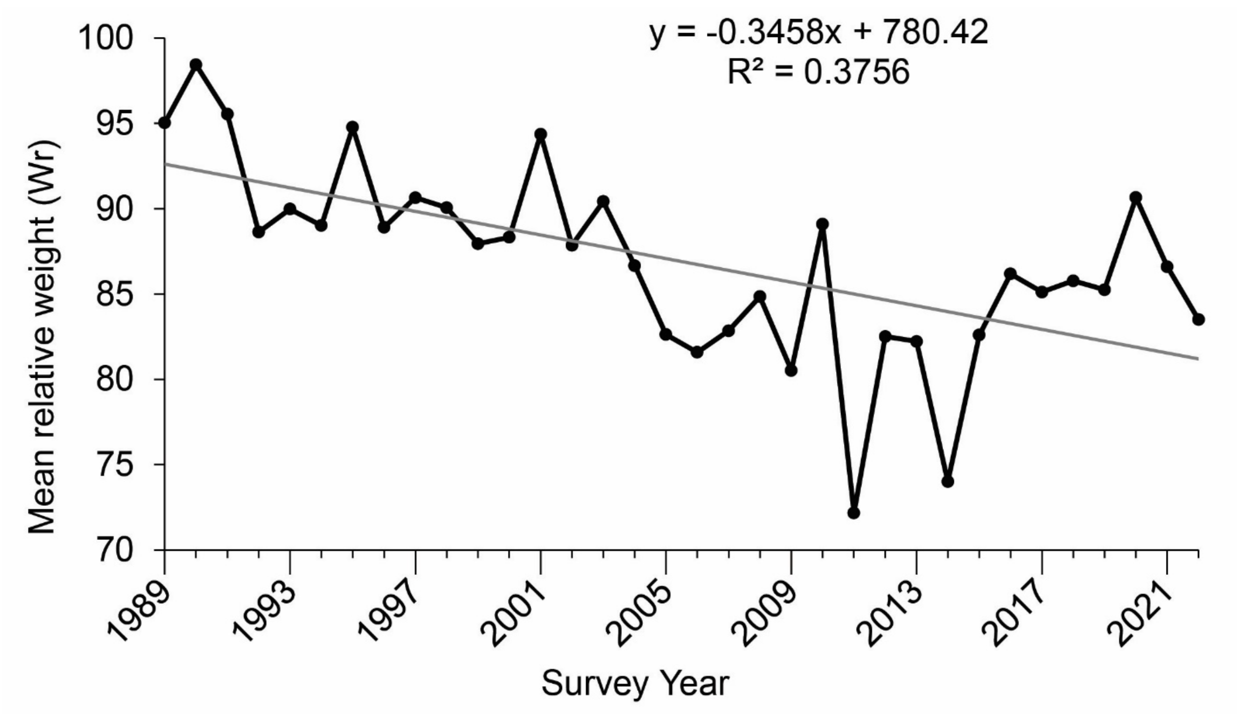

FIGURE 10. Trend in Walleye mean *Wr* from 1989 to 2022 sexes and size classes combined. Linear regression (gray line) indicated with coefficient of determination (R^2) and regression equation indicated in the graphic where 'x' = year and 'y' = *Wr*. Slope is significantly different from zero ($F = 20.163$, total df = 34, $P < 0.0001$).

Male Walleye in Saginaw Bay begin exhibiting sexual maturity as early as age-1 but do not reach 50% mature until age-2.33. Female Walleye mature later with 50% mature at age-3.04 and not reaching a majority of mature until age-4 (Table 8). The trend since 1989 is towards later ages of maturity for both sexes.

TABLE 8. Percent mature and age at 50% maturity for male and female Walleye in Saginaw Bay, 2018–2022 (all years combined) and previous survey periods for comparison (Fielder et al. 2022; Fielder and Thomas 2014).

Walleye

Age	Males Number	Males % mature	Females Number	Females % mature
0	11	0.0	8	12.5
1	227	6.2	213	2.3
2	415	32.5	498	6.8
3	295	84.7	351	48.4
4	193	96.9	147	86.4
5	94	98.9	83	90.4
6	58	100.0	41	97.6
7	54	100.0	28	92.9
8	47	100.0	19	100.0
9	23	95.7	11	100.0
10	27	100.0	8	100.0
11	14	100.0	3	100.0
12	1	100.0	2	100.0
13	1	100.0	1	100.0

	Males	Females
Age at 50% maturity	2.33	3.04
2012–2017	2.89	3.50
2005–2011	2.50	2.96
1989–2004	1.51	2.77

Two methods of deriving Walleye total annual mortality were used and they yielded comparable results. The point-in-time catch curve indicated an average of 0.43 since 2018 (Table 9). The cohort method, which overcomes the unlikely assumption of equal annual recruitment, indicated the 2017-year class of Walleyes (between 2018 and 2022) exhibited a total annual mortality rate of 0.49 (Table 10).

TABLE 9. Total annual mortality rate (A) and 95% confidence interval (CI), determined by the Robson-Chapman method of point-in-time catch curve analysis, for Walleye and Yellow Perch collected from fall gillnet samples in Saginaw Bay, 2003–2022. See supplementary material for results from additional survey years.

Survey Year	Walleye A	Walleye CI	Yellow Perch A	Yellow Perch CI
2003	0.47	0.016	0.60	0.015
2004	0.56	0.017	0.53	0.019
2005	0.70	0.018	0.79	0.018
2006	0.65	0.013	0.58	0.020
2007	0.59	0.014	0.51	0.014
2008	0.44	0.010	0.68	0.016
2009	0.55	0.022	0.67	0.012
2010	0.51	0.019	0.61	0.017
2011	0.34	0.009	0.75	0.018
2012	0.62	0.012	0.73	0.019
2013	0.59	0.015	0.63	0.022
2014	0.55	0.015	0.53	0.019
2015	0.44	0.015	0.62	0.015
2016	0.46	0.010	0.56	0.015
2017	0.37	0.006	0.61	0.014
2018	0.46	0.009	0.57	0.021
2019	0.47	0.012	0.57	0.015
2020	0.39	0.010	0.53	1.800
2021	0.40	0.009	0.56	1.160
2022	0.42	0.008	0.68	2.070

TABLE 10. Total annual mortality rate (A) and 95% confidence interval (CI), determined by the cohort method (applying the Robson-Chapman calculation method of catch curve analysis of year classes) for Walleye and Yellow Perch collected from fall gillnet samples in Saginaw Bay, 1989–2022 (1989–2017-year classes). Vacant cells represent insufficient data for calculation.

Year class	Walleye A	Walleye CI	Walleye Years spanned	Walleye Ages spanned	Yellow Perch A	Yellow Perch CI	Yellow Perch Years spanned	Yellow Perch Ages spanned
1989	0.53	0.027	1990–1999	1–10	—	—	—	—
1990	0.46	0.037	1991-2001	1–11	0.47	0.033	1993–2001	3–11
1991	0.47	0.055	1993–2002	2–11		0.084	1996–2000	5–9
1992	0.25	0.073	1993–2002	1–10	0.37	0.051	1993–2000	1–8
1993	0.22	0.096	1994–2004	1–11	0.48	0.050	1996–2001	3–8
1994	0.39	0.062	1996–2005	2–11	0.61	0.046	1996–2001	2–7
1995	0.32	0.059	1996–2007	1–12	0.47	0.049	1997–2003	2–8
1996	0.13	0.134	1997–2004	1–8	0.46	0.058	1998–2004	2–8
1997	0.41	0.073	1998–2008	1–11	0.62	0.078	1999–2003	2–6
1998	0.45	0.063	1999–2007	1–9	0.53	0.044	1999–2005	1–7
1999	0.35	0.140	2002–2009	2–9	0.55	0.081	2001–2005	2–6
2000	0.34	0.219	2003–2010	3–10	0.60	0.084	2001–2007	1–7
2001	0.46	0.108	2003–2011	2–10	0.65	0.050	2003–2008	2–7
2002	0.38	0.059	2003–2011	1–9	0.72	0.135	2004–2007	2–5
2003	0.41	0.037	2005–2012	2–9	0.69	0.068	2005–2010	2–7
2004	0.41	0.031	2006–2017	2–13	0.56	0.065	2005–2010	1–6
2005	0.44	0.035	2007–2017	2–12	0.56	0.061	2006–2012	1–7
2006	0.49	0.065	2010–2020	4–14	0.56	0.086	2007–2010	1–4
2007	0.38	0.036	2008–2018	1–11	0.61	0.049	2008–2015	1–8
2008	0.42	0.065	2011–2020	3–12	0.75	0.042	2009–2015	1–7
2009	0.34	0.035	2011–2022	2–13	0.51	0.047	2010–2015	1–6
2010	0.37	0.021	2012–2022	2–12	0.63	0.037	2011–2017	1–7
2011	0.44	0.045	2014–2022	3–11	0.57	0.069	2012–2018	1–7
2012	0.36	0.055	2014–2022	2–10	0.51	0.045	2013–2019	1–7
2013	0.51	0.059	2016–2022	3–9	0.84	0.046	2014–2019	1–6
2014	0.48	0.064	2016–2022	2–8	0.67	0.042	2015–2021	1–7
2015	0.45	0.420	2016–2021	2–7	0.53	0.041	2016–2022	1–7
2016	0.49	0.047	2018–2022	2–6	0.70	0.062	2017–2022	1–6
2017	0.49	0.082	2019–2022	2–5	0.60	0.095	2018–2022	1–5

Abundance of Yellow Perch as indicated by the mean gillnet CPUE ranged from a low of 33.4 fish/net lift in 2018 to a high of 63.4 fish/net lift in 2021, (Table 5), but was not significantly different among survey years (KW test, $H = 2.549$ df = 4, P = 0.636). The five-year mean gillnet CPUE of Yellow Perch declined from the previous reporting period (2012–2017 at 51.1 to 2018–2022 at 46.2), but that difference was not significant (MW-U, $H = 0.612$, df = 1, $P = 0.434$).

Five to seven Yellow Perch year classes were typically reflected in the gillnet collection (Appendix 12). Yellow Perch grow fast in Saginaw Bay, averaging about 61 mm more than the statewide average in the growth index (Table 7). Mean *Wr* as an expression of condition was high for Yellow Perch ranging from 91 to 101 for the reporting period (Appendix 10). Proportions of the Yellow Perch population stock size (130 mm) and larger indicated a high proportion of preferred (250–300 mm) and memorable (300–380 mm) sized fish (Appendix 11).

The derived total annual mortality rate of Yellow Perch ages 1–5 was 0.58 using the point-in-time catch curve method and 0.60 from the cohort method (Tables 9 and 10 respectively). These rates, however, are eclipsed by the annual mortality rates between age-0 and age-1 (Figure 6). The annual mortality from young-of-the-year to yearling has been as much as 99% (2003) and has averaged 85% since 2003 compared to just 67% going back to 1986.

Length-weight regression equations and Von Bertalanffy growth equations for Walleye and Yellow Perch are presented in Appendix 13.

DISCUSSION

Walleye

Walleye remain in high abundance in Saginaw Bay since first attaining recovery targets in 2009. The surge in the Walleye population is attributed to increased reproductive success after its release from the deleterious effects of Alewives (Fielder et al. 2007). Modeling performed by the MDNR estimates that the Saginaw Bay Walleye stock numbers more than 10 million age-2 and older fish (Fielder and Bence 2014, MDNR unpublished data). A clear periodicity in reproductive success has become apparent in the trawling time series, with the catch rate of age-0 Walleye typically showing three strong years of production separated by a single weaker year of production (Figure 4). Ivan et al. (2011) examined this time series from 1970 to 2008 and concluded that Walleye year class strength was set by the fall age-0 abundance. Previously, Fielder and Thomas (2014) and Fielder et al. (2022) reported that such a relationship was no longer the case. Updating that analysis with data through 2022 further reinforces that age-0 Walleye CPUE is no longer a useful indicator of year class strength (Figure 7). Examination of older ages indicates that age-2 is the first age that can be used to predict the majority of the following year's CPUE (Figure 8) suggesting that year class strength is not set until age-2 in the post-recovery period. It is unclear what exactly is determining Walleye year class strength at later ages but it is likely some density-mediated phenomenon.

Fielder et al. (2007) examined what factors were most predictive of Walleye recruitment in Saginaw Bay. While some spring weather factors were statistically significant, the strongest predictor at the time was the abundance of invasive Alewives, because the Alewife is a formidable predator and competitor on newly hatched percid fry. Fielder and Baker (2004) invoked Walters and Kitchell (2001) cultivation/depensation hypothesis where a high-density predatory population (Walleye in Saginaw Bay's case) will groom the prey community (specifically Alewife) to promote good survival of their progeny. This depensatory dynamic is in contrast to conventional compensatory stock-recruitment relationships. Fielder and Baker (2004) were likely correct as indicated by the findings of Fielder et al. (2007), however since the disappearance of Alewives from most of Lake Huron and Saginaw Bay in 2003, Saginaw Bay's Walleye population has exhibited a strong compensatory dynamic where recruitment is greatest at smaller stock sizes (adult Walleye density) and greater stock sizes reduce juvenile Walleye survival resulting in years of lower recruitment.

Fielder et al. (2007) elected to model Walleye recruitment in Saginaw Bay based on a Ricker stock-recruitment function (Ricker 1954; Hilborn and Walters 1992) where recruitment is regulated by density effects of the entire stock of that species. This is in contrast to the Beverton-Holt function that is reflective of recruitment being a function of the magnitude of the cohort in question. Alewife abundance was such a strong determinant in Fielder et al. (2007) analysis that all other factors were not substantially relevant. Fielder et al. (2016), however, needed a Walleye recruitment function to generate recruitment estimates in a stochastic simulation model for Saginaw Bay Walleye and opted for a multivariate version from Fielder et al. (2007) that included both Alewife density and Walleye stock size. In the absence of Alewives, the relationship becomes functionally a more traditional stock-recruitment formula that was once again based on the Ricker formula. We find the patterns of reproductive success as indicated by the trends in abundance of age-0 Walleye (Figure 4), where recruitment is punctuated after about every three years with a weaker year class, to be consistent with compensatory effects but interestingly year class strength isn't set until age-2. Apparently, additional factors are driving juvenile survival from age-0 to age-1 and then onto age-2 (recruitment) that may not be fully related to adult density. Those forces are less clear but may depend partly on prey availability and growth rate determining how quickly juveniles can grow out of sizes of vulnerability to predation. Krabbenhoft et al. (2023) found prey availability and spring environmental conditions to be primary drivers of Walleye recruitment in Great Lakes populations. Cahill et al. (2022) documented cyclic Walleye recruitment patterns in some Wisconsin lakes with pulses about every 6 to 10 years and reported that they can be caused by delayed mortality such as cannibalism or environmental effects. Little or no Walleye cannibalism has been documented in Saginaw Bay, at least not at the time of observation in the early fall (Table 4; Table 6).

While Walleye in Saginaw Bay grow faster than the state average (Figure 9) and faster than they did historically (Table 7) they are still much slower growing than they were prior to recovery. Walleye growth rates are often density-dependent (Bozek et al. 2011). Walleye growth rate also declined in Lake Erie as that population recovered (Muth and Wolfert 1986). Growing degree days is fundamental to determining Walleye growth rates across latitudinal or regional range (Venturelli et al. 2010), but within a single body of water, growth will hinge more on prey availability, density of adult Walleye (intraspecific competition, and thus can be affected by fishing mortality Lester et al. 2014), density of other predators (interspecific competition) and water temperature (Pedersen et al. 2018; Madenjian et al. 1996). Compounding the decline in Walleye growth rate is the disappearance of Alewives from the bay's fish community and the fact that growth rate is ultimately a function of competition (density) and prey availability. Generally, it appears that Walleye have prey-switched (Table 4; Table 6) to other prey species. The decline in condition as indicated by *Wr* (Figure 10) is consistent with slower growth as density has increased. While a statistically significant decline in condition, the drop in *Wr* is only from a mean of 89 pre-recovery to a mean of 83 post-recovery.

Onset of Walleye sexual maturity peaked in the 2012–2017 period but declined some in this reporting period (Table 8). The general trend of later onset of maturity in both male and female Walleye is consistent with slower growth as the population density has increased. Slower growth presumably indicates that allocation of energy and growth to gametes is delayed until somatic growth reaches certain sizes. The same phenomenon was observed in Lake Erie when that Walleye population recovered (Muth and Wolfert 1986). Currently, the Saginaw Bay recreational Walleye fishery is regulated with a 330 mm minimum length limit for harvest. Applying this to the Von Bertalanffy growth equation in Appendix 13 for females, equates to an age of 2.94 years. This compares closely with the age of 50% maturity (3.04 years; Table 8) meaning that it is likely that some immature female Walleyes are being harvested before spawning once.

Total annual mortality rate was within sustainable limits during the reporting period with the point-in-time catch curve estimate at 43% (Table 9) and 49% for the 2016 cohort between 2018 and 2022 (Table 10). The MDNR maintains two additional studies that produce estimates of total annual mortality. An annual jaw tagging study utilizing a Brownie style analysis (Fielder 2014) indicates an A value of 48% between 2018 and 2022 (MDNR unpublished data) which compared closely with the cohort-based estimate. The other value of A is 31% from the statistical-catch-at-age (SCAA) model analysis (Fielder and Bence 2014). The SCAA derived estimate may be more sensitive to the lower mortality rates of younger age classes and is regarded as a state-of-the-art method. From this we can conclude that total annual mortality was somewhere between 31% and 49% over the reporting period. The Saginaw Bay management plan (Jolley et al. 2024) for the Walleye recreational fishery defines the target ranges for A as being between 30% and 40% and principally relies on the SCAA estimate for that metric.

The diet of Walleye in Saginaw Bay underwent a shift in 2003 from one dominated by clupeids (Alewives and Gizzard Shad) to a more diverse diet that features Yellow Perch as a prominent item (Table 4; Table 6). Yellow Perch were the more commonly encountered dietary item eaten by Walleye in the majority of years since 2018 with Gizzard Shad the next most frequently consumed item. The invasive Round Goby also figures prominently as a dietary item in most years. Onboard specimen processing does not include attempts at length and weights on dietary items as they are often too far along in digestion to be accurate, but technicians conducting the examination relay that the Yellow Perch often appear to be juveniles, either age-0 or yearlings. This is consistent with the high mortality observed between age-0 and age-1 Yellow Perch in recent years (Figure 6). It is worth noting that diets reported in this time series are reflecting those Walleyes that are remaining resident to the bay or have returned to the bay from the main basin. A previous telemetry study indicated that 37% of the bay's Walleye make an emigration from the bay to the main basin for the summer and early fall months (Hayden et al. 2014). Pothoven et al. (2017) compared diets of Walleyes between those resident to the bay and those inhabiting the main basin. Main basin Walleyes tended to consume Rainbow Smelt and

Round Goby. That study concluded that bay resident Walleyes need to consume 10% to 18% more food than a Walleye that inhabits the cooler main basin for the same time period to achieve similar growth rates.

Yellow Perch

The Yellow Perch population in Saginaw Bay continues to subsist at depressed levels as indicated by both indices of abundance, the trawling catch rate (Table 1) and the gillnetting catch rate (Table 5). Yellow Perch existed at relatively high abundance and supported both substantial recreational and commercial fisheries until as recently as the early 1990s. The recreational Yellow Perch fishery harvest averaged 2.3 million/year from 1986–1994 but has declined to an average of 0.2 million/year, just 8% as much (Fielder et al. 2014). Similarly, the state-licensed commercial fishery in Saginaw Bay harvest declined from an average yield of more than 69,000 kgs/year for 1972–1994 to a little more than 10,000 kgs/year for 2018–2022, just 15% as much (Fielder et al. 2014; MDNR unpublished data).

Yellow Perch continue to reproduce well in Saginaw Bay as evidenced by the abundant annual production of fall age-0 fish (Tables 1, 2, and 3; Figure 5). Yellow Perch appear to be beneficiaries of the disappearance of Alewives just as Walleye have been. Unlike Walleyes, however, Yellow Perch are not recruiting to older ages (yearling and older; Figure 5). Fielder and Thomas (2014) explored a variety of reasons to account for the poor survival of juvenile Yellow Perch and chief among the reasons is heavy predation on age-0 Yellow Perch. Although other predators consume juvenile Yellow Perch, including the Double-Crested Cormorant (*Phalacrocorax auratus*) in Saginaw Bay (DeBruyne et al. 2017), it is primarily the abundant Walleye that are believed to be the principal limitation to juvenile Yellow Perch survival as evidenced by their diet (Table 4; Table 6). There is recognition that many Yellow Perch populations and fisheries across their range are now operating in a distressed state due to predation (Forney 1974; Craig 1987; Lyons and Magnuson 1987; Koenig 2020; Holbrook et al. 2022). However, Saginaw Bay historically sustained large fisheries for both Walleye and Yellow Perch (Baldwin et al. 2009) so there appears to be no intrinsic reason why the bay environment shouldn’t be able to still achieve such productivity. Similarly, Walleye and Yellow Perch coexist with both in high abundance in Lake Erie (Lake Erie Committee 2020), although Walleye predation has also been implicated in limiting Yellow Perch there as well (Hartman and Margraf 1993; Zhang et al. 2018).

Fielder et al. (2022) hypothesized that, historically, Yellow Perch were likely buffered from predation by the abundant pelagic planktivores from the main basin of Lake Huron. Cisco produced an enormous annual fishery in Saginaw Bay up until the 1940s and the bay served as spawning and nursery grounds for their progeny. Cisco were largely supplanted by Alewives, which offered that same predatory buffer up until their collapse in 2003. The annual onshore migration and habitation of the bay by abundant pelagic planktivores constituted a critical trophic link between the main basin and the bay. The link has not been restored so far. It remains to be determined if the recent efforts at Cisco stocking are successful or not, but if so, it is hoped and expected that juvenile Yellow Perch survival would improve.

In an effort to address the poor survival of juvenile Yellow Perch, the Michigan DNR imposed liberalized Walleye harvest regulations in the recreational fishery in 2015. As an experimental management strategy, it was hypothesized that increased harvest of Walleye might reduce predation on juvenile Yellow Perch, and result in improved survival and ultimately perch recruitment. By 2021, it was evident that the liberalized harvest regulations, while partially successful at increasing harvest, were not succeeding in reducing the overall Walleye population. Unpublished analysis by the Michigan DNR indicated that any reductions in the Walleye population only reduced the spawning stock such that the compensatory stock-recruitment dynamic resulted in greater production of Walleye year classes. In fact, the Walleye population in Saginaw Bay has grown to record modern highs since the implementation of the liberalized harvest regulations. This recognition led the Michigan DNR to develop a new recreational fishery management plan for Walleye and Yellow Perch that now strives for sustainability and quality of the Walleye fishery and to sustain Yellow Perch from further losses until conditions can improve to favor their recruitment (Jolley et al. 2024).

Total annual mortality rate for Yellow Perch between age-0 and age-1 has increased, consistent with the predation hypothesis. The mean annual mortality rate of 85% since 2003 represents a significant increase over the prior rate of 67%. Predation likely continues to be major source of mortality for age-1 Yellow Perch, which further erodes year class strength prior to recruitment to the fisheries in the bay. Adult total annual mortality is also high although there is not full agreement between estimates generated from the trawling collection (79% for the reporting period) and those collected from the gillnets (58% point-in-time estimate and 60% for the cohort-based estimate). The reason for the discrepancy is unclear, but possibly trawling is more efficient at capturing juvenile Yellow Perch and thus reflects a more comprehensive age distribution compared to gillnetting. Fishery harvest can exceed sustainable levels for Yellow Perch populations and lead, or at least contribute, to collapses (Wilberg et al. 2005). It appears that the decline of Yellow Perch in Saginaw Bay is recruitment driven but the adult total annual mortality rate may be excessive in light of this poor recruitment.

The early onset of maturity of Yellow Perch (age-1 for females and the majority of males maturing by the fall as age-0) may be a reflection of their high mortality rate (Feiner et al. 2017). Hayes and Taylor (1990) further found that early Yellow Perch maturity was induced by high adult mortality and shifts in age-at-maturation are most pronounced when Yellow Perch diet spans zooplankton, benthos and fish, as is likely the case in Saginaw Bay. Directing energy to gonadal development at an early age may come at a cost to somatic growth whereby leaving young fish vulnerable to predation longer and exacerbating the high mortality rate (between age-0 and age-1). Once past that point, however, Yellow Perch are growing fast in Saginaw Bay, presumably due to consuming a full fish diet as opposed to zooplankton and benthos.

Prey fish base

The prey base of Saginaw Bay no longer features abundant pelagic planktivores that may enter the bay from the main basin and use the bay for spawning or nursery grounds. That trophic link was last expressed by Alewives which became scarce in the lake and bay beginning in 2003. Another forage species to decline over time has been Rainbow Smelt (Table 1). While a clupeid closely related to Alewives, Gizzard Shad have not expanded in abundance in the bay but still figure somewhat prominently overall in the forage base. Trout-Perch are abundant but are almost never observed in the diet of Walleye (Table 6; Blouzdis et al. 2013). Some of the rise of the overall forage index (Figure 3) in recent years has been driven by gains in one or two forage species. The most striking has been the strong production of the native cyprinid, Mimic Shiner. Mimic Shiners are noted to exhibit various patterns of diel inshore/offshore movement possibly as a predator avoidance adaption (Scott and Crossman 1979; Hanych et al. 1983). Round Goby are also an abundant feature of the prey base and likely underestimated by trawling (Foley et al. 2017) given their preference for rocky habitat which is difficult to effectively sample with a trawl. While the trawl-based forage CPUE and index (Table 1; Figure 3) is an important metric for monitoring, the growth rate of Walleye (Table 7; Figure 9) may offer the best indicator of predator/prey balance in the bay.

Other species

Cisco is a species of conservation importance in Lake Huron and Saginaw Bay (Latta 2005) and the target of a reintroduction effort using the bay as a stocking location (LHTC 2007). The prescribed evaluation plan for gauging success of that reintroduction includes this study. While no Cisco have been collected by gillnetting and trawling so far, they have been collected in other targeted collection efforts (USFWS unpublished data). The next five-year cycle of monitoring will likely be the most indicative of any success of the Cisco reintroduction effort.

The encounter of two Lake Sturgeon in 2021 and one in 2022 represents the first collected since the beginning of monitoring in 1971. Historically they provided annual yields in the fishery as great as 25,000 kg (Baldwin et al. 2009). Stocking of Lake Sturgeon fingerlings was implemented by the MDNR and USFWS in tributaries to the Saginaw River in 2018 targeting at least 2,000 fingerlings released each year. Juvenile Lake Sturgeon have become a common encounter in the recreational and commercial fisheries as well. Origin has been confirmed from the presence of passive integrated transponder (PIT) tags in recaptured fish.

Invasive species and climate change

Based on habitat suitability, Saginaw Bay is very susceptible to invasion by invasive carp species such as Bighead Carp and Silver Carp. These invasive species have become abundant in the Mississippi and Illinois Rivers and while not established in the Great Lakes so far, they are spatially close and considered a dangerous possibility (Davidson et al. 2017). Saginaw Bay is predicted to offer ideal ecological conditions for invasive carp and they are anticipated to thrive there if they are ever able to invade (Ivan et al. 2020). Ruffe, a European invasive species has been documented in northern Lake Huron and the St. Marys River. If this perch-like fish ever invades Saginaw Bay, it is likely Yellow Perch would be most affected. Newman et al. (2020) determined Ruffe have a considerable diet overlap with Yellow Perch and that abundant Ruffe will result in slower growth of Yellow Perch.

It is unclear what is driving the observed trend of increasing water temperature (Figure 2), but it is consistent with the climate change phenomenon and the prolonged summer stratification in late summer and early fall (Collingsworth et al. 2017; Xue et al 2022). Recent work (Meyer 2024) has documented the occurrence of summer low levels of dissolved oxygen, hypoxia, in certain parts of Saginaw Bay, usually coinciding with late summer warming and low wind conditions. It is hypothesized that the frequency of summer hypoxia will increase with increasing temperatures stemming from climate change. Peat et al. (2015) concluded that Saginaw Bay Walleyes that emigrate from the bay into the main basin during the summer are likely motivated by cooler, more optimal water temperatures and that may, in turn, translate into a growth advantage. By extrapolation, increasing water temperatures in Saginaw Bay may motivate more Walleye to emigrate from the bay for parts of the year and may affect growth (Pothoven et al. 2017) either by slowing (due to greater energetic demands in the bay) or possibly increasing as a result of a longer growing season. The increase in water clarity in Saginaw Bay is consistent with trends documented across the Great Lakes and is attributed to warmer climate, reduced phosphorus loading, and invasion by dreissenid mussels (Dobiesz and Lester 2009). Collectively, changing water temperature and clarity represent added uncertainty over the future of the Saginaw Bay fish community.

RECOMMENDATIONS

1. Continue this fish community netting survey as designed. This survey series has proven valuable in gauging the status of key fish populations within Saginaw Bay. The catch rates and age structure are important inputs to the Saginaw Bay Walleye SCAA model and some of the metrics generated by this study are directly used in the Saginaw Bay Walleye and Yellow Perch Recreational Management Plan.
2. Maintaining a high Walleye abundance in the bay may be the best defense against colonization by new invasive species and against the resurgence of Alewives.
3. Lake Sturgeon fingerling stocking appears to yield good survival and stocking should continue.
4. Develop SCAA model for Yellow Perch in Saginaw Bay. It would greatly elucidate the status of that important fish population.

SUPPLEMENTARY MATERIAL

Supplementary material is available on MDNR Fisheries Division’s online library catalog, FishCat. To accommodate readers viewing a printed version of this article, the URL for the supplementary material is https://www2.dnr.state.mi.us/publications/pdfs/DNRFishLibrary/FisheriesReports/FR045_supp_material.xlsx.

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APPENDICES

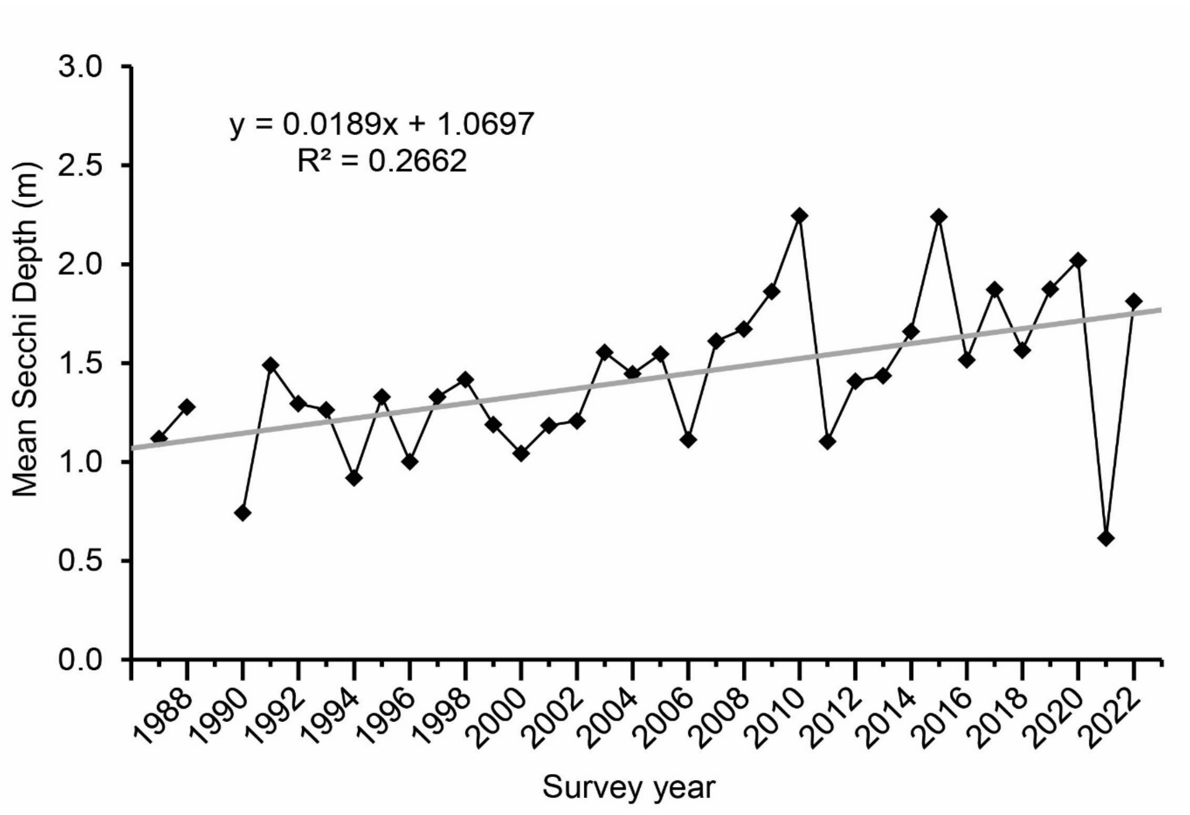
APPENDIX 1. Common and scientific names of fishes and other aquatic organisms mentioned in this report.

Common name	Scientific name
Alewife	*Alosa pseudoharengus*
Bighead Carp	*Hypophthalmichthys nobilis*
Black Carp	*Mylopharyngodon piceus*
Black Crappie	*Pomoxis nigromaculatus*
Bluegill	*Lepomis macrochirus*
Bowfin	*Amia calva*
Brown Bullhead	*Ameiurus nebulosus*
Brown Trout	*Salmo trutta*
Burbot	*Lota lota*
Channel Catfish	*Ictalurus punctatus*
Chinook Salmon	*Oncorhynchus tshawytscha*
Cisco	*Coregonus artedi*
Common Carp	*Cyprinus carpio*
Emerald Shiner	*Notropis atherinoides*
Eurasian Ruffe	*Gymnocephalus cernua*
Freshwater Drum	*Aplodinotus grunniens*
Gizzard Shad	*Dorosoma cepedianum*
Golden Redhorse	*Moxostoma erythrurum*
Goldfish	*Carassius auratus*
Johnny Darter	*Etheostoma nigrum*
Lake Sturgeon	*Acipenser fulvescens*
Lake Trout	*Salvelinus namaycush*
Lake Whitefish	*Coregonus clupeaformis*
Largemouth Bass	*Micropterus salmoides*
Logperch	*Percina caprodes*
Longnose Gar	*Lepisosteus osseus*
Longnose Sucker	*Catostomus catostomus*
Mimic Shiner	*Notropis volucellus*
Muskellunge	*Esox masquinongy*
Northern Pike	*Esox lucius*
Northern Redhorse	*Moxostoma macrolepidotum*
Pumpkinseed	*Lepomis gibbosus*
Quillback	*Carpiodes cyprinus*
Rainbow Smelt	*Osmerus mordax*
Redhorse spp.	*Moxostoma* spp.
Rock Bass	*Ambloplites rupestris*
Round Goby	*Neogobius melanostomus*
Round Whitefish	*Prosopium cylindraceum*
Ruffe	*Gymnocephalus cernua*
Shorthead Redhorse	*Moxostoma macrolepidotum*
Silver Carp	*Hypophthalmichthys molitrix*
Smallmouth Bass	*Micropterus dolomieu*
Spottail Shiner	*Notropis hudsonius*

APPENDIX 1. continued.

Trout-Perch	*Percopsis omiscomaycus*
Walleye	*Sander vitreus* formerly *Stizostedion vitreum*
White Bass	*Morone chrysops*
White Crappie	*Pomoxis annularis*
White Perch	*Morone americana*
White Sucker	*Catostomus commersoni*
Yellow Perch	*Perca flavescens*

APPENDIX 2. Mean Secchi disk transparency recorded during fall trawling on Saginaw Bay, 1987–2022. No Secchi depth data were recorded in 1989. Gray line represents linear regression line with line equation inset in the graphic. The regression line is statistically significant (F = 11.972, df = 34, P = 0.002). Starting in 2019, turbidity was measured instead of Secchi depth. Secchi depth values since 2019 were calculated from turbidity measurements using the equation: Secchi depth = $4.89267 * turbidity^{-0.67425}$.



APPENDIX 3. Mean catch-per-unit-effort (number of fish per 10-min tow) for common species collected during fall bottom trawling in Saginaw Bay, 2010–2022, including data previously reported by Fielder and Thomas (2014), and Fielder et al. (2022). See supplementary material for results from additional survey years.

Species	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Alewife	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	4.0	0.0	0.0	0.0
Channel Catfish	0.4	0.6	1.6	3.0	0.5	0.1	0.2	0.3	0.5	0.5	0.3	0.5	0.5
Common Carp	3.7	3.9	4.0	2.4	2.1	1.8	2.3	2.0	1.6	1.7	0.8	1.1	0.8
Emerald Shiner	0.5	10.6	4.8	7.1	39.0	4.2	3.0	16.0	4.1	0.4	2.3	0.8	2.2
Freshwater Drum	5.6	19.3	82.0	16.4	12.8	4.4	7.1	8.9	4.8	10.8	7.5	5.8	5.5
Gizzard Shad	6.6	15.3	38.2	40.0	16.5	26.9	15.3	42.3	8.9	14.1	29.6	31.1	8.6
Johnny Darter	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 Whitefish	0.7	0.1	0.0	0.0	0.1	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0
Mimic Shiner	132.6	375.7	962.3	661.8	43.2	411.2	430.0	403.5	240.5	185.4	452.8	666.0	246.5
Quillback	0.7	0.9	0.6	0.7	0.7	0.2	0.4	0.5	0.1	0.4	0.1	0.3	0.4
Rainbow Smelt	5.7	500.6	1.0	70.9	2.6	89.8	10.2	10.3	27.6	67.4	11.7	27.8	2.2
Rock Bass	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Round Goby	209.1	123.5	81.5	85.7	165.2	436.7	123.2	108.7	27.3	125.9	98.7	214.1	112.5
Shorthead Redhorse	0.0	0.1	0.0	0.0	0.1	0.1	0.0	0.2	0.0	0.0	0.0	0.0	0.1
Spottail Shiner	86.6	228.3	99.8	130.3	11.2	12.7	21.9	26.8	10.5	8.2	7.6	20.5	32.4
Trout-Perch	297.0	383.9	542.8	429.3	97.0	122.0	554.3	329.1	203.6	206.8	134.4	376.1	280.6
Walleye	36.1	35.0	19.6	30.9	32.8	30.0	11.3	31.5	32.6	32.8	16.8	42.8	51.4
White Bass	12.3	13.8	8.8	15.4	4.4	10.1	4.8	5.5	9.7	10.4	1.6	2.7	12.1
White Perch	452.5	238.6	223.8	51.2	54.3	142.8	350.4	35.8	73.3	96.4	772.9	354.2	215.6
White Sucker	5.3	9.6	4.1	3.6	4.7	4.9	3.6	3.6	4.1	3.7	2.7	2.0	2.2
Yellow Perch	240.1	202.3	143.0	164.9	73.4	197.0	149.7	187.9	172.2	97.9	434.3	287.2	114.4
Number of tows	24	27	24	24	24	24	24	24	24	24	8	24	24

APPENDIX 4. Total number captured, mean catch-per-unit-effort (number per 10-min tow), and mean total length of age-0 Walleyes (mm) collected from fall trawl samples in Saginaw Bay, 2010–2022. 2SE = two standard errors of the mean. Mean length data not available prior to 1998 or for 2001. See **supplementary material** for results from additional survey years.

Survey year	Total number captured	Mean catch rate	2SE	Mean length	2SE
2010	576	30.8	14.1	119	1.7
2011	599	29.9	8.9	134	1.3
2012	243	11.8	2.9	142	2.8
2013	603	27.3	8.6	117	1.4
2014	539	23.3	6.0	120	1.9
2015	595	29.9	8.3	109	1.7
2016	149	6.2	2.2	147	3.0
2017	638	26.6	8.5	118	1.9
2018	661	29.8	6.6	112	1.9
2019	597	26.5	5.2	113	2.9
2020	60	7.6	5.6	167	5.3
2021	831	36.8	17.5	129	3.1
2022	991	46.7	9.6	115	3.3

APPENDIX 5. Mean male to female sex ratio (M/F), by age, of Yellow Perch in Saginaw Bay from fall trawl samples collected since the Alewife collapse in 2003 (2003–2022). CI = confidence interval; N = number of years with data available in the time period.

Age	M/F ratio	95% CI	N
1	1.06	0.96–1.15	20
2	0.72	0.60–0.84	20
3	0.75	0.61–0.89	19
4	1.73	1.04–2.42	12
5	3.71	0.65–6.77	4
6	4.99	—	1
All ages	1.00	0.91–1.08	20

APPENDIX 6. Mean length-at-age (mm) of Yellow Perch collected from fall trawl samples in Saginaw Bay, 2018–2022. SWA = fall statewide average (Schneider 2000).

Males

Age	SWA	2018	2019	2020	2021	2022	Five-year mean
Age-1	—	142	131	101	137	136	129
Age-2	—	197	203	140	208	193	188
Age-3	—	233	250	—	243	231	239
Age-4	—	256	265	—	—	—	261
Age-5	—	—	—	—	—	—	—
Age-6	—	—	—	—	—	—	—

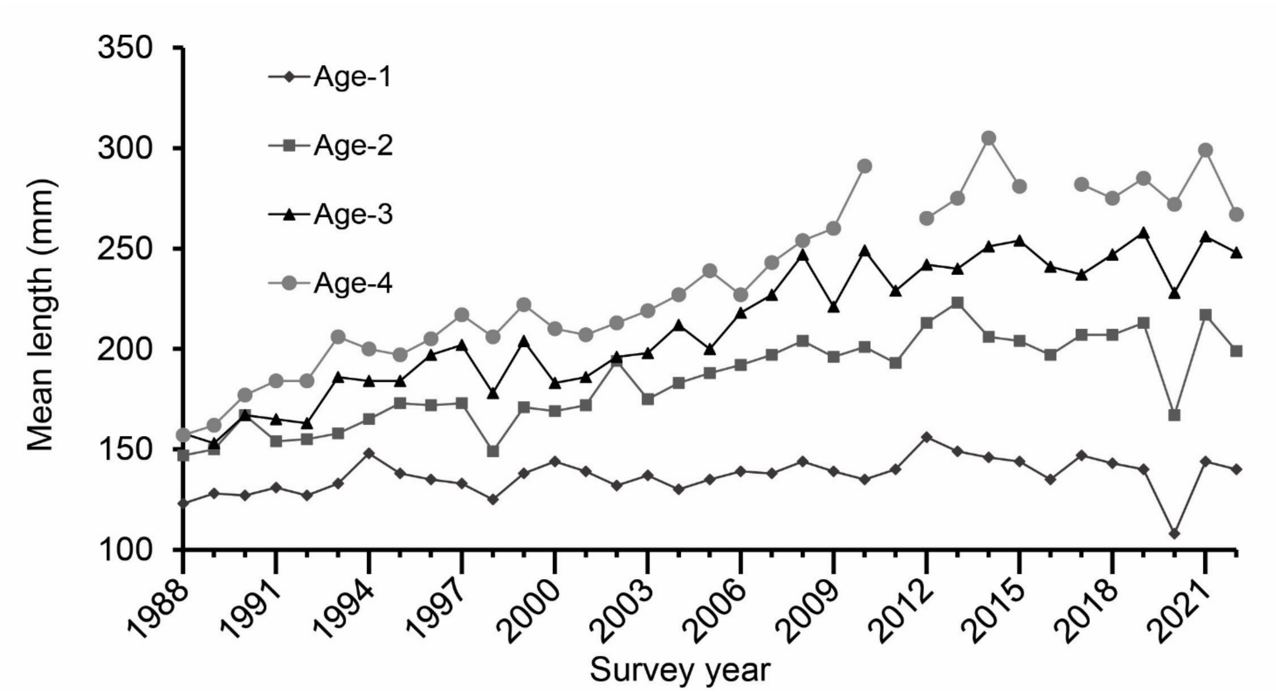
Females

Age	SWA	2018	2019	2020	2021	2022	Five-year mean
Age-1	—	143	146	115	151	145	140
Age-2	—	212	217	182	222	207	208
Age-3	—	260	267	228	260	258	255
Age-4	—	313	298	272	299	280	292
Age-5	—	—	—	—	—	289	289
Age-6	—	—	—	—	—	—	—

Sexes Combined

Age	SWA	2018	2019	2020	2021	2022	Five-year mean
Age-1	127	143	140	108	144	140	135
Age-2	160	207	213	167	217	199	201
Age-3	183	247	258	228	256	248	247
Age-4	208	275	285	272	299	267	280
Age-5	234	—	—	—	—	289	289
Age-6	257	—	—	—	—	—	—

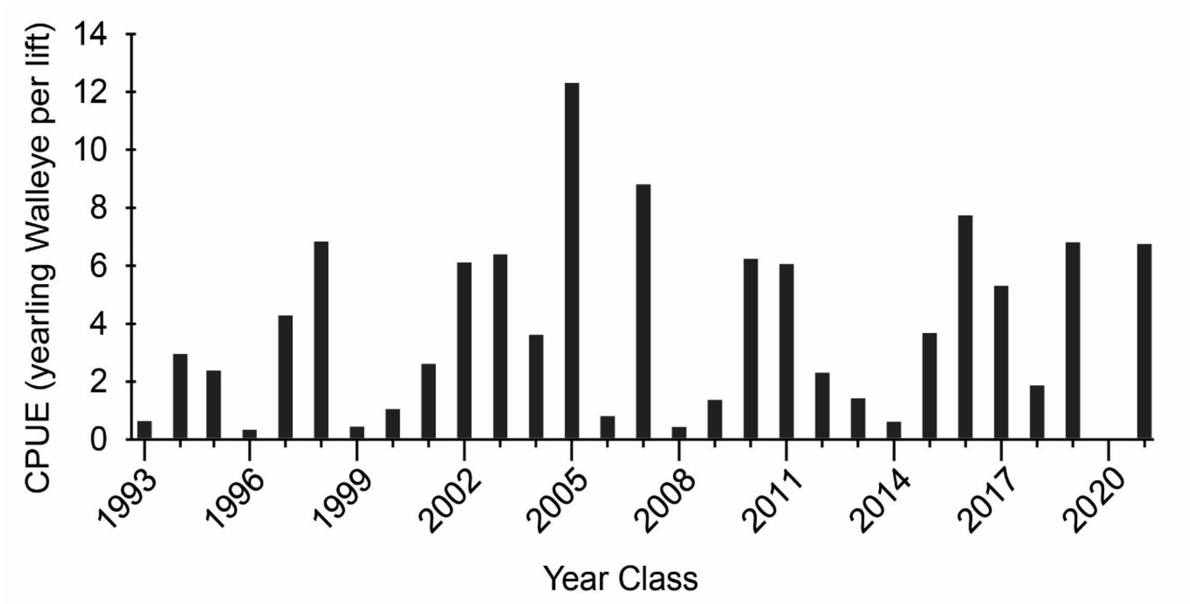
APPENDIX 7. Mean length-at-age during September for Yellow Perch (sexes combined) from Saginaw Bay trawls, 1988–2022. Statewide average lengths: age-1 = 127 mm, age-2 = 160 mm, age-3 = 183 mm, age-4 = 208 mm (Schneider 2000).



APPENDIX 8. Catch-per-unit-effort (CPUE, number per 335-m gillnet lift) by year class of Walleye in fall gillnet survey catches, Saginaw Bay, 2018–2022. Total CPUE values are based on aged sample and therefore may differ slightly from the value reported in Table 5. See supplementary material for results from additional survey years.

Year class	2018 Age	2018 CPUE	2019 Age	2019 CPUE	2020 Age	2020 CPUE	2021 Age	2021 CPUE	2022 Age	2022 CPUE
2022	—	—	—	—	—	—	—	—	0	0.06
2021	—	—	—	—	—	—	0	0.19	1	6.69
2020	—	—	—	—	0	0.38	1	8.75	2	15.06
2019	—	—	0	0.19	1	6.75	2	10.81	3	6.38
2018	0	1.00	1	1.81	2	6.25	3	5.50	4	2.31
2017	1	5.25	2	7.00	3	6.56	4	3.63	5	1.63
2016	2	18.19	3	12.38	4	7.38	5	3.75	6	1.50
2015	3	9.63	4	5.94	5	3.69	6	2.19	7	1.75
2014	4	2.00	5	0.88	6	0.38	7	0.56	8	0.13
2013	5	1.13	6	1.06	7	1.06	8	0.63	9	0.31
2012	6	1.06	7	0.69	8	0.75	9	0.25	10	0.38
2011	7	1.06	8	0.94	9	0.63	10	0.81	11	0.25
2010	8	1.69	9	0.69	10	0.63	11	0.44	12	0.13
2009	9	0.25	10	0.25	11	0.06	—	—	—	—
2008	10	0.13	11	0.19	12	0.06	13	0.06	—	—
2007	11	0.13	—	—	13	0.00	—	—	—	—
2006	—	—	—	—	14	0.06	—	—	—	—
2005	—	—	—	—	—	—	16	0.06	—	—
Mean age	2.8		3.4		3.4		3.2		2.9	
Total CPUE		41.50		32.00		34.63		37.63		36.63

APPENDIX 9. Walleye year-class strength as determined by gillnet catch-per-unit-effort (CPUE) of yearling Walleye in Saginaw Bay for year classes 1993–2021. Data for year classes 1993–1996 from Fielder et al. (2000), year classes 1997–2004 from Fielder and Thomas (2006), year classes 2005–2011 from Fielder and Thomas (2014), and year classes 2012–2017 from Fielder et al. (2022).



APPENDIX 10. Mean *Wr* by size structure category (Gabelhouse 1984; Anderson and Weithman 1978; Anderson and Gutreuter 1983) and all sizes combined for Walleyes and Yellow Perch collected from fall gillnets in Saginaw Bay, 2010–2022. N = number of fish sampled. See supplementary material for results from additional survey years.

Size structure category

Walleye

Survey year	Stock-quality (250-380 mm)	Quality-preferred (380-510 mm)	Preferred-memorable (510-630 mm)	All sizes combined	N
2010	91	88	88	89	465
2011	72	72	72	72	528
2012	82	82	85	83	699
2013	84	81	80	82	535
2014	76	74	66	74	472
2015	82	83	80	83	341
2016	87	86	85	86	733
2017	86	83	83	85	788
2018	87	85	84	86	663
2019	89	83	79	85	512
2020	94	88	88	91	554
2021	88	85	85	87	596
2022	84	83	80	83	583

Yellow Perch

Survey year	Stock-quality (250-380 mm)	Quality-preferred (380-510 mm)	Preferred-memorable (510-630 mm)	All sizes combined	N
2010	88	90	90	90	367
2011	89	83	79	88	420
2012	95	91	89	93	399
2013	88	90	91	89	228
2014	100	83	88	97	219
2015	101	98	94	99	565
2016	92	90	92	91	405
2017	96	97	94	96	481
2018	91	94	95	93	275
2019	99	101	98	99	436
2020	100	94	96	98	399
2021	99	97	93	97	561
2022	96	96	95	96	348

APPENDIX 11. Walleye and Yellow Perch proportional stock density (PSD)[a] and relative stock density (RSD) (with RSD-Preferred and RSD-Memorable shown in parentheses)[b] from fall gill-net data, 2018–2022 from Saginaw Bay, Lake Huron.

Species	2018	2019	2020	2021	2022
Walleye	66(6,0)	76(8,0)	68(9,0)	62(15,1)	68(12,0)
Yellow Perch	69(41,4)	39(21,6)	46(22,6)	51(18,4)	45(18,3)

[a] Stock and quality size for Walleye is 250 mm and 380 mm, respectively. For Yellow Perch they are 130 mm and 200 mm, respectively. 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).

[b] 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).

APPENDIX 12. Catch-per-unit-effort (CPUE, number per 335-m gillnet lift) by year class for Yellow Perch collected from fall gillnet samples in Saginaw Bay, 2018–2022. Total CPUE values are based on aged sample and therefore may differ slightly from the value reported in Table 5. See supplementary material for results from additional survey years.

Year class	2018 Age	2018 CPUE	2019 Age	2019 CPUE	2020 Age	2020 CPUE	2021 Age	2021 CPUE	2022 Age	2022 CPUE
2022	—	—	—	—	—	—	—	—	—	—
2021	—	—	—	—	—	—	—	—	1	17.7
2020	—	—	—	—	0	0.1	1	31.6	2	16.0
2019	—	—	—	—	1	20.1	2	27.8	3	7.0
2018	0	0.7	1	27.3	2	18.3	3	7.8	4	1.1
2017	1	14.3	2	10.6	3	6.5	4	1.6	5	0.2
2016	2	11.5	3	6.4	4	1.5	5	1.4	6	0.3
2015	3	16.2	4	7.6	5	24.3	6	0.4	7	0.1
2014	4	2.8	5	2.8	—	—	7	0.1	—	—
2013	5	0.7	6	0.1	—	—	—	—	—	—
2012	6	0.2	7	0.3	—	—	—	—	—	—
2011	7	0.2	—	—	—	—	—	—	—	—
2010	—	—	—	—	—	—	—	—	—	—
2009	—	—	—	—	—	—	—	—	—	—
Number aged	279		440		406		565		355	
Mean age	2.2		2.1		2.0		1.8		1.9	
Total CPUE		33.4		60.2		40.6		63.4		33.5

APPENDIX 13. Length-weight regression equations and von Bertalanffy growth equations for Walleye and Yellow Perch. Natural log length/weight equations are based on data pooled for both sexes combined, from the fall gillnet collections in Saginaw Bay, 2018–2088. Weight (Wt) is in grams, and length (Len) is in mm. Von Bertalanffy equations are based on pooled length-at-age data from the 2018–2022 fall gillnet collections where ‘t’ is age in years.

Species	Sex	Length/Weight Equation	Len/Wt R^2	Von Bertalanffy Equation	K	L∞	t_o
Walleye	Males	ln(wt) = 3.061 ln(len)-12.001	0.98	$L_t = 528[1-e^{-0.3688(t+1.00)}]$	0.3688	528	-1.00
Walleye	Females	ln(wt) = 3.035 ln(len)-11.846	0.96	$L_t = 627[1-e^{-0.2596(t+0.06)}]$	0.2596	627	-0.06
Walleye	Combined	ln(wt) = 3.046 ln(len)-11.911	0.97	$L_t = 542[1-e^{-0.4250(t+1.36)}]$	0.4250	542	-1.36
Yellow Perch	Males	ln(wt) = 3.201 ln(1en)-12.281	0.96	$L_t = 310[1-e^{-0.4320(t+0.51)}]$	0.4320	310	-0.51
Yellow Perch	Females	ln(wt) = 3.171 ln(1en)-12.138	0.97	$L_t = 357[1-e^{-0.3856(t+0.52)}]$	0.3856	357	-0.52
Yellow Perch	Combined	ln(wt) = 3.169 ln(1en)-12.120	0.97	$L_t = 318[1-e^{-0.5008(t+0.46)}]$	0.5008	318	-0.46

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