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Abstract.–Historically, the walleye fishery in Saginaw Bay was among the largest in the Great Lakes, second only to that of Lake Erie. Walleye likely spawned in both tributaries and on offshore reefs. While exploited heavily by the commercial fishery, an average yield of over 458,000 kg per year was sustained for nearly a century. The walleye population and fishery collapsed in 1944, however, due primarily to the loss of spawning habitat as a result of sedimentation, dam construction, industrial pollution, and eutrophication. Subsequent invasions of nonnative planktivores and their competition with, and predation on, larval walleyes is thought to have exacerbated the problem and suppressed natural recovery. Water quality improvements after 1970, along with the closure of the commercial fishery for walleye that year, laid the foundation for a walleye recovery. Large-scale walleye fingerling stocking began in the early 1980s and a sport fishery emerged by 1988. Runs of spawning walleyes also began in some tributaries. Recovery of the population, however, appeared to plateau by the early 1990s, far short of the historical or biological capacity of the bay. Questions arose as to what sources of recruitment were contributing to the modern population and what was limiting the recovery of the fishery. This study sought to survey the historic reef habitat to determine its condition and utilization by spawning walleyes, and to measure the contribution of hatchery walleyes in local recruitment. I surveyed 20 historic reefs using underwater video and sonar. Two reefs were sampled for the presence of spawners, egg deposition, and larval production for years 1997-2000. I also marked hatchery walleye with oxytetracycline and examined recruits for the mark to determine percent contribution of hatchery fish. Alternate year stocking was also employed. Reef surveys indicated that nearly all inner bay reefs thought historically important to spawning walleye were of low quality, suggesting a degraded condition. Some quality reef habitat remains in the outer portion of the bay. Sampling of reefs indicated only sparse usage, few spawners collected, and little egg deposition or larvae production measured. Oxytetracycline marked hatchery fish comprised an average of 80% of four year classes of locally reproduced recruits. Similarly, recruitment from stocked years was 86% greater than recruitment from nonstocked years. From this, it is apparent that the source of local recruitment (excluding immigration) contributing to the modern population is a combination of wild fish from tributary spawning and hatchery fish, with the latter contributing the majority. To make further progress towards recovery, a series of management recommendations are offered based on an adaptive management approach. Access to tributary spawning grounds by dam removal or fish passage needs to be increased to increase that source of recruitment. Increased stocking will not directly result in increased reproduction but could facilitate a balancing of predator/prey ratios, and likely increase the Saginaw Bay walleye population and fishery. Stocking plans should consider utilization of reef spawning strains, although the poor habitat and continued presence of alewives on the reefs make the reestablishment of reef-spawning tenuous.

Saginaw Bay is a large, 2,960 km^2 embayment that lies entirely in the Michigan waters of Lake Huron. The inner bay is shallow, averaging 4.6 m in depth, while the outer bay depth averages 14.6 m. The inner and outer bays are defined by a line between Point Au Gres and Sand Point (Figure 1). There are several tributaries to the bay, the largest being the Saginaw River system. Water circulates in a counterclockwise direction (Danek and Saylor 1977) and the flushing rate is approximately 186 days (Keller et al. 1987). Coastal wetlands are scattered around the bay, particularly in the mouth of the Saginaw River and along the west and southeast shorelines. The inner portion of the bay is generally regarded as eutrophic with productivity declining towards the outer bay reaches (Beeton et al. 1967; Smith et al. 1977).

Historically, Saginaw Bay supported the largest commercial walleye (See Appendix 1 for a complete list of scientific names of fishes mentioned in this report) fishery in Lake Huron and was second in the Great Lakes to only that of Lake Erie (Baldwin and Saalfeld 1962). The earliest commercial fisheries dated to the 1830s, and walleye were specifically noted in catch records as early as 1858 (Schneider 1977). The fishery peaked in 1942 at about 930,000 kg, but then collapsed shortly after in 1944 (Baldwin and Saalfeld 1962; Keller et al. 1987). Several localized walleye fisheries collapsed around the turn of the century within Saginaw Bay due to over harvest (Schneider 1977), yet the overall open water fishery sustained an average yield of 458,000 kg from 1885 through 1950 (Figure 2). Fluctuations in the fishery during this time probably represented cyclical periods of over fishing and recovery. However, since the fishery was sustained for such a long period, the collapse in 1944 has not been attributed to the commercial fishery. Instead the collapse was attributed to a series of year class failures (Schneider 1977; Schneider and Leach 1977; Schneider and Leach 1979), although the relatively intensive exploitation by the fishery no doubt hastened the demise of the population.

The year class failures and subsequent collapse of the walleye fishery in 1944 were the culmination of a series of events that had been taking place since European settlement. The transformation of the Saginaw Bay watershed began with the large scale harvest of timber resources, peaking in the 1880s (Dunbar and May 1980). Deforestation of the region increased sedimentation of the watershed's rivers and streams (Schneider and Leach 1977). Logs were transported in rivers to sawmills. The sawmills disposed of sawdust and other wood waste in the rivers. Together, these practices further degraded the riverine spawning habitat (Schneider 1977). Sedimentation of the rivers and ultimately the bay itself continued as the principle use of the watershed transitioned to agriculture. Use of the rivers by spawning walleyes was further impeded by the construction of dams and spillways in the first half of the 1900s. Finally, portions of the region, especially along the Saginaw River system, became heavily industrialized and water quality declined drastically due to pollution (Schneider and Leach 1977; Schneider and Leach 1979).

Recruitment of walleyes from off-shore reef spawning is thought to have sustained the walleye population for some time after the loss of tributary spawning sites (Schneider and Leach 1977). Eventually, however, even the off-shore reefs, the most productive of which followed a line from the mouth of the Saginaw River to Charity Islands, failed to provide suitable spawning habitat due primarily to sedimentation (USFWS 1969; Schneider and Leach 1977; Schneider and Leach 1979; Keller et al. 1987). The year class failures that brought about the collapse of the walleye population and fishery in Saginaw Bay were primarily attributed to the loss of spawning habitat in both the watershed's rivers as well as off-shore reefs.

Exacerbating the collapse and confounding any natural recovery that may have otherwise occurred, was the invasion of the bay by non-native planktivores such as rainbow smelt and alewives (Schneider 1977; Schneider and Leach 1977; Schneider and Leach 1979; Keller et al. 1987). The invasion of rainbow smelt and alewives in the Great Lakes has generally coincided with the collapse and decline of native walleye populations. The theorized mechanism is competition with, and predation on, larval walleyes (Smith 1970; Schneider and Leach 1977; Schneider and Leach 1979). Rainbow smelt first became abundant in Saginaw Bay in the 1930s (Christie 1974) and alewives by the early 1950s (Miller 1957). Alewives particularly have been documented as a formidable predator on walleye fry (Kohler and Ney 1980; Wells 1980; Brandt et al. 1987; Brooking et al. 1998,) and have been reported as obstacles to walleye recovery in some Great Lakes locations (Hurley and Christie 1977; Bowlby et al. 1991).

In the absence of a top predator, rainbow smelt and alewife flourished in Saginaw Bay (Schneider and Leach 1977). Keller et al. (1987) concluded that in the post collapse period, Saginaw Bay's zooplankton community shifted to unfavorably small organisms due to intensive grazing by overabundant prey fish resulting from too few predators. Other native fish populations, including lake herring, lake whitefish, and lake trout collapsed or declined during this time (Baldwin and Saalfeld 1962; Haas and Schaffer1992). The remaining commercial fishery turned to yellow perch, the only remaining species of value and to less desirable species like white sucker (Eshenroder 1977; Ebener 1995). The remnant walleye commercial fishery was formally closed in 1970.

The foundation for a recovery of the walleye population in Saginaw Bay began with the passage of the Clean Water Act of 1972. Walleye fry stocking was initiated in the early 1970s, but met with poor success (Schneider and Leach 1977). Walleye fingerling stocking first began in 1974 and then increased by the late 1970s (Table 1). By the 1970s, alewife and rainbow smelt abundance had also been brought under partial control in Lake Huron by the introduction of Pacific salmon species. Anglers started to report catching small walleyes by 1979 and incidental catch in commercial trapnets increased eight fold by 1981 (Mrozinski et al. 1991). Spawning walleyes were also observed in the Tittabawassee River, a tributary of the Saginaw River system (Mrozinski et al. 1991).

A sport fishery for walleyes in Saginaw Bay and portions of the Saginaw River system quickly emerged. By 1983, over 2,000 walleyes were harvested by anglers during the open water season and the number jumped to more than 59,000 just three years later (Ryckman 1986; Rakoczy and Rogers 1987, Figure 3). From 1987 (through 2000) the open water harvest alone averaged 68,852 and the tributary and ice fisheries were substantial as well (Rakoczy and Rogers 1988; Rakoczy and Rogers 1990; Rakoczy and Rogers 1991; Rakoczy 1992a; Rakoczy 1992b; Rakoczy and Svoboda 1994; Rakoczy and Svoboda 1995; Rakoczy and Svoboda 1997; G.P. Rakoczy, MDNR, unpublished data). The commercial fishery for walleyes remained closed.

Natural reproduction of walleyes was first documented in the Tittabawassee and Rifle Rivers in 1985 via fry collections (Mrozinski et al. 1991; Jude 1992). Todd and Haas (1995) investigated the genetic composition of Tittabawassee River spawning walleyes from 1983 through 1988 and concluded the run was comprised of increasing proportions of wild fish. The impressive recovery of the Lake Erie walleye population and fishery around the same time bolstered public optimism and confidence for a similar revival in Saginaw Bay (Anonymous 1988; Huggler 1988).

Biologists, however, were less certain of the long-term prognosis for full recovery of a self-sustaining walleye population (Keller et al. 1987). The long-term average walleye yield that the historic commercial fishery sustained for several decades prior to collapse in the 1940s was established as a bench mark with which to gauge a restored Saginaw Bay walleye population (Keller et al. 1987; Mrozinski et al. 1991). The average yield of 458,000 kg equated to about 600,000 walleyes harvested in an average year (Baldwin and Saalfeld 1962; Mrozinski et al. 1991). Even early in the recovery, concern was expressed that the population and fishery could plateau short of the biological potential of the bay (Keller et al. 1987; Mrozinski et al. 1991). Keller et al. (1987) modeled the population and predicted that without expanding natural recruitment, the resulting walleye fishery would reach its peak in the mid 1990s, short of historic proportions or full recovery.

Several unknowns prevented the formulation of a sound strategy to further the recovery of walleye in Saginaw Bay (Keller et al. 1987; Mrozinski et al. 1991). Despite the documentation of some natural reproduction, the relative contribution of natural reproduction and fingerling stocking to walleye year classes in Saginaw Bay was unclear. Also unclear was the status of historic spawning reefs and if they were a current or potential source of recruitment. This study was designed to address these management questions.

The objectives of this study were to: (1) locate historic walleye spawning reefs (2) determine their condition in terms of the presence of potential spawners, eggs, larvae, and zooplankton, and (3) determine the relative contributions of hatchery and wild recruits to the population. These data and previous studies of the population and recovery are used to recommend potential strategies for completing the recovery of the Saginaw Bay walleye population.

Methods

Historic Walleye Spawning Reefs

Search for reefs focused on the inner bay region of Saginaw Bay. Schneider (1977) and Organ et al. (1979) both reported that nearly all the historic walleye reef spawning was thought limited to this area. The outer bay region of Saginaw Bay includes vast areas of rock and gravel. The outer bay area, however, is more characteristic of the main basin in its habitat (Beeton et al. 1967). This area may either warm too late into the spring to prove attractive to spawning walleyes or be too infertile to sustain walleye fry.

Reefs were located for inspection by several means. The locations of important historic spawning reefs are described by Schneider (1977) and by Organ et al. (1979). These descriptions were supplemented with reports by commercial fishermen from around the bay. Navigation charts and bathymetry maps were also used to predict the size and shape of probable spawning reefs.

Areas identified through this process were then examined for condition. Sonar was used to assist in the initial location of hard bottom substrate. Examinations were done using an underwater video camera. Typically, the first camera observation was taken near the expected center of the reef. Subsequent observations were then made radiating out from the starting point. The percentage of the substrate that was cobble or gravel versus the area that was sand, silt, or mud was visually estimated from the video and recorded. If rock or gravel was noted in any abundance, then additional camera observations were conducted to assess the reef's size and shape. If no appreciable rock or gravel was observed, only enough additional observations were conducted to ensure the absence of a reef. Substrate was classified as reef habitat if it was composed of an area of 100% rock (either cobble and/or gravel size stone) in a continuous formation of at least 0.40 ha in total area. The basis for this criteria is the composition of the most productive reefs from other Great Lake locations (Herdendorf 1985, Roseman 1997) as well as the findings of Johnson (1961) that walleye reproduction is most successful over this type of substrate. Most inspections were done in the open water season in 1990 and 1996 (Appendix 2, Figure 1). Based upon the findings of the reef search work, the two largest remaining inner bay reefs were monitored for usage by spawning walleye.

Reef Condition

Spawning Walleyes–Duck and North Island Reefs, two inner bay reefs identified in the reef search, were monitored for spawning walleyes and the subsequent production of juveniles. The methodology was patterned after the work of Roseman (1997). Monitoring involved four phases; gillnetting for spawning adults, egg pumping for walleye eggs, zooplankton sampling to determine available prey for juvenile walleyes, and larval sampling for newly hatched walleye fry.

Gillnetting was performed with multifilament nets measuring 183 m long by 2 m deep. Each net was composed of two 15.2-m panels of 38-mm and 51-mm stretch measure, and 30.4-m panels of 64-mm, 76-mm, 89-mm, 102-mm, and 114-mm stretch measure mesh. Nets were fished on the bottom, overnight. This sampling design has been shown effective in collecting mature walleyes in Saginaw Bay (Fielder et al. 2000). One such net set was made on each reef, each week starting when water temperatures approached preferred spawning temperatures of 4.4^{o}C or warmer, which was usually around mid-April and continued until temperature reached 13 ^{o}C. Sampling was performed from 1997 through 2000 and usually lasted about three weeks each year except in 2000, which was limited to the peak spawning period.

All fish collected with gillnets were identified, enumerated, and measured for total length. To determine if limitations to successful reproduction might be attributed to egg predation, the stomach of each fish collected (other than walleye) was examined for the presence of fish eggs. All walleye collected were externally sexed and scored for maturity in one of six categories; immature, mature, gravid, ripe, partially spent, or spent. The criteria for each maturity level followed the methods described by Fielder (1998). Walleyes were also weighed and scales collected for age estimation.

Eggs and Larvae–Egg pumping was performed with a 39 kg iron sled (0.25 m wide) attached to a diaphragm pump at the surface by a flexible hose 5 cm in diameter as designed by Stauffer (1981). On each occasion, the sled was towed 10 minutes at 0.5 m/s, typically sampling a 75 m^2 area. Sample depths varied over the surface of the reefs but were generally < 5 m. These depths encompassed the preferred spawning depths identified by Roseman (1997) for Lake Erie reef spawners. Eggs and benthic debris were deposited in a screened sluice, which served to sort items by size and eliminate any sand encountered. Remaining debris and eggs were stored in water, labeled, and refrigerated until they could be further sorted. Eggs were counted within 48 hours of collection. A minimum of three egg pumping tows were made at each reef, each week in the spring while water temperatures ranged from 4.4^{o}C to 13.7^{o}C. Sampling in 2000 was limited to the period of peak spawning temperatures. In 1997 and 1998, walleye eggs were identified by incubating the eggs and identifying the resulting larvae. Identification of eggs in 1999 and 2000 was limited to visual examination of the eggs with comparison to known reference samples.

Larval Fish and Zooplankton–Larval fish and zooplankton sampling were performed concurrently on or near the reefs, beginning the first week of May each year and lasting until surface water temperature reached 18^{o}C. Larval fish were collected with a framed ichthyoplankton (neuston) net of 500μm mesh and had a 2 m^2 opening. A flow meter was positioned in the center of the mouth of the net to record the volume of water sampled. The net was towed in the upper 2 m of the water column by boat at approximately 1.0 m/sec. for 10 minutes. Three tows were made per week at each reef. Samples were preserved in a commercial alcohol-based preservative mixture and identified following Auer (1982).

Zooplankton were collected using a Student zooplankton net with a 20 cm mouth and 80 micron mesh net. The net was dropped to the bottom, and retrieved in a vertical pull. Volume sampled was calculated as the product of the area of the net mouth and the depth of the pull. Zooplankton were preserved with a commercial alcohol-based preservative mixture and identified to major taxonomic groups following Pennak (1978).

Contribution of Stocked Fingerlings

The contribution of stocked spring walleye fingerlings to the population was determined with two methods, each providing independent measures of the same parameter; the proportion of the locally produced year class that could be attributed to stocking. First, alternate-year stocking was employed to insert years of no stocking to allow comparisons of subsequent year class strength. No walleye were stocked in 1993 and 1996, while fingerlings were stocked in all other years of the study (Table 1).

Year class strength was determined by examining the walleye recruitment index used by the Michigan Department of Natural Resources (MDNR). That index is based on the proportion of age-1 walleye in gillnet collections. Those collections were part of an annual fish population survey performed each September (Fielder et al. 2000). Measurements of walleye recruitment examined by Fielder et al. (2000) included trends in both the catch-per-unit-effort (CPUE) of age-1 walleye as well as the proportion of yearlings to the rest of the annual walleye catch. The latter technique was employed to compensate for changes in gear efficiency, and proved to be a representative measure of local recruitment. The annual percent contribution of age-1 walleyes (recruitment index value) was then compared for stocked and non-stocked years using the nonparametric Mann-Whitney U test (Sokal and Rohlf 1981).

Because the number stocked has varied (Table 1), the opportunity existed to describe the relationship between number stocked and the recruitment index value from Fielder et al. (2000). Linear regression was used with a $\log_{10}$ transformation of the recruitment index value as the dependent variable and the number stocked as the independent variable (Sokal and Rohlf 1981). Significance for all statistical tests was determined at $P<0.05$.

The second method used to determine the contribution of hatchery reared fish to the walleye population was using oxytetracycline (OTC) marker. All walleye fry used to rear fingerlings for stocking in Saginaw Bay were immersion marked in OTC at the hatchery for the years 1997-2000. Oxytetracycline marking followed the methods of Fielder (2002) including immersion in 700 ppm and a minimum 6 hour exposure. Specimens for analysis were principally collected by bottom trawling and electrofishing in Saginaw Bay during the summer in the same year the stocking took place.

Juvenile walleye specimens for OTC analysis were collected by trawling with a towed 4.9 m otter trawl during July in 10 nursery areas around the bay. Typically, twelve 10-minute tows were made after dark at each location. Additional sampling was performed by electrofishing at night from an electrofishing boat during August for 2 hours of generator time at 14 nursery locations. All catch from both collection efforts were identified, enumerated, and liberated except age-0 walleyes, which were frozen to provide otoliths for OTC examination. Samples of age-0 walleyes were supplemented with catches from other sources, including summer and fall trawling surveys performed by the U. S. Fish and Wildlife Service, and trawling and gillnetting by the MDNR as part of the annual fish population survey.

Detection of OTC marks followed the methods of Fielder (2002). Fish were either scored as marked (hatchery fish) or unmarked (wild fish) with results being tabulated by sample location. Results were stratified by sample location but also pooled to produce a bay-wide total estimate of hatchery contribution for each year class. Collections and examinations each year included older specimens to reexamine the percentage of hatchery fish in the year class as the cohort aged.

Survival of stocked walleye fingerlings to age-1 was calculated based on estimates of walleye harvest, exploitation, and survival by working backwards from harvest estimates to population estimates. Estimates of annual harvest were available for the open water and ice fisheries in most years, and the fishery in the Saginaw and Tittabawassee Rivers for some years (Rakoczy and Rogers 1988; Rakoczy and Rogers 1990; Rakoczy and Rogers 1991; Rakoczy 1992a; Rakoczy 1992b; Rakoczy and Svoboda 1994; Rakoczy and Svoboda 1995; Rakoczy and Svoboda 1997; G.P. Rakoczy, MDNR, unpublished data). In years where estimates of tributary or ice fishery harvest were lacking, estimates were generated using the average contribution of the tributary and ice fishery harvests from other years expressed as percentage of the open water fishery. The estimates were then combined to represent all the walleye harvested from all sources in Saginaw Bay for that year (H). The proportion of age-2 fish in the harvest (b_2) was derived from age data collected in the creel surveys for each year. The harvest of age-2 walleyes (H_2) was derived as;

$$H_2 = H\ b_2$$

The estimated number of age-2 walleyes in the population (P_2) was then derived by dividing the age-2 harvest (H_2) by that year's exploitation rate (E_{T+2}) from Fielder et al. (2000), where T is the year the fingerlings were originally stocked.

$$P_2 = H_2 / E_{T+2}$$

Not all age-2 walleyes in the population, however, were fully recruited to the fishery because of the minimum length limit. The estimate of age-2 fish in the population (P_2) was then adjusted by the proportion of age-2 fish in the population (a_2) that were smaller than the 381 mm minimum length limit. That proportion was derived from the length structure of the age-2 walleyes using data from the annual fish population survey (Fielder et al. 2000). The resultant was an estimate of the full population of age-2 walleyes (P_2).

$$P_2 = p_2\ a_2$$

For each year class examined, the number of age-1 walleyes in the population (P_1) was then derived by dividing the estimated number of age-2 fish (P_2) by the annual survival rate (S_{T+2}) from Fielder et al. (2000).

$$P_1 = P_2 / S_{T+2}$$

The numerical abundance of yearling hatchery fish for each cohort was then estimated as the product of the overall population of age-1 walleyes (P_1) and the proportion of hatchery fish for that year class as determined by the OTC analysis (h).

$$P_{1h} = P_1 h$$

Finally, cohort-specific survival of stocked walleye fingerlings to age 1 (C_T) was derived by dividing the estimates of age-1 hatchery fish in the cohort (P_{1h}) by the number stocked for that year class (N_S).

$$C_T = P_{1h} / N_S$$

Stocked fingerlings survival was then estimated, according to these formulas, for seven different stocked years ranging from 1989 through 1997. Assumptions of this estimation was that exploitation rate (E_{T+2}) derived for the entire fishery in year T+2 is constant across all ages. Another assumption is that the proportions of age-2 walleye above and below the minimum length limit as measured in the September annual netting survey is the same as throughout the entire year's fishery. Lastly, the calculations assume that survival rate estimated for the adult population from tagging surveys in year T+2 (S_{T+2}) is constant across all ages. The degree to which these assumptions are valid is not fully known and likely account for some degree of error in the estimation.

Estimates of survival of stocked fingerlings were used to model the number of fingerlings needed ($N_{S\text{-hypo}}$) to achieve historical yields if proportions of hatchery to wild fish remained static. The historic average commercial yield of 458,000 kg was established as the benchmark. The average size of walleyes harvested in the present fishery was 1.81 kg; thus the benchmark yield value translated to an annual harvest of about 250,000 walleye. For the purpose of the calculations, immigration was credited with 50,000 fish (R. Haas, MDNR, personal communication). The remaining 200,000 was apportioned between hatchery fish and wild based on the ratios determined by the overall OTC analysis (80% hatchery / 20% wild locally produced) yielding a hypothetical fishery of 160,000 hatchery fish (U). The model used the adult survival rate of exploited walleyes determined for 1999 at 66.39% (MDNR, unpublished data) to produce the total harvest of 160,000 hatchery (U) fish for exploited ages (age-2+) out to age-13. The SOLVE function in Microsoft Excel program (Microsoft Corporation 1997) was used to "game" through various starting age-2 specific harvests, diminishing each year by the total annual mortality rate (1-S) to produce the benchmark yield (160,000 total harvest over 13 year classes).

$$U = 160{,}000 \text{ age-2+ walleyes} = \sum U_{2\text{-}13}$$

Because the model is cohort based, the theoretical harvest of age-2 walleye (U_2) was then isolated. Dividing the hypothetical harvest of hatchery age-2 walleyes (U_2) by the exploitation rate (E) for the year T, (again, where T = the year from the fingerling survival estimate (S_T) yielded the hypothetical age-2 population size ($P_{2\text{-hypo}}$)

$$P_{2\text{-hypo}} = U_2 / E_T$$

The hypothetical number of age-1 hatchery fish ($P_{1\text{-hypo}}$) was then derived by dividing the hypothetical hatchery age-2 population ($P_{2\text{-hypo}}$) by the annual survival rate for year T (C_T).

$$P_{1\text{-hypo}} = P_{2\text{-hypo}} / S_T$$

Lastly, the hypothetical population of hatchery age-1 walleye ($P_{1\text{-hypo}}$) was divided by the estimate of hatchery fingerling survival rate (to age 1) as determined for that year in the exercise described previously (C_T). The result was the number of stocked fingerlings ($N_{s\text{-hypo}}$) that would be required each year for 13 years to achieve a sport fishery harvest near the benchmark (historic proportions).

$$N_{s\text{-hypo}} = P_{1\text{-hypo}} / C_T$$

The generation of U_2 used the 1999 survival estimate as that was the most up to date value available at the time and best reflected the modern Saginaw Bay walleye population. Calculation of $N_{s\text{-hypo}}$ used E, S and C values that were all specific to the year (T) because the intent of the model was to predict $N_{s\text{-hypo}}$ for each year that fingerling survival estimates were available (1989–97) and made to reflect the dynamics of the walleye population and fishery in those years. For the model to work mathematically, it had to assume that wild walleyes would be more abundant in the hypothetical fishery as well (20% of 200,000 or 40,000) because of the application of the OTC derived proportions. Under conditions of a walleye population at full carrying capacity of the bay, some increased natural recruitment might be expected. Other assumptions besides static natural recruitment proportions included static immigration, emigration, exploitation, and survival.

The estimation of stocked fingerling survival, simulation of the hypothetical fishery, and corresponding estimates of stocking number needed was compiled as an interactive program in Microsoft Excel (Microsoft Corporation 1997). In addition to simulations for the years 1989–97, mean rates and input variables were also modeled.

Results

Reef Search

Nearly all the most important inner bay historic walleye spawning reefs were found to be of low quality suggesting a degraded condition (Appendix 2, Figure 4). Most exhibited less than 25% rock with sand being the most common material covering reefs. The Kawkawlin River mouth reef did include some small localized areas of 100% rock, but overall the reef comprised only about 50% rock. The other areas immediately adjacent to the Saginaw River mouth ranged from less than 10% rock to only about 25% rock. In all, a total of 20 reef inspections were made comprising 224 individual observations (Figure 1, Appendix 2).

Only two relatively small inner bay areas meeting the criteria of a reef were located. They were Duck Reef and North Island Reef, both of which are near the outer limits of the inner bay (Figure 5). These rock reefs served as the primary locations for sampling to determine use by spawning walleye. Large areas of rock substrate and rock reefs were located in outer Saginaw Bay. Most notable were Whitestone Point, around the Charity Islands, Oak Point Reef, and Hat Point Reef (Figure 4).

Reef Monitoring

Adult walleyes were collected from Duck and North Island Reefs in most years, however, catches were never large (Table 2). Males were generally more common than females and were usually mature and ripe. Females were often spent or immature, although gravid (green) females were encountered. The only ripe or partially spent female walleyes collected were in 1997 and 1998. It is these latter two groups (ripe female and partially spent females) that are probably most indicative of active spawning in the immediate vicinity. One spent female encountered in 1999, however, was tagged just one week before in the Tittabawassee River as part of that spawning run. From this it was apparent that post-run river spawners could quickly migrate back to the open water, potentially confounding the interpretation of these catches. Given the proximity of these reefs (being relatively removed from nearby rivers), however, it is unlikely that ripe river-spawning females would be found on the reefs.

Walleye eggs were collected with the egg pump in at least one location each year (Table 3). The mean CPUE of eggs per pumping run, however, was very low in all locations compared to other Great Lakes locations. The greatest mean CPUE measured was 70 eggs (SE 27.02) from Duck Reef in late April of 1998. In both instances, the greatest mean egg density was less than one egg/m^2. Two eggs were successfully hatched for identification from reef sampling in 1997. Both resulting larvae were positively identified as walleyes. All other eggs in the sampling appeared to be consistent with the known size and morphology of walleye eggs.

Stomach examinations of fish collected from the gillnets only rarely revealed eggs. Of all the fish collected by gillnets from 1997 through 2000, only four fish were found to have eggs in their stomachs; two menominee in 1997 (from North Island Reef) and two fish in 1998 (one menominee from Duck Reef, and one channel catfish from North Island Reef). In all, 373 stomachs were examined from 1997 through 2000.

Only two larval walleye were collected while sampling with the neuston net. They were from May 13, and May 21, 1997 at North Island Reef (Appendix 3). Species composition of the larval sampling varied by year, but yellow perch, lake whitefish, and white sucker were common. In all, 126 tows with the neuston net were made from 1997-2000.

The density of zooplankton in samples collected was generally low compared to other areas of walleye reproduction for the Great Lakes (Appendix 3). Densities increased over time possibly as water warmed in the spring. The highest densities measured were in early June. The zooplankton densities at the time the two walleye fry were collected in 1997 at North Island Reef was 9.11 plankters/liter and 13.51 plankters/liter (Appendix 4).

Contribution of Stocked Fingerlings

Recruitment was low in the nonstocked years relative to most stocked years (Figure 6). Nonstocked years produced 14% as much recruitment as an average stocked year based on differences in means of the recruitment index (Figure 6). The annual recruitment index values for stocked and nonstocked years were significantly different (P<0.001). Based on the recruitment index, recruitment in stocked years was consistently greater except for the 1992 and 1999 year classes.

There was a significantly positive relationship between number stocked and recruitment as determined by regression (P = 0.012). The relationship is described by the simple linear equation

$$\log_{10}(\text{recruitment index value}) = 7.637\times10^{-7}(\text{number stocked}) + 0.628$$

From this, the number of walleye fingerlings stocked explained 48% of the variability in the recruitment index ($r^2 = 0.48$).

Catches of age-0 walleyes for OTC analysis were variable (Appendix 5). Sampling was not entirely uniform among years, but served to provide a representative collection of specimens from around the bay. In all, 946 specimens were collected from 1997 through 2000 for OTC analysis. Although the summer trawling and electrofishing were not intended to be measures of abundance, the catch is assumed to reflect year class strength because sampling effort was held relatively constant among years (Appendix 5). Analysis for OTC marks included older walleyes after 1997 (primarily from other sources) in order to follow marked year classes as they aged, thereby providing multiple measures of hatchery contribution for the same year class.

The proportion of marked (hatchery) fish to unmarked (wild) fish varied by location within the bay. Contribution for each year class by age and locality are given in Appendix 6. The percentage of hatchery fish at age-0 was often greater near the stocking release sites and lowest near the Saginaw River mouth where natural reproduction is known to occur. The age-0 fish were likely still oriented to nursery areas that were in close proximity to their point of origin. Older walleyes of both hatchery and natural origin were more dispersed. No walleye were collected from some locations despite substantial sampling effort (Appendix 5).

By pooling all specimens collected in Saginaw Bay within a year class over the study period, an estimate of composition can be derived for each cohort. Contribution of hatchery fish to the composition of each cohort ranged from 73% to 96% (Table 4). Pooling all marked year classes, 80% of walleyes examined were of hatchery origin (Table 4).

Estimates of hatchery fingerling survival to age 1 varied from a low of 0.73% to a high of 30.21% (Table 5). The low value stemmed from the unusually weak 1992 year class. The next lowest value of fingerling survival to age-1 was 7.49% and probably more realistically represents the low end of the range of hatchery fingerling survival in years where measurable recruitment is achieved. The highest values of fingerling survival stemmed from the 1989 and 1991 year classes. These estimates, however, were derived based on population estimates from 1991 and 1993 which may have been years of greater immigration levels and might have included some age 2 Lake Erie immigrants (R. Haas, MDNR, personal communication), violating the assumption of no age-2 immigration. This would have served to over estimate the survival of stocked fish. An overall average value of 14.67% was determined for stocked fingerling survival to age-1.

The average annual number of stocked walleye fingerlings needed to achieve a hypothetical fishery of historic proportions was estimated to be about 6 million for thirteen years (Table 5). These calculations used the above estimated overall proportions of hatchery fish to wild fish locally produced (excluding immigration) from the OTC marking results. Calculations of necessary stocking numbers were thus based on 80% hatchery (160,000 walleyes of hatchery origin from the hypothetical 200,000 locally produced walleyes necessary to create a hypothetical fishery of historic proportions via stocking) and 20% wild (40,000 walleyes in the calculations). The 6 million hatchery fingerlings estimate is based on an average of simulation input values from the range of years examined (Table 5).

Discussion

Recruitment from Reproduction on Reefs

Although reported to be historically important, off-shore reefs are not presently a significant source of walleye recruitment in Saginaw Bay. The habitat is of low quality, degraded by sand, and doesn't offer the interstitial spaces normally necessary to successfully incubate eggs. Because it is not fully clear as to what the exact condition of the reef habitat was historically, it is difficult to say with certainty to what degree the modern condition reflects degradation. It can only be assumed that if these reefs were historically productive, then their historic condition must have been more pristine. Assuming the modern condition does represent a degraded condition, then it is not clear if the degradation is a lingering result of the sedimentation from early deforestation and agricultural practices or if it also results from on-going farming and erosion. Regardless, reef habitat has not scoured clean from wave action over the decades. Meanwhile, high quality, undegraded outer bay reef habitat apparently goes unused by reef spawning walleyes, likely due to unfavorable environmental conditions.

Several factors probably limit successful reproduction from reefs by walleyes besides the aforementioned habitat problems. Reef spawning walleyes of Saginaw Bay may now be brood-stock limited and perhaps nearly extirpated. Because the habitat has been largely unavailable for so long, few adults probably remain as evidenced by the low abundance of spawners collected from the reefs. Likely, many of the spent females encountered were actually river spawners that had already migrated back to the open water. Mitochondrial DNA analysis performed on walleyes collected in 1997 from Duck and North Island Reefs revealed, however, a haplotype that was not previously identified for Great Lakes walleye populations (Billington et al. 1998). It is possible that sampling, at least that year, detected a remnant reef spawning stock of fish. Apparently, there is at least small-scale spawning still occurring as evidenced by the collection of eggs each year and two fry in 1997.

While the findings of this study suggest that fundamental limitations to reproduction on reefs can be attributed to degraded habitat and low brood stock density, another probable factor is predation by alewives. Alewives are still abundant in Saginaw Bay (Fielder et al. 2000) and enter the bay for spawning about the time fry would emerge. Although not as abundant as in the 1950s and 1960s before Pacific salmon were introduced, they likely pose a continued hurdle to successful recruitment.

Egg predation was not observed to be wide spread in this study. In Lake Erie, however, white perch were noted as walleye egg consumers (Schaeffer and Margraf 1987, Roseman 1997). Saginaw Bay has an abundant white perch population (Fielder et al. 2000) but none were observed eating eggs as part of this study. The near lack of egg predation observed may be a factor of the low egg density occurring on the remaining reefs. If egg deposition were to increase as a result of management initiatives, the incidence of egg predation could become more prevalent.

Egg densities observed in other studies suggest that those measured in Saginaw Bay were low. Roseman (1997) reported averages of 4,400 to 19,500 walleye eggs per ten-minute tow on Niagara and Toussaint Reefs (Lake Erie) respectively. Peak egg collections in Saginaw Bay by comparison were only 70 eggs per ten-minute tow. Density of walleye eggs in Lake Winnibigoshish, Minnesota averaged 1,545 /m^2

(Johnson 1961), compared to less than one egg /m^2 in Saginaw Bay. Walleye egg density on Sunken Chicken Reef in Lake Erie ranged from 145 – 277 /m^2 (Fitzsimons et al. 1995). Walleye egg density in streams has been documented to be as great as 6,241 /m^2 (Corbett and Powles 1986). Clearly, production of walleye eggs on off-shore reefs in Saginaw Bay was greatly depressed.

Survival of walleye fry can be limited by the amount of prey available to sustain the larvae (Haas and Thomas 1997). While seemingly low, the density of zooplankton measured in this study was similar to those densities observed in Lake Erie river mouths (Haas and Thomas 1997) and on open water reefs (Roseman 1997). Zooplankton prey is not presently a limiting factor to production of walleye fry from reefs in Saginaw Bay, because few larvae are produced there. Like egg predation, zooplankton density could become a factor if the other problems of degraded habitat and very low spawner density are over come.

Recruitment from Stocking

Clearly, stocked walleye fingerlings survive well in Saginaw Bay and contribute substantially to local recruitment. Oxytetracycline marking (indicating an 80% annual contribution of hatchery fish) and alternate-year stocking (indicating an 86% average annual contribution of hatchery fish) analyses produced remarkably similar estimates of the proportion of locally produced year classes that can be attributed to stocking. The alternate year stocking evaluation, however, depended on only two nonstocked years. Normally, such an evaluation approach is best done with several years of each.

While year class strength has fluctuated, the relative contributions of hatchery and wild recruits have remained fairly constant during the years of the study. The weak stocked year classes of 1992 and 1999 illustrate, however, that stocking does not contribute consistently every year, probably as a result of varying environmental or climatic conditions. The 1992 year class was generally poor for walleye production and survival in other walleye populations in Michigan (Haas and Thomas 1997) and is thought to be due to climatic effects resulting from the eruption of Mt. Pinatubo (Schupp 2002). Overall, stocking numbers by themselves explains 48% of the variability in recruitment patterns, with natural reproduction, environmental conditions, and other unknown variables explaining the remainder.

Levels of stocked fingerling recruitment commensurate with those documented for Saginaw Bay by this study, have been achieved in other lakes. Lucchesi (2002) reported stocked fingerlings accounted for an average of 87% of the year-class in four South Dakota lakes. Similarly, five reservoirs in Nebraska, managed with fingerling stocking, routinely exhibited year-classes comprised of 75% hatchery fish (D. Bauer, Nebraska Game and Parks Commission, personal communication). McWilliams and Larscheid (1992) reported similar returns (70% - 99%) from stocking with small fingerings in Okoboji Lakes, Iowa. These lakes, however, are all smaller than Saginaw Bay and are require less hatchery resources to achieve these levels.

It is important to recognize that these are measurements of local recruitment and the reported proportions may not fully apply to the adult population. Saginaw Bay experiences considerable immigration of walleye each year from Lake Erie (Haas et al. 1988, Fielder et al. 2000). These additional wild walleye are supplementing the locally produced adult population and fishery at seasonally variable rates. The magnitude of the contribution by walleyes from outside the bay is not easily discernable but has been substantial in certain years of high Lake Erie walleye abundance (R. C. Haas, MDNR, personal communication).

Estimates of survival of stocked fingerlings in Saginaw Bay from this study suggest a high rate of survival. Laarman and Schneider (1986) documented 14% first year survival for summer fingerlings in Manistee Lake, Michigan, the same as the average calculated for spring fingerlings in Saginaw Bay in this study. Such a survival rate could account for the high contribution of hatchery fish determined by OTC marking, and generally bodes well for the efficacy of stocking in Saginaw Bay.

Hatchery fingerlings stocked in Saginaw Bay average 4.2 cm in total length at stocking. These fish are at the stage of converting to piscine prey and are large enough to avoid predation by alewife (Brooking et al. 1998). If, in fact, alewife predation and/or zooplankton prey are two critical limiting factors, then hatchery fingerlings stocked in June have bypassed both of these factors. Undoubtedly, some stocked walleyes are lost to predation by other fishes, however, the high abundance of other prey fishes in the bay (Fielder et al. 2000) may buffer stocked walleye fingerlings from predation. Walleyes also grow very fast in Saginaw Bay (Fielder et al. 2000) and their period of vulnerability to predators may be short compared to other walleye populations.

Modeled estimates of the number necessary for stocking to create a yield of historic proportions should be interpreted cautiously. Several assumptions were necessary to derive the estimates which are intended only to provide a general reference point for future contemplation of management strategies. The estimates of fingerling survival for example were dependent on exploitation rates and general survival rates developed for the entire walleye population and fishery in Saginaw Bay. The lack of age specific exploitation and survival rates lessens the overall confidence of these estimates and necessitates caution in interpretation. This exercise does, however, make use of the best parameter values available at the time and produces a fingerling survival estimate that was previously lacking and that was necessary for further modeling. The estimation exercise may also facilitate additional modeling of the population, fishery, and management alternatives.

Factors Affecting Further Recovery

The prospects for restoring walleye production from off-shore reefs are uncertain. More than five decades have past since the initial collapse of the walleye fishery in the mid 1940s. If the sources of sedimentation that initially led to reef degradation have been controlled, and reef habitat could scour clean from wave action, then it would likely have done so in this time. Without suitable habitat in the inner bay region of Saginaw Bay, it's very unlikely that substantial recruitment could ever be realized from that source again. However, if the degradation of reef habitat is a result of modern agricultural practices and other erosion in the watershed, together continuing to keep reefs smothered, then improved land management practices may someday still lead to recovered reef habitat.

In the presence of suitable habitat, remnant reef spawning stocks of walleyes may prove sufficient to serve as seed for a recovery. For walleyes, the disposition to spawn on reefs or in rivers is a heritable characteristic (Jennings et al. 1996). However, the abundance of reef spawning walleyes, in the absence of recruitment, will continue to decline in Saginaw Bay and may eventually cross (or already have done so) some threshold to complete extirpation.

Potentially, migrants from Lake Erie could serve as a source for recolonization by reef spawning strains of walleye. However, walleyes tagged in Lake Erie have never been observed in the annual tagging operations at Dow Dam in the Tittabawassee River. This suggests that the river spawning strains of Lake Erie walleye exhibit a high degree of fidelity to Lake Erie for spawning and make little or no reproductive contribution to Saginaw Bay. If Lake Erie reef spawners also home strongly to their natal spawning grounds, they would contribute little to recolonization of the bay.

The only other remaining option to maintain or increase the abundance of reef-spawning walleyes in Saginaw Bay would be to utilize such a strain of walleye as the source for hatchery production. The success of this approach would depend on the degree to which those fish would seek out and successfully reproduce on the remaining reef habitat. This approach might allow for the selection of adult brood that utilize reef habitat similar to the more abundant outer bay reefs in Saginaw Bay. In fact, Lake Erie reef spawners were used as the primary brood source for Saginaw Bay stocked fingerlings for years 1991, 1992, and 1994 (MDNR 1991, 1992, and 1994). These plants were not evaluated for their reproductive contribution but many of the walleyes collected by gillnets from the study reefs were from these same year classes.

Because recruitment from off-shore reef spawning remains negligible in Saginaw Bay, it can be inferred that nearly all the wild walleyes locally produced are a result of river spawning. As with reef spawning, the primary limiting factor in recruitment from river spawning is likely the amount of quality habitat available.

Numerous dams and spillways exist in the Saginaw Bay watershed, nearly all impeding the migration of spawning walleyes. Many of these dams block rivers that served as the walleyes' traditional riverine spawning grounds. Although a detailed inventory of river substrate habitat is lacking for the Saginaw Bay watershed, anecdotal evidence indicates that there are substantial reaches of gravel river beds above some of these dams. A comprehensive inventory of the habitat in these rivers is needed to help identify which areas are best candidates for restoration.

Measuring Progress to Recovery

Recovery goals for Great Lakes fish populations and their fisheries have traditionally been based on returning to average yield levels of the historic commercial fishery (Colby et al. 1994; DesJardine et al. 1995). Sport fisheries, however, are fundamentally different and it may not be realistic to expect that they will achieve the same degree of exploitation. In addition, the productivity of the bay's ecosystem may have changed altering the biological capacity of the prey base. For these reasons, additional recovery criteria should be considered.

Growth rate of fish is often density dependent, especially at higher levels of abundance (Hayes et al. 1999). Saginaw Bay walleyes presently grow extremely fast, well above the state average (typically age-3 walleyes at 130%), much faster than they did historically, and faster than walleye in Lake Erie (Hile 1954; Colby et al. 1994; Fielder et al. 2000). A similar growth pattern existed in Green Bay, Lake Michigan during recovery (Colby et al. 1994). The growth rate of walleyes in Lake Erie dropped as that population recovered (Colby et al. 1994; Muth and Wolfert 1986). Growth rate changes are thus excellent indicators of recovery for walleye populations and decreases in Saginaw Bay walleye growth rate can be expected with progress towards a recovered state (Colby et al. 1994).

The state average walleye growth rate (Schneider et al. 2000) should be used as the criteria for gauging recovery in Saginaw Bay. As density increases and growth rate decreases, trophy size walleye would still be available to anglers by virtue of escapement and longevity as opposed to extremely fast growth rates. In addition to the growth index, historic commercial yield can be maintained as a benchmark for comparison. Continued differentiation of the contribution of hatchery and wild fish will also be essential in monitoring recovery progress. If natural reproduction increases stocking should be decreased, especially once the growth rate objectives are attained.

Monitoring of walleye population parameters other than growth rate should be continued. Annual tagging provides estimates of exploitation and total annual survival. Creel survey, provides estimates of harvest, angler catch rate, fishing pressure, and biological data on the catch. Lastly, the annual fish population survey provides biological data on the population, abundance, growth rate, and recruitment.

Conclusions and Recommendations

Walleye stocking in Saginaw Bay was originally intended to reestablish a sport fishery and restore natural reproduction. This goal has been partially realized. However, the Saginaw Bay walleye population remained below the biological capacity of the adult habitat, did not provide for a fishery that is commensurate with historic yields, or lead to the desired predator/prey balance for the fish community. Walleye stocking continued and evolved into a put-grow-and-take supplemental program.

The findings of this study indicate that walleye stocking in Saginaw Bay with spring fingerlings has been extremely effective despite its supplementary nature. This was because natural reproduction was still insufficient to fulfill the carrying capacity of the bay's habitat and prey base. Thus walleye stocking in recent years has actually been more of a maintenance stocking than a supplemental stocking as defined by Laarman (1978).

Unlike Lake Erie, the walleye population in Saginaw Bay will not fully recovery without significant intervention. Saginaw Bay continues to suffer degraded and lost habitat as well as an abundance of alewives, factors that did not plague Lake Erie's walleye recovery to the same extent (Schneider and Leach 1979). Keller et al. (1987) predicted correctly that the fishery would plateau in the mid 1990s without expanding recruitment. It is unlikely that a single course of action will lead to the final recovery of walleye in Saginaw Bay. However, with a concerted effort on several fronts it is possible the walleye population can be brought to the capacity of the adult habitat, attaining the desired balancing of predator/prey ratios. Thus, to complete the goal of walleye recovery in Saginaw Bay and restore ecological balance to its ecosystem, a course of adaptive management is recommended.

Adaptive management is a management approach to natural resources that acknowledges the inherent uncertainty of natural systems like fish populations and their ecosystems. Rather than proceeding with management strategies that are assured a precise outcome, the uncertainty is embraced as a learning process by applying an investigational management style (Walters 1987). Walters (1987), in his treatise on the concept of Adaptive Management, argues that management initiatives need to constitute bold moves to affect measurable change and overcome ecosystem inertia. In Adaptive Management, managers and researchers partner to form the basis of the management by evaluation approach. The management initiatives in Saginaw Bay will have to be of sufficient scale and magnitude so as to produce quantifiable results. These initiatives, when properly evaluated, can serve as a means to move walleye recovery forward based on the most effective strategies that evolve in the face of an ever changing ecosystem. Equally important, will be the commitment and resolve by the administration of the MDNR's Fisheries Division and the public to see the walleye population in Saginaw Bay recovered to self sustaining status, and at a density that fully utilizes the available adult habitat and prey base. Recommended is an adaptive management approach based on the following elements:

1. Increase fish passage in Saginaw Bay tributaries. Because river based reproduction is presently occurring and forms the basis of the only natural reproduction by walleye for the bay, it also constitutes the most realistic means to expand natural recruitment. Fish passage by either ladder construction or dam removal should be aggressively undertaken throughout the bay's watershed.
2. Increase walleye stocking in Saginaw Bay to the extent possible. Doing so will help bring about the desired ecological shifts such as the minimization of alewives and achieving a balance of predator and prey. Increased stocking would also benefit the fishery. Hatchery plants should continue to be marked with OTC so as to further evaluate their contribution and the amount of natural reproduction.
3. Shift from river spawning strains of walleye for stocking to reef spawning strains of walleye (at least partially if not wholly). Eggs from reef spawning strains in Lake Erie should be used. This would serve to maintain a brood source for off-shore reef spawning when and where conditions may prove sufficient for successful reproduction.
4. Explore the efficacy of artificial reef construction as a means to reestablish some off-shore walleye reproduction in the inner bay. Done initially as a demonstration project and evaluated, this effort may lead to strategies for diversifying sources of recruitment in at least some years. Because of the potential for on-going degradation, included in the evaluation should be the study of sedimentation rates in the inner bay area.
5. Design and implement a study of tributary habitat in the Saginaw Bay watershed with the objective of identifying the river reaches most worthy of fish passage or dam removal. Employ a Geographic Information System approach and consider predicting through modeling, the productive capacity of these river reaches. Use the information for prioritizing fish passage and dam removal initiatives.
6. Design and implement a study of walleye fry production, transport, and subsequent survival and relate to the availability of downstream nursery habitat in Saginaw Bay tributaries with the objective of determining and understanding factors affecting and limiting river based natural reproduction.
7. Continue to annually monitor growth rate, recruitment, abundance, and age structure through the existing Saginaw Bay Fish Population Survey. Continue to estimate survival, and exploitation from the annual tagging operation. Continue to annually

estimate harvest and fishing pressure, and collect biological data from the sport catch in the open water, ice, and Saginaw River system fisheries.

8. Consolidate these recovery strategies in a plan for the recovery and management of Saginaw Bay walleye and the bay's fish community. Include revised recovery objectives and benchmarks in the plan based on criteria such as growth rates and percent recruitment from natural reproduction.

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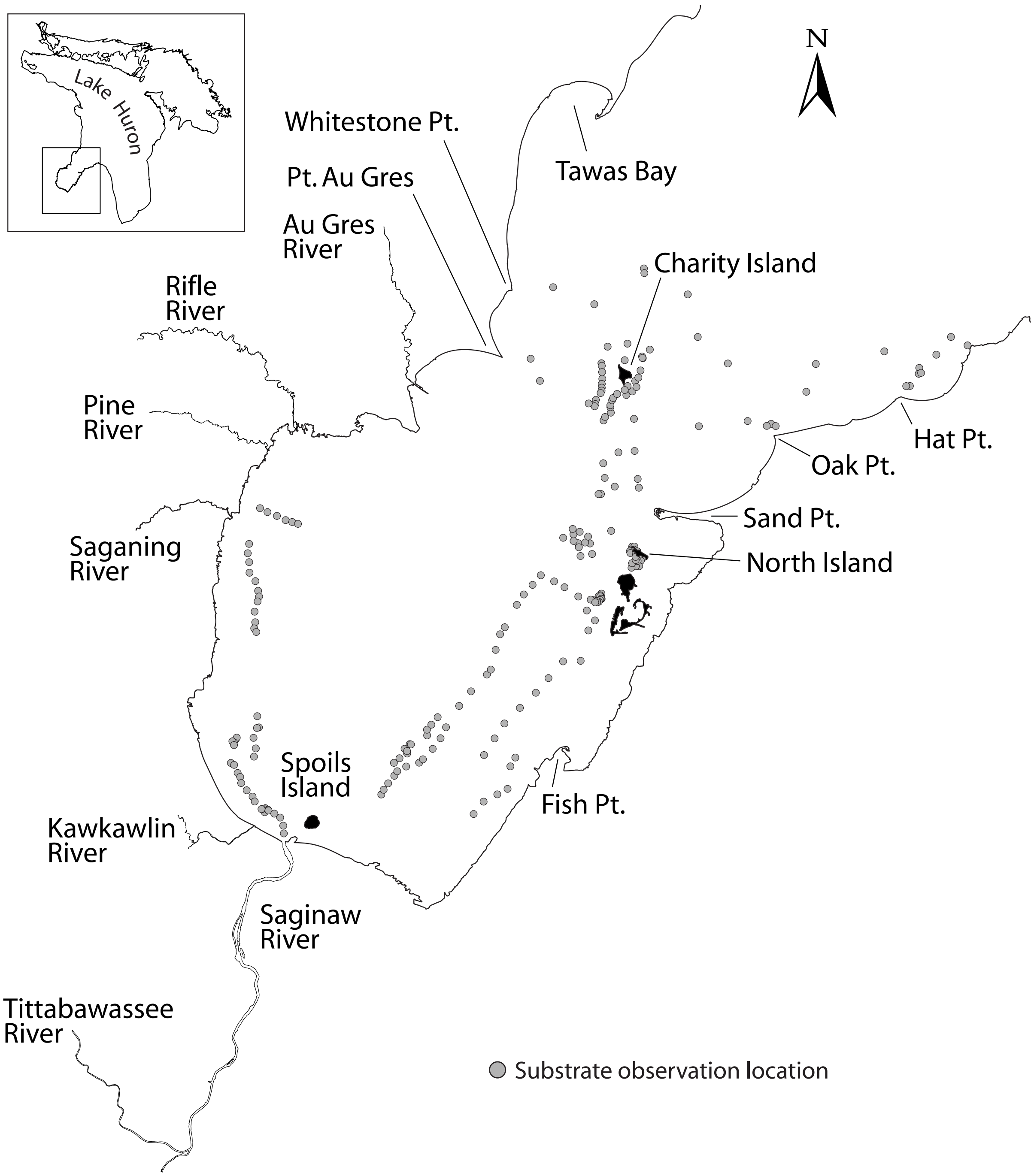

Figure 1.–Locations of bottom substrate inspections using under water video for historic reef condition determination in Saginaw Bay, Lake Huron.

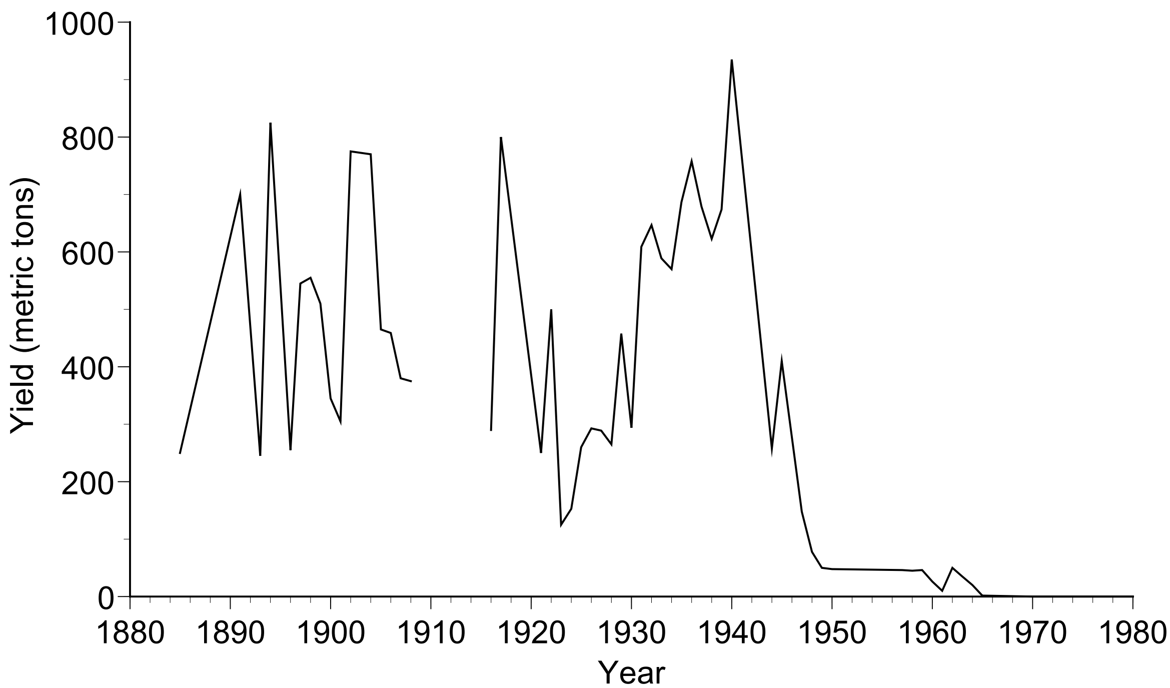

Figure 2.–Historic commercial walleye yield in Saginaw Bay, Lake Huron, 1885-1965 as reported by Baldwin and Saalfeld (1962) and Keller et al. (1987).

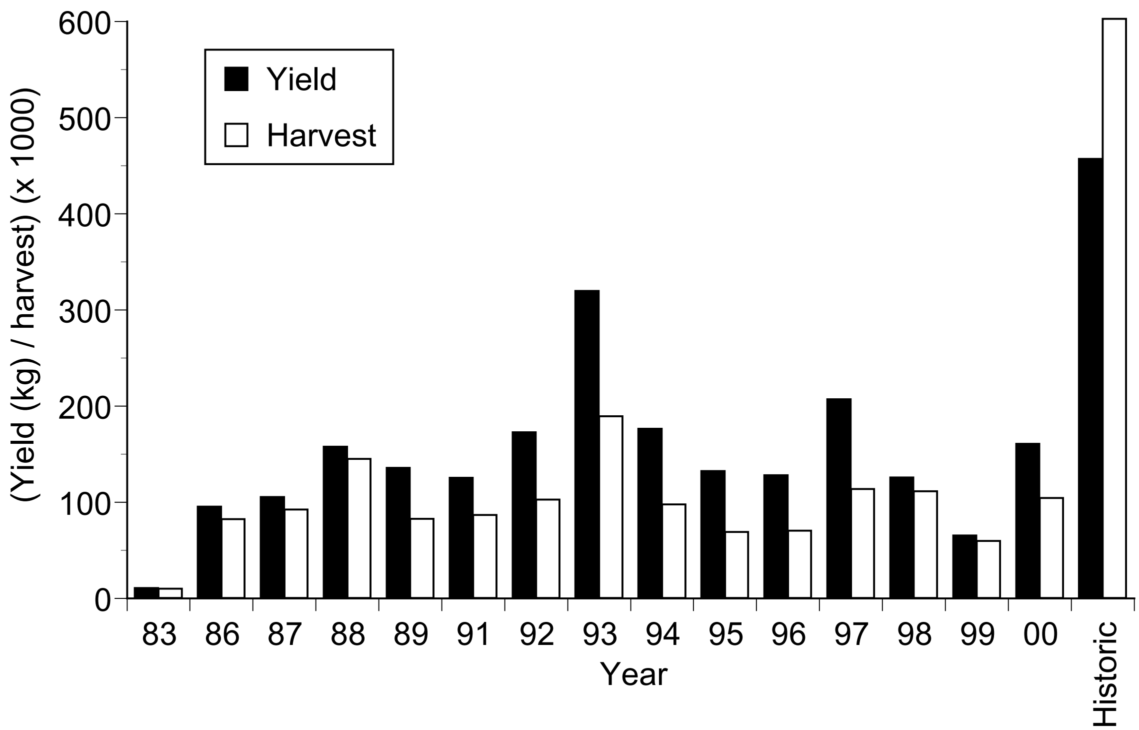

Figure 3.–Total annual harvest and yield from Saginaw Bay sport fishery 1983-2000, with average annual historic (1891-1944) commercial values for comparison. Sport fishery values include open water, ice fishery, and Saginaw/Tittabawassee River harvests as estimated by creel surveys with non surveyed portions extrapolated from averages of surveyed years.

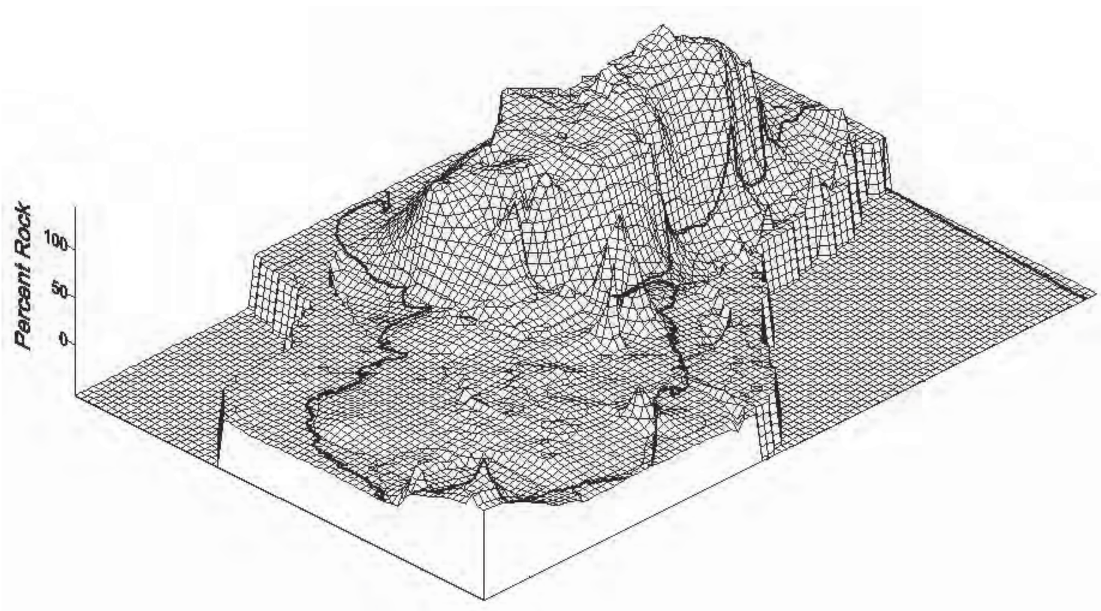

Figure 4.–Percentage of rock substrate in Saginaw Bay, Lake Huron, extrapolated from reef search data.

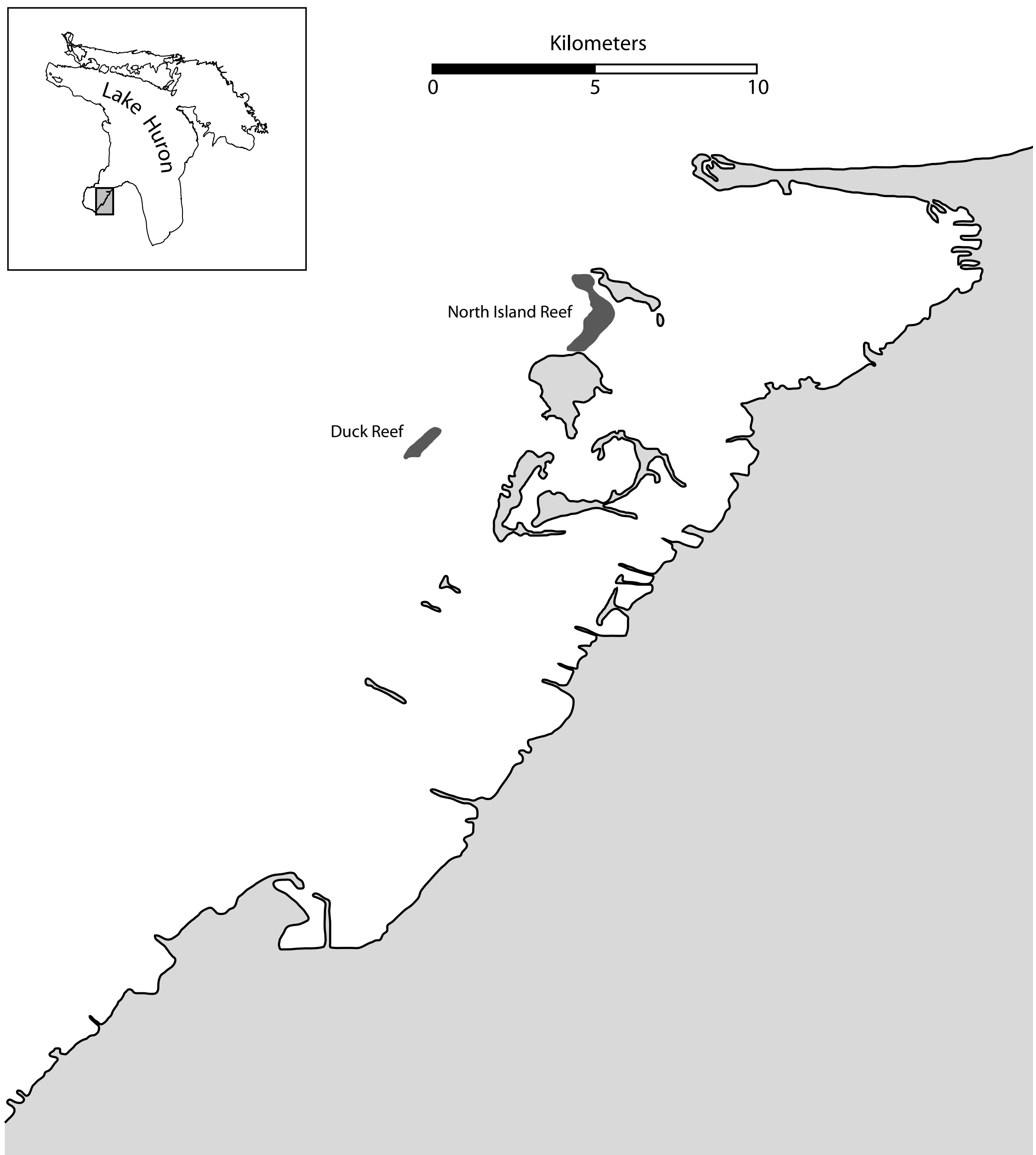

Figure 5.–Locations of North Island and Duck reefs in Saginaw Bay.

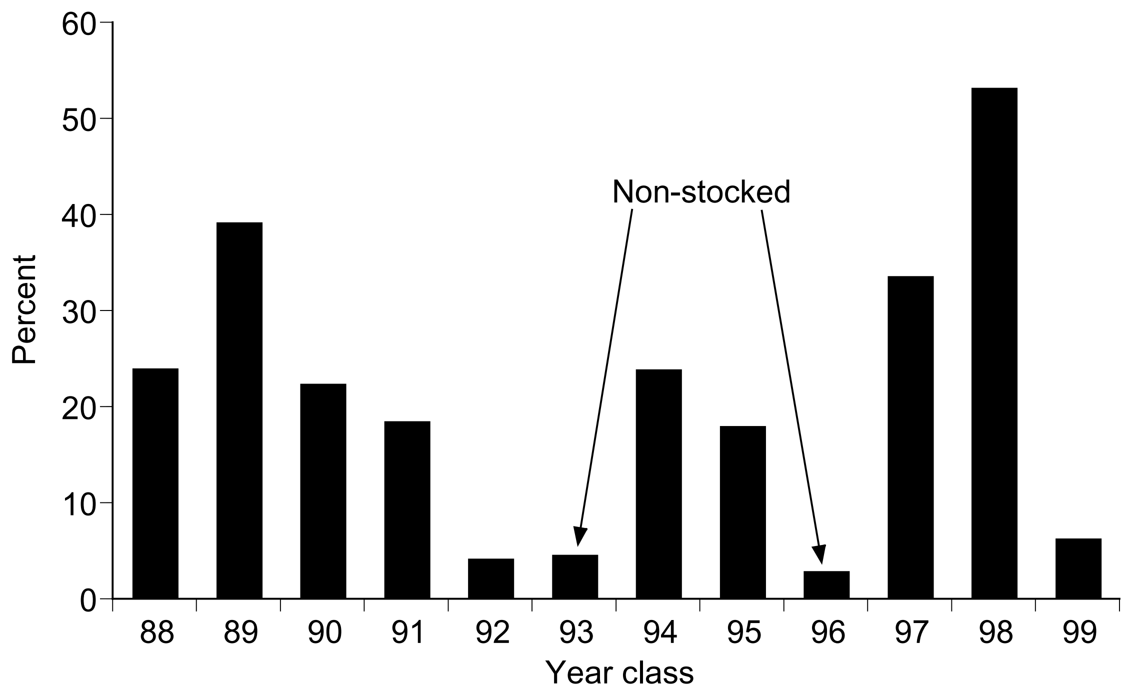

Figure 6.–Walleye recruitment index based on percent of yearling walleye from fall survey gillnet catches in Saginaw Bay from 1988-99 year classes (Fielder et al. 2000, and MDNR unpublished data). Survey year is one plus year class.

Table 1.–Walleye spring fingerlings stocked in Saginaw Bay through 2000. There was no fingerling stocking prior to 1974. OTC = oxytetracycline.

Year	Number	Mark
1974	5,500	None
1975	0	None
1976	0	None
1977	4,070	None
1978	25,000	None
1979	334,427	None
1980	9,989	None
1981	294,656	None
1982	269,540	None
1983	869,000	None
1984	947,796	None
1985	954,218	None
1986	871,263	None
1987	632,204	None
1988	345,537	None
1989	834,375	None
1990	850,085	None
1991	622,687	None
1992	787,675	None
1993	0	None
1994	1,282,992	None
1995	717,519	None
1996	0	None
1997	1,006,377	OTC
1998	1,106,000	OTC
1999	645,951	OTC
2000	675,000	OTC
Total	14,191,861	

Table 2.–Gillnet mean catch-per-unit-effort (CPUE) of walleye from Duck and North Island Reefs, Saginaw Bay, 1997-2000. Standard error (SE) of the mean in parentheses.

	Duck Reef			North Island Reef		
Year	N	CPUE (SE)	% female ripe or partially spent	N	CPUE (SE)	% female ripe or partially spent
1997	5	7.20 (2.96)	17	5	1.20 (0.49)	33
1998	3	6.00 (2.08)	0	3	10.67 (1.86)	23
1999	2	2.00 (1.00)	0	2	0.00 (---)	0
2000	1	0.00 (---)	0	1	0.00 (---)	0

Table 3.–Mean egg catch-per-unit-effort (CPUE) from Duck and North Island Reefs, 1997-2000. Standard error (SE) of the mean is in parentheses. Each unit of effort is one 10-minute tow with egg pump.

Year	N	Mean Egg CPUE (SE)
Duck Reef		
1997	19	5.84 (2.53)
1998	19	30.11 (8.63)
1999	6	0.67 (0.42)
2000	3	8.67 (8.67)
North Island Reef		
1997	22	2.55 (0.64)
1998	18	4.00 (2.33)
1999	6	4.67 (4.28)
2000	1	0.00 (---)

Table 4.–Percent hatchery contribution of fingerling stocked walleye 1997-2000, as determined by oxytetracycline marking over four year classes in Saginaw Bay. Sample sizes in parentheses.

Year class	Age-0	Age-1	Age-2	Age-3	Composite for year class
1997	81% (392)	50% (124)	73% (34)	69% (26)	73% (576)
1998	81% (420)	83% (237)	92% (79)		83% (736)
1999	85% (85)	84% (45)			85% (130)
2000	96% (49)				96% (49)
			Composite for all groups		80% (1,491)

Table 5.–Estimated percentage of walleye fingerlings surviving to age-1 and the corresponding number of spring walleye fingerlings estimated to be necessary under that survival rate to achieve a harvest of 160,000 hatchery fish over 13 hypothetical year classes.

Year	Estimated % fingerling survival	Number needed for stocking
1997	7.49	9,819,850
1996	nonstocked	---
1995	7.56	11,756,839
1994	13.28	6,595,691
1993	nonstocked	---
1992	0.73	112,854,010
1991	23.52	3,699,471
1990	9.07	10,302,323
1989	30.21	2,843,782
Average	14.67	5,890,441

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Appendix 1.–Common and scientific names of fishes mentioned in this report.

Common name	Scientific name
Alewife	*Alosa pseudoharengus*
Brook silverside	*Labidesthes sicculus*
Burbot	*Lota lota*
Channel catfish	*Ictalurus punctatus*
Emerald shiner	*Notropis atherinoides*
Gizzard shad	*Dorosoma cepedianum*
Lake chub	*Couesius plumbeus*
Lake herring	*Coregonus artedii*
Lake trout	*Salvelinus namaycush*
Lake whitefish	*Coregonus clupeaformis*
Longnose gar	*Lepisosteus osseus*
Menominee	*Prosopium cylindraceum*
Northern pike	*Esox lucius*
Rainbow smelt	*Osmerus mordax*
Rock bass	*Ambloplites rupestris*
Walleye	*Stizostedion vitreum*
White bass	*Morone chrysops*
White perch	*Morone americana*
White sucker	*Catostomus commersoni*
Yellow perch	*Perca flavescens*

Appendix 2.–Locations of reefs and bay areas searched for remaining reef habitat, and the overall percentage of rock found in 1990 and 1996.

Reef Name	Number of observations	Mean % rock (SE)	Mode % rock	Continuous formation of rock > 0.40 ha
		Inner Bay		
Coreyon Reef west humps	9	11.11 (1.39)	15	None observed
Hoyles to Nayanguing Pt.	5	0.00 (0.00)	0	None observed
Kawkawlin River mouth	5	54.00 (17.42)	50	None observed
Saginaw River to Hoyles	14	16.43 (1.69)	15	None observed
Pinconning Bar	13	0.00 (0.00)	0	None observed
Middle Ground Reef	9	10.56 (4.37)	0	None observed
Sunset to Coreyon	20	5.50 (1.14)	5	None observed
Callahan Hump	2	5.00 (0.00)	5	None observed
Hog Back Reef	13	6.31 (0.60)	5	None observed
Saganing Bar	6	7.00 (1.00)	5	None observed
Thomas Reef	6	14.17 (7.24)	5	None observed
Coreyon Reef	16	9.38 (1.01)	10	None observed
Hoyles	7	27.57 (9.62)	15	None observed
Duck Reef	17	62.35 (8.89)	100	Yes
North Island Reef	20	70.75 (7.29)	100	Yes
		Outer Bay		
Little Charity Island	9	48.67 (15.26)	95	Yes
Hat Point Reef	7	72.14 (17.99)	100	Yes
Oak Point Reef	3	83.33 (8.33)	75	Yes
Big Charity Island	38	81.97 (4.99)	100	Yes
Whitestone Point	5	97.00 (3.00)	100	Yes

Appendix 3.–Larval fish densities from Duck Reef and North Island Reef, Saginaw Bay, 1997-2000. All densities are number per m^3.

Year	Reef	Date	Walleye	Yellow perch	Whitefish	White sucker	Rainbow smelt	Unidentified	Cyprinidea sp.	Northern pike	Rock bass	Gizzard shad	Longnose gar	Lake chub	Menominee	Notropis sp.	White perch	White bass	Emerald shiner	Burbot
1997	Duck	5/7	---	---	.0293	---	---	---	---	---	---	---	---	---	.0080	---	---	---	---	---
		5/13	---	.7237	.0042	---	.0066	.0147	---	---	---	---	---	---	---	---	---	---	---	---
		5/21	---	.3377	.0018	---	.0067	.0065	---	---	---	---	---	---	---	---	.0158	---	---	---
		5/27	---	1.1532	.0035	---	.0139	.0521	---	---	---	---	---	---	---	---	.0121	---	---	---
		6/9	---	.0596	---	.0084	.0008	---	---	---	---	---	---	---	---	.1099	---	---	---	---
	North Island	5/7	---	---	.0446	---	---	.0197	---	---	---	---	---	---	.0020	---	---	---	---	---
		5/13	.0041	1.5785	.0202	---	.0052	.0248	---	---	---	---	---	---	---	---	.0148	.0016	---	---
		5/21	.0016	.2907	.0048	---	.0007	.0063	---	---	---	---	---	---	---	---	.0066	---	---	---
		5/27	---	.7049	.0013	.0007	.0071	.0045	---	---	---	---	---	---	---	---	.0032	---	---	---
		6/2	---	.2530	.0004	.0005	.0175	.0009	---	---	---	---	---	---	---	---	---	---	---	---
		6/9	---	.0177	---	.0067	.0235	---	---	---	---	---	---	---	---	.0302	---	---	---	---
1998	Duck	5/5	---	.0133	.0010	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
		5/12	---	.0097	.0057	.0027	.0027	.0007	---	---	---	---	---	---	---	---	---	---	---	---
		5/19	---	.0021	---	---	.0052	.0028	.0229	.0007	---	---	---	---	---	---	---	---	---	---
		5/26	---	.0022	---	---	---	.0214	.5909	---	.0032	---	.0006	.0028	---	---	---	---	---	---
		6/5	---	.0017	---	---	---	.0141	1.0028	---	---	---	.0018	---	---	---	---	---	---	---
		6/9	---	---	---	---	---	.0226	1.6732	---	---	.0135	---	---	---	---	---	---	---	---
	North Island	5/5	---	.4750	.0017	.0047	---	.0163	---	---	---	---	---	---	---	---	---	---	---	---
		5/12	---	.1070	---	.0007	.0087	.0007	---	---	---	---	---	---	---	---	---	---	---	---
		5/19	---	.0118	---	---	.0043	.0123	.5937	.0016	---	---	---	---	---	---	---	---	---	---
		5/26	---	.0082	---	---	.0007	.0222	2.4385	---	---	---	---	---	---	---	---	---	---	---
		6/5	---	---	---	---	---	.1999	1.2207	---	---	---	---	---	---	---	---	---	---	---
		6/9	---	.0012	---	---	---	.0135	.8349	---	---	---	---	---	---	---	---	---	---	---

Appendix 3.–Continued.

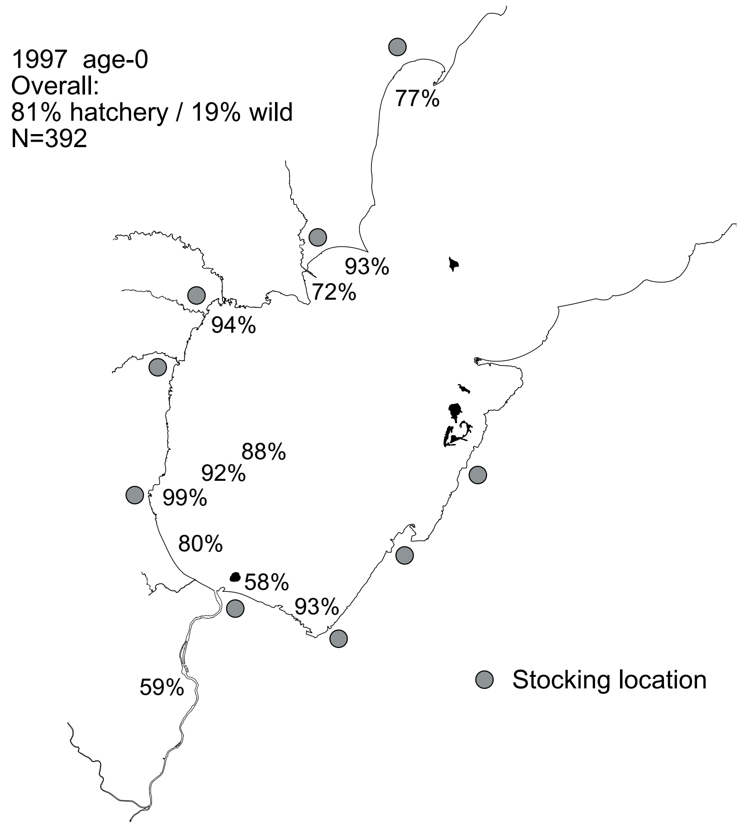
Year	Reef	Date	Walleye	Yellow perch	Whitefish	White sucker	Rainbow smelt	Unidentified	Cyprinidea sp.	Northern pike	Rock bass	Gizzard shad	Longnose gar	Lake chub	Menominee	Notropis sp.	White perch	White bass	Emerald shiner	Burbot
1999	Duck	5/5	---	.1273	---	.0019	---	.0012	---	---	---	---	---	---	---	---	---	---	---	---
		5/10	---	.0044	---	---	.0009	---	---	---	---	---	---	---	---	---	---	---	---	---
		5/20	---	.0185	---	.0019	---	.0006	---	---	---	---	---	---	---	---	---	---	---	---
		5/28	---	.0037	---	.0005	.0064	.0038	.5875	---	---	---	---	---	---	---	---	---	---	---
		6/2	---	---	---	.1384	.0830	.0113	.4283	---	---	---	---	---	---	---	---	---	---	---
		6/8	---	---	---	.0013	.1948	.0070	.1098	---	---	---	---	---	---	---	---	---	---	---
	North Island	5/5	---	1.4533	.0017	.0047	---	.0304	---	.0006	---	---	---	---	---	---	---	---	---	---
		5/10	---	.0415	---	.0305	---	.0021	---	---	---	---	---	---	---	---	---	---	---	---
		5/20	---	.2625	---	---	.0006	.0022	.2245	---	---	---	---	---	---	---	---	---	---	---
		5/28	---	.0106	---	---	.0026	.0147	2.1546	---	---	---	---	---	---	---	---	---	---	---
2000	Duck	5/3	---	---	.0105	---	---	---	---	---	---		---	---	---	---	---	---	---	.0006
		5/16	---	.160	---	---	---	.0406	.1128	---	---	.2200	---	---	---	---	---	---	.1078	---
	North Island	5/3	---	.0221	---	.0139	---	.0096	---	---	---		---	---	---	---	---	---	---	---
		5/16	---	.2447	---	.0139	---	.0984	.1186	---	---	.0310	---	---	---	---	---	---	.1522	.0011

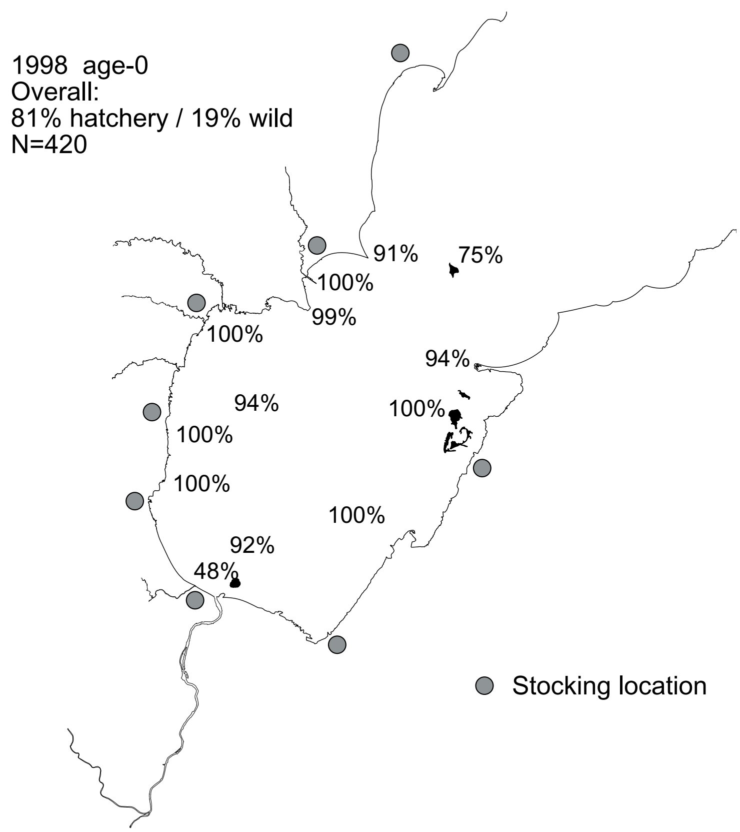
Appendix 4.–Mean zooplankton density (taxonomic groups combined) for Duck Reef and North Island Reef, Saginaw Bay, 1997-2000.

1997		1998		1999		2000	
Date	No./l	Date	No./l	Date	No./l	Date	No./l
			Duck Reef				
05/03/97	6.52	05/05/98	0.74	05/05/99	2.57	05/03/00	1.31
05/21/97	10.39	05/12/98	0.84	05/10/99	5.68	05/16/00	8.44
05/27/97	18.35	05/19/98	4.34	05/20/99	10.98		
06/02/97		05/26/98	5.11	05/28/99	1.21		
06/09/97	30.97	06/05/98	57.15	06/02/99	40.69		
		06/09/98	83.54	06/08/99	17.23		
			North Island Reef				
05/13/97	9.11	05/05/98	1.82	05/05/99	7.90	05/03/00	0.22
05/21/97	13.51	05/12/98	5.15	05/10/99	7.62	05/16/00	8.29
05/27/97	16.36	05/19/98	4.26	05/20/99	7.00		
06/02/97	14.84	05/26/98	na	05/28/99	1.62		
06/09/97	18.88	06/05/98	14.17	06/02/99	12.71		
		06/09/98	25.12	06/08/99	54.48		

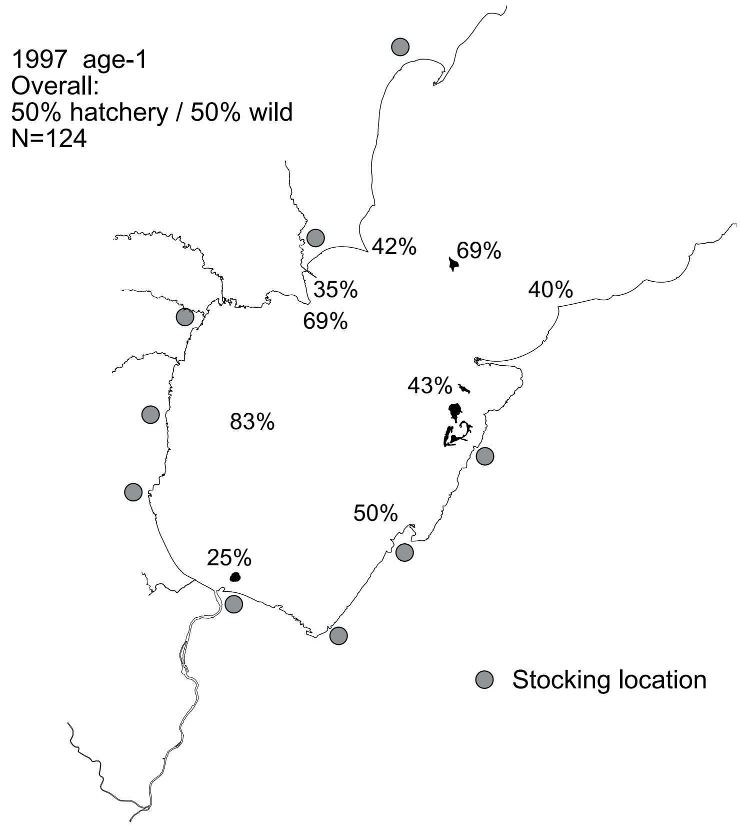
Appendix 5.–Age-0 walleye catch-per-unit-effort by collection location from summer trawling and electrofishing for analysis of oxytetracycline marks. (trawling effort; number of 10 minute tows, and electrofishing effort; hours of generator time, are in parentheses).

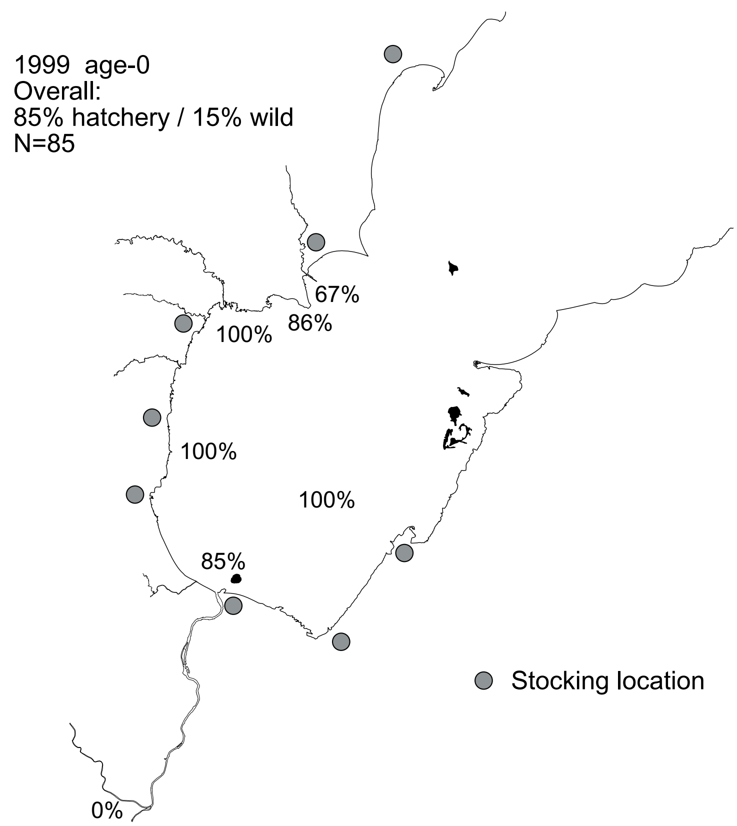
Gear	Year	AuGres area	Pine/Rifle/ Saganing area	Linwood/ Nayanguing area	Saginaw/ Kawkawlin area	Lower Saginaw River	Spoils Island vicinity	Quanicassee area	Geiger Rd. area	Sebewaing	North Island/Sand Point
Trawling	1997	0.00	0.25	0.27	2.00	1.10	2.30	1.40	0.00	---	---
		(7.8)	(12.0)	(15.0)	(2.0)	(12.8)	(12.0)	(5.0)	(9.0)	---	---
	1998	0.33	0.17	0.18	---	5.30	0.55	---	0.10	---	0.00
		(12.0)	(12.0)	(11.0)	---	(11.8)	(12.7)	---	(10.0)	---	(4.0)
	1999	0.00	0.00	0.00	---	1.60	0.00	1.40	---	---	---
		(7.8)	(7.0)	(5.0)	---	(6.3)	(5.5)	(5.0)	---	---	---
	2000	0.00	0.00	0.00	---	1.50	1.70	0.33	---	0.00	---
		(5.8)	(6.0)	(5.0)	---	(6.0)	(6.0)	(6.0)	---	(6.0)	---
Electro-fishing	1997	4.50	17.00	35.00	---	25.00	5.00	6.20	0.50	---	---
		(2.0)	(2.0)	(2.0)	---	(3.0)	(2.0)	(1.3)	(2.0)	---	---
	1998	2.50	10.50	18.50	---	42.00	2.50	---	0.50	---	1.00
		(3.2)	(2.0)	(2.0)	---	(2.0)	(2.0)	---	(2.0)	---	(2.0)
	1999	7.00	0.50	0.50	3.00	5.30	---	---	---	---	---
		(2.0)	(2.0)	(2.0)	(2.0)	(3.0)	---	---	---	---	---
	2000	1.50	0.00	1.50	---	7.00	1.50	0.00	---	0.00	---
		(2.0)	(2.0)	(2.0)	---	(2.0)	(2.0)	(2.0)	---	(2.0)	---



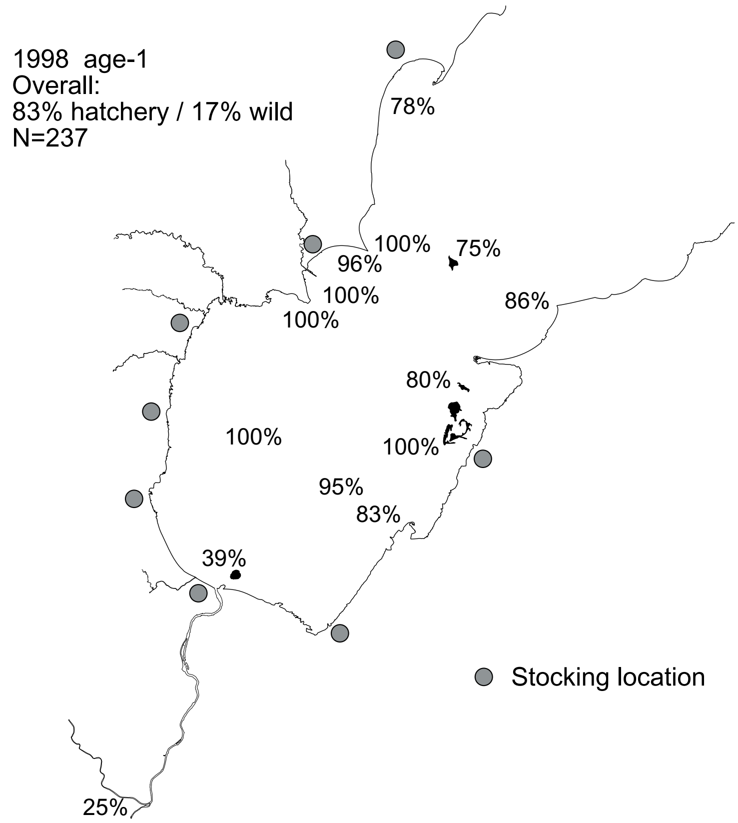


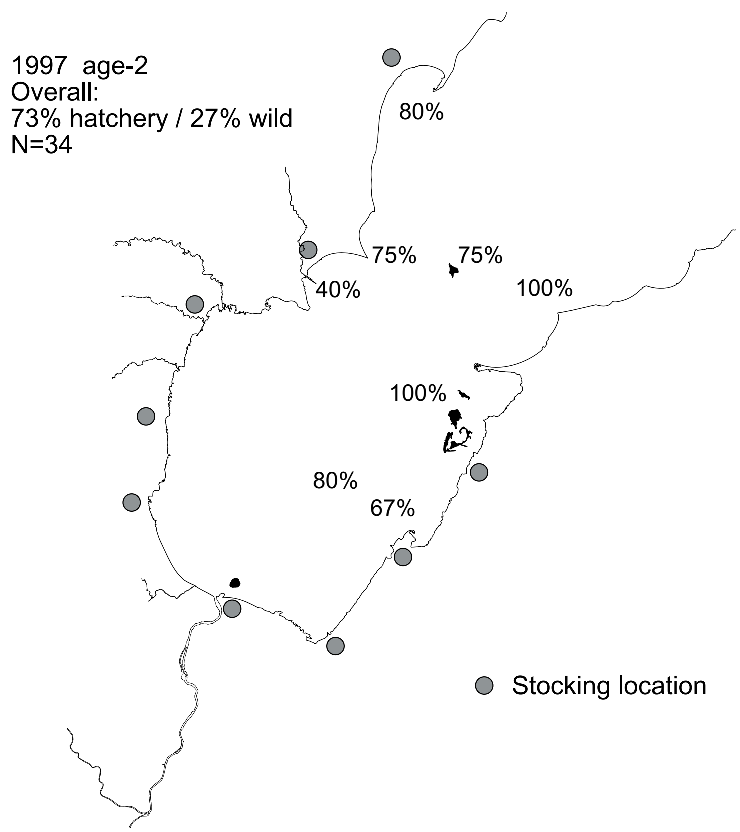
Appendix 6.–Percent contribution of hatchery fish to various year classes by sample location in Saginaw Bay, Lake Huron, as determined by analysis of oxytetracycline marks, 1997-2000.



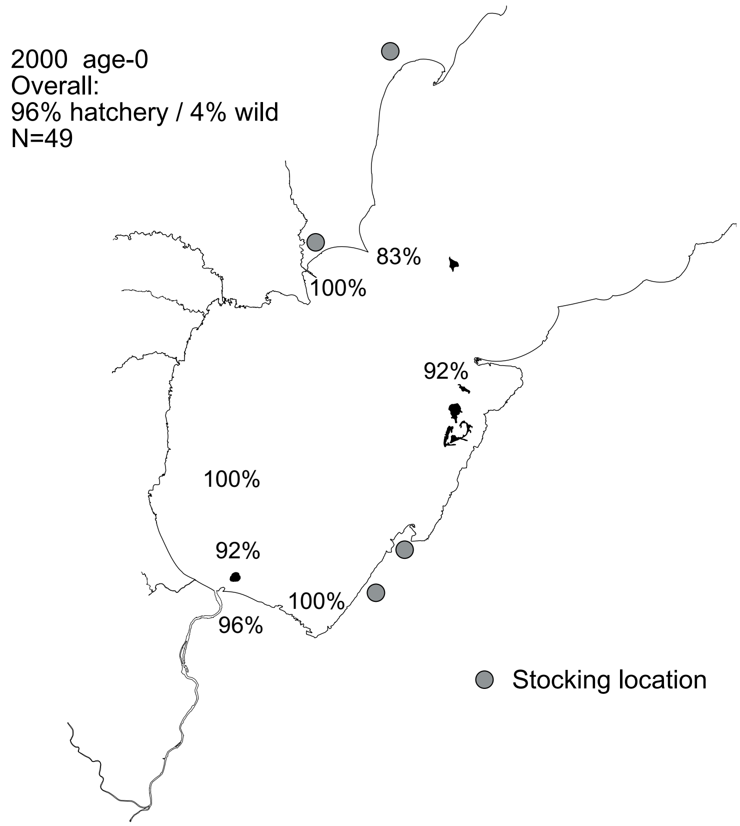


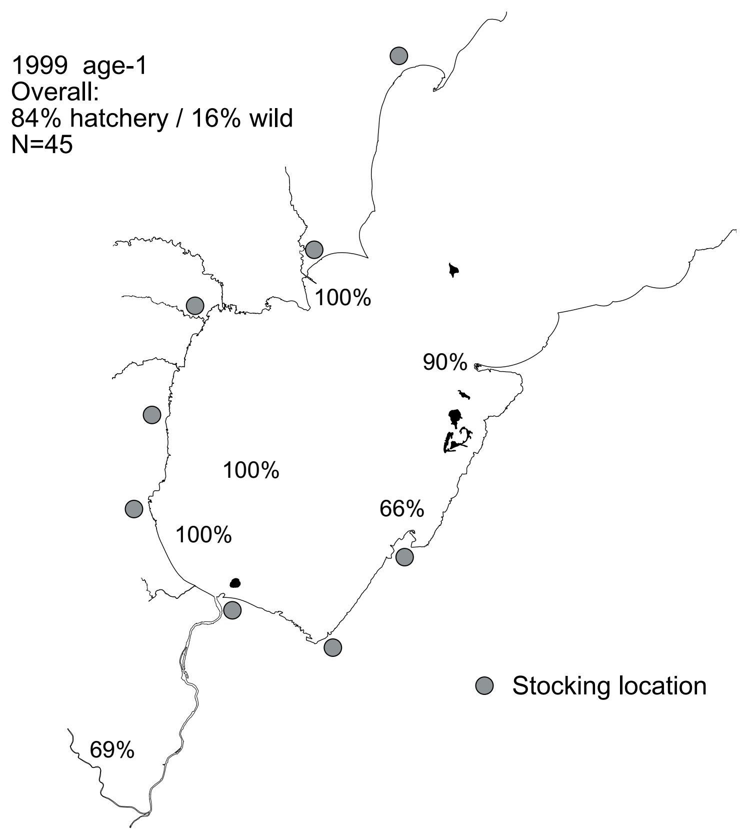
Appendix 6.–Continued.



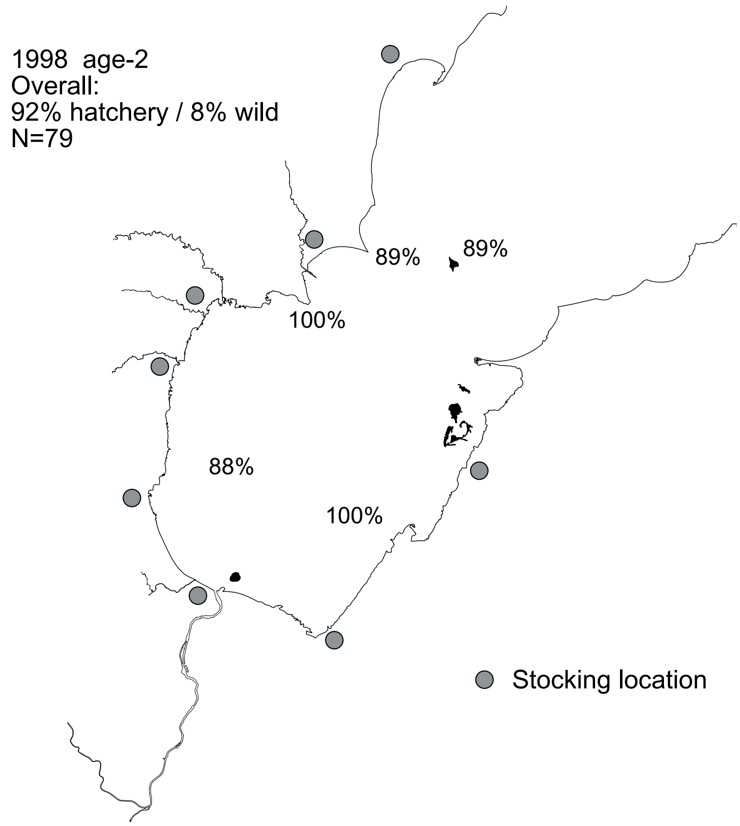


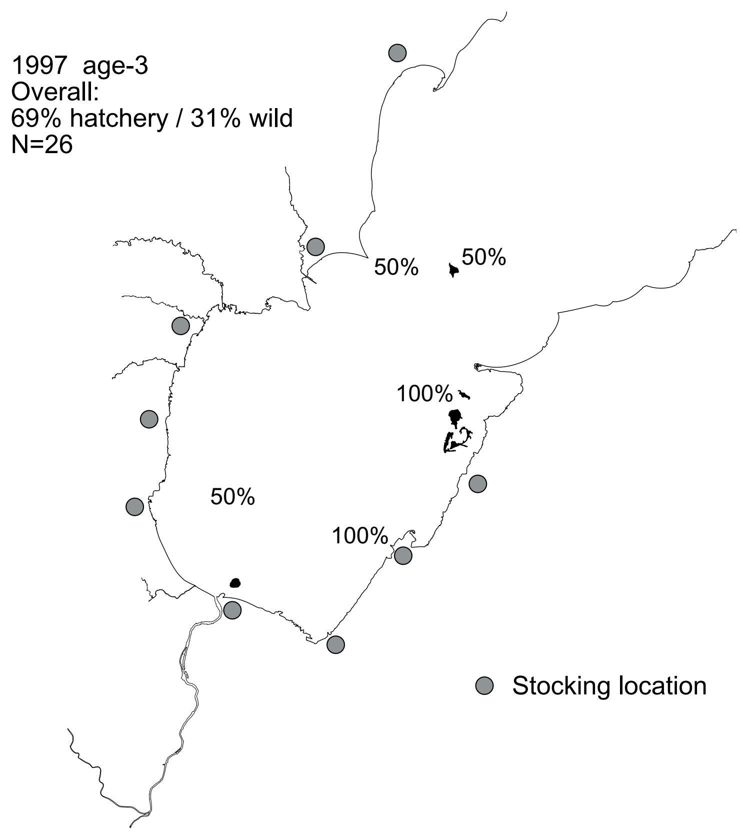
Appendix 6.–Continued.





Appendix 6.–Continued.





Appendix 6.–Continued.