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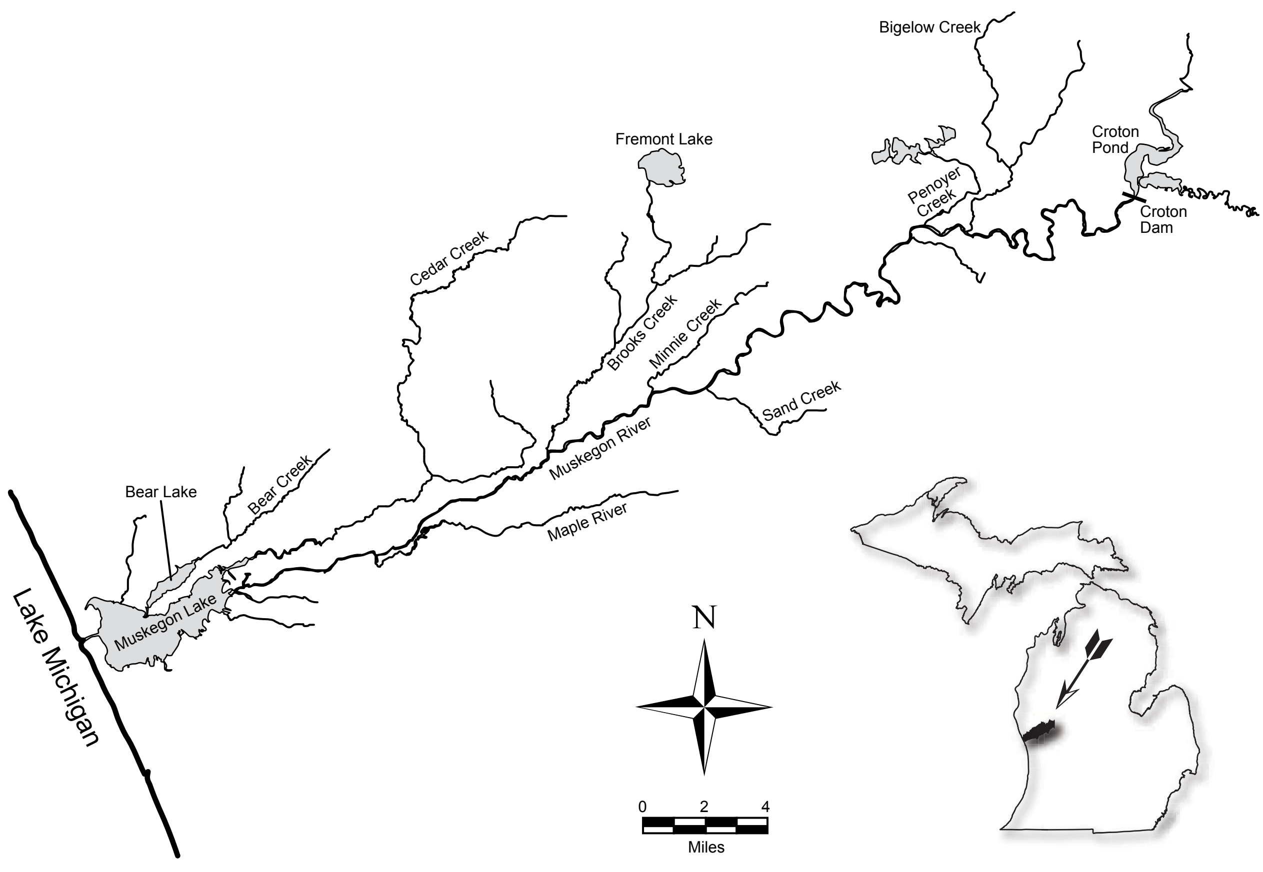

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Table of Contents

Michigan Department of Natural Resources
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The Walleye Population and Fishery of the Muskegon Lake System, Muskegon and Newaygo Counties, Michigan in 2002

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Introduction

The Michigan Department of Natural Resources (MDNR), Fisheries Division surveyed fish populations and angler catch and effort in the Muskegon Lake System, Muskegon and Newaygo Counties, Michigan from March 2002 through March 2003. For the purposes of this report, we defined the Muskegon Lake System as Muskegon Lake and about 45 miles of the Muskegon River from the lake to Croton Dam (Figure 1). When we refer to the Muskegon System, we mean both the lake and river combined. We will be specific when we are referring to either the lake or the river separately. This work was part of a statewide program designed to improve assessment and monitoring of fish communities and fisheries in Michigan's largest inland lakes. Known as the Large Lakes Program, it is currently scheduled to survey about four lakes per year through 2010 (Clark et al. 2004). The Large Lakes Program has three primary objectives. First, we want to produce consistent indices of abundance and estimates of annual harvest and fishing effort for important fishes. Initially, important fishes are defined as species susceptible to trap or fyke nets and/or those readily harvested by anglers. Our hope is to produce statistics for important fishes to help detect major changes in their populations over time. Second, we want to produce sufficient growth and mortality statistics to be able to evaluate effects of fishing on special-interest species, which support valuable fisheries. This usually involves targeting special-interest species with nets or other gears to collect, sample, and mark sufficient numbers. We selected walleye *Sander vitreus* as a special-interest species in this survey of the Muskegon Lake System. Finally, we want to evaluate the suitability of various statistical estimators for use in large lakes. For example, we applied and compared three types of abundance, and two types of exploitation rate, estimators for walleyes.

The Large Lakes Program will maintain consistent sampling methods over lakes and time. This will allow us to build a body of fish population and harvest statistics to directly evaluate differences between lakes or changes within a lake over time. However, Muskegon Lake has unique features that caused us to deviate somewhat from our usual methods. Muskegon Lake is one of several lakes in Michigan commonly known as "drowned-river-mouth lakes". All these lakes are located at the mouths of rivers flowing into Lake Michigan and are separated from Lake Michigan only by short channels (Figure 1). Both Lake Michigan and the lower Muskegon River significantly affect the ecology of Muskegon Lake, especially with regard to our target species, walleye. Because it was well known from previous biological surveys that most walleyes in the system spawned in the Muskegon River between the lake and Croton Dam, we devoted most of our biological sampling efforts to electrofishing the river. Most of the biological sampling efforts in previous large lake surveys were devoted to netting in the lakes.

We will refer to fishes by common name in the text. We listed common and scientific names of all fish species referenced in the Appendix.

Study Area

The Muskegon Lake System is located in west-central Michigan (Figure 1). The original river channel draining from Muskegon Lake to Lake Michigan is now a shipping channel with functional piers extending into Lake Michigan. Bear Lake and channel, several small streams, and the Muskegon River are tributaries. The Muskegon River system is 212 miles long and is one of the largest watersheds in the State, encompassing over 2,350 mi^2 (O’Neal 1997). The Muskegon River has numerous coldwater and warmwater tributaries, and the watershed contains many inland lakes. The upper watershed drains from Higgins Lake, one of the largest, deep, coldwater lakes in Michigan, and Houghton Lake, the largest inland lake in Michigan that is shallow and has warmer waters. Immediately upstream of Muskegon Lake, the river flows through a wetland approximately 10–15 mi^2 in size. The association of the streams, the extensive marsh, and Lake Michigan provides a rich and productive environment supporting a high diversity of fish and other aquatic life in Muskegon Lake. The Muskegon Lake System and its associated marshes are considered important parts of the coastal wetlands of the Great Lakes.

The size of Muskegon Lake was estimated by the Michigan DNR in 1950 at 4,150 acres. Breck (2004) estimated the size at 4,232 acres using aerial photos and computerized digitizing methods, and his estimate is probably the most accurate. We will use Breck’s estimate in our calculations in this report. Breck also estimated the lake to have a maximum depth of 70 ft, mean depth of 24 ft, and volume of 101,635 acre-ft.

The Muskegon River and Lake Michigan systems have long histories of environmental changes that have affected aquatic resources in Muskegon Lake (O’Neal 1997). The watershed was extensively logged in the mid to late 1800s, resulting in severe habitat degradation in the river. Muskegon Lake was used for milling of logs and transport for shipping, resulting in degraded habitat in the littoral zone and adjacent wetlands. The lake was heavily industrialized during the 20^{th} century, resulting in severe water pollution from organic contaminants and nutrients. Water quality was so poor that fish could not be eaten from the lake for some time due to strong petroleum tastes and odors in the flesh. Dredging and filling of the lake during this period was extensive. Dams were constructed in the Muskegon River and tributaries that blocked fish migrations.

Water quality in Muskegon Lake has gradually improved since the 1960s, although some fish eating advisories remain. Considerable contamination of lake sediments is still present, and nutrient levels are elevated due to agricultural and urban discharges, but the lake is generally classified as mesotrophic. Industrial and urban development is present around the entire shoreline of the lake. Natural shorelines are non-existent except for a small area within a state park. Natural wetlands and forests lying adjacent the shoreline in the main basin have been removed. Nearly the entire southern shore of the lake has been dredged or filled for urban use, or marina and shipping activities, and much of the remaining littoral zone has been altered. Aquatic macrophyte distribution has likely been reduced by the historical dredging and filling. Biomass and diversity of submerged and floating-leaved aquatic plants is high. This may partly be the result of nutrient enrichment of the sediments. Maximum aquatic plant biomass in 1995 was measured at 19,000 g/m^2, and biomass along most of the 26 study transects exceeded 6,000 g/m^2 (Luttenton 1995). Twenty-two plant species were identified including the exotic species Eurasian water-milfoil *Myriophyllum spicatum* and curly-leaf pondweed *Potamogeton crispus*. Exotic species were widespread but were not dominant plants in the community. Woody debris from sawmill waste is present in several locations around the lake providing a limited amount of fish habitat. No naturally occurring woody debris exists along the lake shoreline, but some enters the lake from the river.

Muskegon Lake has a very diverse fish community, containing warmwater and coolwater fish, along with seasonal migrations of coldwater fish from Lake Michigan. Important game species include yellow perch, walleye, largemouth and smallmouth bass, northern pike, bluegill, pumpkinseed, crappie, channel catfish, flathead catfish, and seasonally, Chinook salmon, steelhead (rainbow trout), brown trout, and lake whitefish. A summary of the original and present fish community of the watershed is provided in the Muskegon River Watershed Assessment (O’Neal 1997). Sixty-five species of fish were collected in surveys of Muskegon Lake between 1948 and 2002 (Appendix). Additional species of fish may be present in the lake and some have been extirpated. A thorough fish community survey has never been completed on this lake, although fairly extensive surveys were conducted in 1950 and 1978–80. Very limited sampling has been conducted in recent years.

Substantial changes occurred in the fish community composition of the Muskegon Lake System between 1950 and 1970. Most notable, the abundance of exotic species, such as sea lamprey, alewife, rainbow smelt, and gizzard shad, greatly increased and the abundance of native walleyes decreased. The number of walleyes spawning in the Muskegon River declined from about 120,000 in the early 1950s (Crowe 1955) to only 2,000 by 1975 (Schneider and Leach 1979). Schneider and Leach tried to determine the reason for the walleye decline by examining the possible affects of several changing factors. They concluded that sea lamprey predation, fishing exploitation, and deteriorating water quality might have contributed to the decline, but that the huge increase in alewife abundance was probably the principal cause. They surmised that alewives preyed on walleye eggs and fry causing a failure of recruitment. Since the 1970s, sea lampreys and alewives have declined, harvest regulations have become more restrictive, and water quality has improved. The walleye population has partially rebounded to 43,200 in 1986 (Day 1971) and 46,500 in 1998 (R. O’Neal, MDNR), due in part to a fingerling stocking program.

About 500,000 walleye fingerlings were stocked annually into the Muskegon Lake System during the 1990s (Table 1). This program began in 1978 with the purpose of restoring a self-sustaining walleye population, and continues today. Annual plants of Chinook salmon, steelhead, and brown trout also occur in the lake or the river annually. Historically, lake trout were stocked near the outlet to Lake Michigan during some years in the 1980s and 1990s. Future restoration programs are being considered for white bass, lake sturgeon, and muskellunge.

Large fish of many species are common in Muskegon Lake. For example, there were 110 State of Michigan, Master Angler Awards issued for fish taken from Muskegon Lake between 1990 and 2000, including white perch, walleyes, common carp, Chinook salmon, longnose gar, northern pike, bowfin, freshwater drum, quillback, flathead catfish, brown trout, yellow perch, green sunfish, gizzard shad, and coho salmon. Additionally, many Master Angler Awards were issued for fish taken from Lake Michigan waters near the mouth of the Muskegon River and the Muskegon River between Muskegon Lake and Croton Dam.

Methods

We used the same basic methods on the Muskegon Lake System as Clark et al. (2004) used on Houghton Lake. However, we used less netting effort and more electrofishing effort than they did because walleye spawning was concentrated in the Muskegon River. We will give a complete overview of methods in this report, but will refer the reader to Clark et al. (2004) for details.

We used electrofishing gear to collect spawning walleyes from the Muskegon River in March. No other species were taken during this operation. We conducted a limited amount of netting effort in the lake proper and recorded catch by individual net lift. Total lengths were measured for all fish collected with nets. All walleyes were measured and legal-size fish were tagged with individually numbered jaw tags. Tagged fish were also fin clipped to evaluate tag loss. Angler catch and harvest surveys were conducted the year after tagging—one covering the summer/fall fishery from April 27 through November 30, 2002 and one covering the winter fishery from January 1 through March 31, 2003. Tags on walleyes observed during angler surveys were tallied and the ratios of marked to unmarked fish were used to make abundance estimates for walleyes. In addition, voluntary tag recoveries were requested. All tags contained a unique number and the mailing address of an MDNR field station. To encourage voluntary tag returns, about 50% of tags were identified as reward tags, and we paid $10 to anglers returning them.

Fish Community

We described the status of the spawning walleye population in terms of number collected, catch per unit effort, percent by number, and size distribution. We also collected more detailed data for walleyes as described below. We sampled walleye populations in the lower Muskegon River with electrofishing gear from March 4–29, 2002. We used two boomshockers and two chase boats daily when electrofishing, each with three-person crews, for 2 weeks. We used a Smith-Root® boat equipped with boom-mounted electrodes (DC) for electrofishing. Latitude and longitude were recorded for all net locations and electrofishing runs using geographical positioning systems (GPS).

We attempted to collect walleyes with trap and fyke nets in Muskegon Lake. Trap and fyke net collections were limited due to time limitations and effectiveness of the gear. Few incidental species were collected in this study. Fyke nets were 6 ft x 4 ft with 1.5-in stretch mesh and 100-ft leads. Trap nets were 8 ft by 5 ft by 3 ft with 1.25-in stretch mesh on the pot, and 1.5-in stretch mesh on 100-ft leads. Duration of net sets ranged from 1–4 nights, but most were 1 night.

During electrofishing collections, we collected only walleyes, and did not collect non-target species. We identified species and counted all fish captured in nets. For non-target species collected in nets, we measured total lengths of all fish to the nearest 0.1 in. We used Microsoft Access© to store and retrieve data collected during the tagging operation. Size distribution summaries only included fish on their initial capture occasion.

Walleye

Size structure.–Total lengths of all walleyes were measured to the nearest 0.1 in and the size structure of the sample was characterized as number per inch group (i.e., 12.0–12.9 in, 13.0–13.9 in, etc.). We defined legal walleyes as those 15.0 in and larger and calculated the percent of legal-size fish in the sample as an additional index for comparison to other walleye populations. We defined adult walleyes as fish of legal size plus sub-legal fish of identifiable sex.

Sex composition.–We recorded sex of walleyes. Fish with flowing gametes were categorized as male or female, respectively. Fish with no flowing gametes were categorized as unknown sex.

Abundance.–We estimated abundance of legal-size walleyes using mark-and-recapture methods. Walleyes were fitted with monel-metal jaw tags. In order to assess tag loss, we double-marked each tagged fish by clipping the left pelvic fin. Reward ($10) and non-reward tags were issued in an approximate 1:1 ratio. Initial tag loss was assessed during the marking period as the proportion of recaptured fish of legal size without tags. This tag loss was largely caused by entanglement with nets, and thus was not used to adjust estimates of abundance or exploitation. Newman and Hoff (1998) reported similar concern for netting-induced tag loss. All fish that lost tags during netting recapture were re-tagged, and so were accounted for in the total number of marked fish at large.

We compared three different abundance estimates from mark-and-recapture data, one derived from marked-unmarked ratios during the spring survey (multiple-census), one derived from marked-unmarked ratios from the angler survey (single-census), and one derived from marked-unmarked ratios from the 2003 egg-take operation (single-census). Also, as part of the 2003 egg-take recapture process, we recorded recaptures by sex and made separate abundance estimates for male and female walleyes.

For the multiple-census estimate, we used the Schumacher-Eschmeyer formula (±95% symmetrical confidence limits) from daily recaptures during the tagging operation (Ricker 1975). The minimum number of recaptures necessary for an unbiased estimate was set a priori at four. For the first single-census estimate, we used numbers of marked and unmarked fish seen by clerks in the companion angler survey as the "recapture-run" sample. For the second single-census estimate, we used the numbers of marked and unmarked fish seen in the walleye egg-take operation conducted one year following the tagging operation as the "recapture-run" sample. The Chapman modification of the Petersen method (Ricker 1975) was used to generate population estimates (±95% symmetrical confidence limits). Probability of tag loss was calculated as the number of fish in a recapture sample with fin clips and no tag divided by all fish in the recapture sample that had been tagged, including fish that had lost their tag. Standard errors were calculated assuming a binomial distribution (Zar 1999). If we detected annual tag loss, we adjusted the single-census abundance estimate by reducing the number of marked fish at large. For more details on methods for abundance estimates, see Clark et al. (2004).

A 1998 abundance estimate of 45,805 legal (46,479 adult) walleyes in the Muskegon River helped us gauge how many fish to mark. We determined our tagging goal by evaluating the effect of increasing the proportion tagged on the precision of the estimate. Based on this analysis, it was our judgment that marking 10% of the population achieved a good compromise between marking effort and precision, assuming the fraction marked was a function of marking effort (Clark et al. 2004). Thus, we set our tagging goal at 10% of the population or approximately 5,000 walleyes.

Our primary, single-census estimates were only for walleyes 15 in and larger. Because we clipped fins and recorded recaptures of all walleyes, we were also able to make a direct multiple-census estimate of adult walleyes using the Schumacher-Eschmeyer formula and including the sub-legal and mature fish that were marked and recaptured.

We estimated numbers of adult walleyes from our single-census estimates by dividing our estimate of walleyes 15 in and larger by the proportion of adult walleyes on the spawning grounds that were 15 in and larger, using the equation in Clark et al. (2004).

We accounted for fish that recruited to legal size over the course of the year between mark and recapture by removing a portion of the unmarked fish observed by the angler survey clerk and egg collectors (i.e., reduced C in the Petersen formula for abundance estimate). Removal of unmarked fish was based on a weighted average monthly growth for fish of slightly sub-legal size (i.e., walleyes 14.0–14.9 in). For a detailed explanation of methods see Clark et al. (2004) and Ricker (1975). This adjusted ratio was used to make the primary (single census) population estimates.

The reliability of all abundance estimates was assessed using the coefficient of variation (CV; standard deviation/mean). Following the methods of Hansen et al. (2000), we considered abundance estimates with a CV less than or equal to 0.40 to have adequate precision to possibly be useful.

For comparison, we also used two regression equations developed for Michigan lakes to provide additional estimates of abundance. These regressions predict legal and adult walleye abundances based on lake size. These equations were derived from historic abundance estimates made in

Michigan over the past 20 years. The following equation for adult walleyes was based on 35 abundance estimates:

$$\ln(N) = 0.1087 + 1.0727 \times \ln(A),$$

$$R^2 = 0.84, \qquad P = 0.0001,$$

where *N* is the estimated number of adult walleyes and *A* is the surface area of the lake in acres. The equation for legal walleyes was based on 21 estimates:

$$\ln(N) = 0.3323 + 1.0118 \times \ln(A),$$

$$R^2 = 0.85, \qquad P = 0.0001,$$

where *N* is the estimated number of legal walleyes and *A* is the surface area of the lake in acres. For both regressions, we calculated prediction intervals with 95% confidence (Zar 1999).

Mean lengths at age.–We used dorsal spines to age walleyes. We used these structures because we thought they provided the best combination of ease of collection in the field, and accuracy and precision of age estimates. Clark et al. (2004) described advantages and disadvantages of various body structures for aging walleyes and northern pike.

Sample sizes for age analysis were based on historical length at age data from the lower Muskegon River system and methods given in Lockwood and Hayes (2000). Our goal was to age 15 male and 15 female walleyes per inch group. Samples were sectioned using a table-mounted Dremel® rotary cutting tool. Sections approximately 0.5-mm thick were cut as close to the proximal end of the spine or ray as possible. Sections were examined at 40x–80x with transmitted light, and the image was archived for multiple reads.

Two technicians independently aged walleyes. Ages were considered correct when results of both technicians agreed. Samples in dispute were aged by a third technician. Disputed ages were considered correct when the third technician agreed with one of the first two. Samples were discarded if three technicians disagreed on age, though occasionally an average age was used when differences between ages assigned to older fish (≥ age 10) were less than 10%.

After a final age was identified for all samples, weighted mean lengths at age and age-length keys (Devries and Frie 1996) were computed for males, females, and all fish (males, females, and fish of unknown sex) for walleyes.

We compared our mean lengths at age to those from previous surveys of Muskegon Lake and other large lakes. Also, we computed a mean growth index to compare our data to Michigan state averages as described by Schneider et al. (2000). Basically, the mean growth index is the average of deviations between the observed mean length and the seasonal statewide average length. In addition, we fit mean length at age data to a von Bertalanffy growth equation using nonlinear regression, and calculated the total length at infinity (L_∞) for use as an index of growth potential. All growth curves were forced through the origin. The total length at infinity is a mathematically-derived number representing the length that an average fish approaches if it lives to age infinity, and grows according to the von Bertalanffy curve (Ricker 1975).

Mortality.–We estimated instantaneous total mortality rates using a catch-curve regression (Ricker 1975). We used age groups where the majority of fish in each age group were sexually mature, recruited to the fishery (≥ minimum size limit), and represented on the spawning grounds in proportion to their true abundance in the population. For a more detailed explanation of age group selection criteria see Clark et al. (2004). We computed separate catch curves for males and females to determine if total mortality differed by sex. A catch curve was also computed for all fish that included males, females, and fish of unknown sex.

We estimated angler exploitation rates using two methods: 1) the percent of reward tags returned by anglers; and 2) the estimated harvest divided by estimated abundance. We compared these estimates of exploitation and converted them to instantaneous fishing mortality rates.

In the first method, exploitation rate was estimated as the fraction of reward tags returned by anglers adjusted for tag loss. We did not assess tagging mortality or incomplete reporting of reward tags. We assumed that tagging mortality was negligible and that nearly 100% of reward tags would be returned.

Voluntary tag returns were encouraged with a monetary reward ($10) denoted on approximately one half of the tags. Tag return forms were made available at boater access sites, at MDNR offices, and from angler survey clerks. Additionally, tag return information could be submitted on-line at the MDNR website. All tag return data was entered into the database so that it could be efficiently linked to and verified against data collected during the tagging operation. Return rates were calculated separately for reward and non-reward tags.

In the second method, we used each of the three abundance estimates for walleyes 15 in and larger, that is, the multiple-census estimate (2002 spring survey recapture), the first single-census estimate (angler survey recaptures), and the second single-census estimate (2003 egg-take recaptures). We calculated exploitation rates as the estimated annual harvest from the angler survey divided by the respective abundance estimates. For proper comparison with the abundance of legal fish as existed in the spring, the estimated annual harvest was adjusted for fish that would have grown to legal size over the course of the year for the two single-census estimates (Clark et al. 2004).

Recruitment.–We considered relative year-class strength as an index of recruitment. Year-class strength of walleyes is often highly variable, and factors influencing year-class strength have been studied extensively (Chevalier 1973; Busch et al. 1975; Forney 1976; Serns 1982a, 1982b, 1986, 1987; Madenjian et al. 1996; and Hansen et al. 1998). Density-dependent factors, such as size of parent stock, and density-independent factors, such as variability of spring water temperatures, have been shown to correlate with success of walleye reproduction. In addition, walleye stocking can affect year-class strength, though stocking success is highly variable, depending on the size and number of fish stocked, level of natural reproduction occurring, and other factors (Laarman 1978; Fielder 1992; Li et al. 1996a; Li et al. 1996b; and Nate, et al. 2000).

We obtained population data in the Muskegon Lake System for only one year, and so could not rigorously evaluate year-class strength. However, we suggest that insight about the relative variability of recruitment can be gained by examining the properties of our catch-curve regressions for walleyes. For example, Maceina (2003) used catch-curve residuals as a quantitative index of the relative year-class strength of black crappie and white crappie in Alabama reservoirs. He showed that residuals were related to various hydrological variables in the reservoirs.

We assumed the residuals of our catch-curve regressions were indices of year-class strength. For walleyes, we used correlation analysis and linear regression between catch-curve residuals and environmental variables to determine if there was a relationship. Additionally, we used the approach of Isermann et al. (2002) and calculated the recruitment coefficient of determination (RCD) to index recruitment variability.

Movement.–Movement was assessed in a descriptive manner by examining the location of angling capture versus the location of initial capture at tagging. Capture locations provided by anglers were often vague; thus, statistical analysis of distance moved would be questionable. Instead, we identified obvious, broad-scale movements such as to another lake, or connected river.

Angler Survey

Fishing harvest seasons for walleyes, northern pike, and muskellunge during this survey were April 27, 2002–March 15, 2003. Minimum size limits were 15 in for walleyes, 24 in for northern pike, and 42 in for muskellunge. The daily bag limit was five fish of any combination of walleyes, northern pike, smallmouth bass, and largemouth bass. The daily bag limit for muskellunge was one. Harvest seasons for smallmouth bass and largemouth bass were May 25, 2002 through Dec 31. The minimum size limit was 14 in for both smallmouth bass and largemouth bass.

Harvest was permitted all year for all trout species except lake trout, which was open from May 1 to Labor Day. Minimum size limits were 10 in for all trout species, and bag limits were five fish in any combination, with no more than three fish of any species, except only two lake trout or splake.

Harvest was permitted all year for all other species present. No minimum size limits were imposed for other species. The bag limit for yellow perch was 50 per day. The bag limit for sunfishes, including black crappie, bluegill, pumpkinseed, and rock bass was 25 per day in any combination.

Direct contact angler surveys were conducted during one spring–summer period—April 27 to November 30, 2002, and one winter period—January 1, 2003 through March 31, 2003. Ice cover in winter requires different sampling methods from summer surveys.

Summer.–For the summer survey we used a progressive-access design for the boat fishery and a progressive-roving design for the shore fishery (Lockwood 2000a). One clerk was used for the summer survey. Fishing boats and shore anglers were counted as the clerk progressed along a predetermined path. The clerk collected access boat interviews from five access points, and collected roving interviews from shore anglers fishing along the channel at the mouth of the lake (Figure 2). The survey period was from April 27 through November 30, 2002. Both weekend days and three randomly selected weekdays were selected for counting and interviewing during each week of the survey season. No count or interview data were collected on holidays. Holidays during this period were Memorial Day (May 27, 2002), Fourth of July, Labor Day (September 2, 2001), Veterans Day (November 11, 2002), and Thanksgiving (November 28–29, 2002). Counting and interviewing were done on the same days, and one instantaneous count of fishing boats and one instantaneous count of shore anglers were made per day. No geographical stratification of Muskegon Lake was done; the entire lake was sampled as a single unit.

Two different orders for the counting path were used (Figure 2) and selection of order was randomized. The clerk either began counting at marker 1 and proceeded to marker 14, or began counting at marker 14 and proceeded to marker 1. The clerk followed path direction using GPS coordinates (Table 2). Each count took approximately 1 h to complete and only fishing boats were counted (i.e., watercrafts involved in alternate activities, such as water skiing, were not counted). Time of count was randomized to cover daylight times within the sample period. Count information for each count was recorded on a scanner-ready form. This information included date, count time, unit counted (fishing boats or shore anglers), and number of units counted. No anglers were interviewed while counting (Wade et al. 1991).

All boat access interview data were collected by angling party. All shore roving data were collected by individual angler to avoid party size bias (Lockwood 1997). Minimum fishing time prior to collection of roving interview (incomplete-trip interview) was 1 h (Lockwood 2004).

Interview information collected included: date, fishing mode (unit), start time of fishing trip, interview time, species targeted, bait used, number of fish harvested by species, number of fish caught and released by species, length of harvested walleyes, and applicable tag number. All catch and harvest information was by party for boat interviews and by individual angler for shore interviews. For shore interviews, number of anglers in each party was recorded on one interview form for each party.

One of three shifts was selected each sample day for counting and interviewing (Table 3). Count times were randomly selected within each shift. Interview starting location (access point) and order were randomized daily.

Winter.–We used a progressive-access design for winter surveys (Lockwood 2000a). One clerk working from a motor vehicle collected count and interview data. Both weekend days and three randomly selected weekdays were selected for sampling during each week of the survey season. No holidays were sampled. Holidays during winter sampling period were New Year's Day (January 1, 2003), Martin Luther King Day (January 20, 2003), and President's Day (February 17, 2003). The clerk followed a randomized count and interview schedule. One of two shifts was selected each sample day (Table 3). Starting location (access point) and direction of travel were randomized for both counting and interviewing. Scanner-ready interview and count forms were used.

Progressive (instantaneous) counts of open-ice anglers and occupied shanties were made once per day. Using binoculars, the clerk counted visible open ice anglers and occupied shanties at each access point (Figure 3). Count information collected included: date, fishing mode (open-ice or shanty), count time, and number of units (anglers or occupied shanties) counted.

Similar to summer boat interview methods, only access interviews were collected from open ice and shanty anglers. No anglers were interviewed while counting (Wade et al. 1991). Additional interviewing instructions and interview information collected followed methods for the summer survey period.

Estimation methods.–Catch and effort estimates were made using the multiple-day method (Lockwood et al. 1999). Expansion values ("F" in Lockwood et al. 1999) are the total number of fishing hours within sample days (Table 3) and are used to estimate the total fishing effort for a given day type and period. That is, fishing effort is estimated for each day type and period as the product of the mean number of anglers counted per hour, the total number of days, and the expansion value (F). Thus, the angling effort and catch reported here are for those periods sampled. No estimates were made to include periods not sampled (e.g., 0100 to 0400 hours). Seasonal estimates were the sum of monthly estimates for each given time period and day type.

Angler survey data were used to estimate catch and harvest by species, angling effort expressed as angler hours, and angler trips. An angler trip is defined as the period an angler is at a lake (fishing site) and actively fishing. When an angler leaves the lake or stops fishing for a significant period of time (e.g., an angler leaving the lake to eat lunch), the trip has ended. Movement between fishing spots, for example, was considered part of the fishing trip. Mail or telephone surveys typically report angling effort as angler days (Pollock et al. 1994). Angler trips differ from angler days because multiple trips can be made within a day. Historically, Michigan angler survey data averages 1.2 trips per angler day (MDNR Fisheries Division, unpublished data).

All estimates are given with 2 SE. Error bounds (2 SE) provided statistical significance, assuming normal distribution shape and sample size greater than or equal to 10, of 75% to 95% (Dixon and Massey 1957). All count samples exceeded minimum sample size (10) and effort estimates approximate 95% confidence limits. Most error bounds for catch and release, and harvest estimates also approximate 95% confidence limits. However, coverage for rarely caught species is more appropriately described as 75% confidence limits due to severe departure from normality of catch rates.

Presence or absence of jaw tags and fin clips, tag numbers, and lengths of walleyes were recorded during angler survey interviews. These data were used to estimate tag loss and to determine the ratio of marked-unmarked fish for single-census abundance estimates.

Results

We will give confidence limits for various estimates in relevant tables, but not in the text.

Fish Community

We collected 5,697 fish of nine species in the Muskegon Lake System, but most (5,573) were walleyes (Table 4). The effort was not designed to sample the overall fish community, so we will make no attempt to derive fish community indices with our data.

Walleye

Size structure.–Walleyes were measured in our spring netting and electrofishing surveys (Table 5). The percent of walleyes that were legal size was 99.8. Males averaged 22.5 in and females averaged 26.6 in. The population of spawning walleyes was dominated by 20- to 30-in fish.

Sex composition.–Male walleyes outnumbered females in our spring survey, which is typical for walleyes (Carlander 1997). Of all walleyes captured (initial occasion only), 61% were male, 38% were female, and 1% were of unknown sex. Recapture rates were similar between sexes. Of all male walleyes captured, 2.6% were recaptured fish; for female walleyes, the recapture rate was 2.9%.

Abundance.–We tagged a total of 4,626 legal-size walleyes in the lower Muskegon River and Muskegon Lake (2,255 reward and 2,371 non-reward tags). Of the fish tagged, 2,829 were male and 1,760 were female. Three walleyes were observed to have lost their tags during the spring netting/electrofishing survey and three walleyes were found dead during the survey, so the effective number tagged was 4,620. We also marked eight sub-legal walleyes with a fin clip.

The angler survey clerk observed a total of 77 walleyes, of which 2 were marked. We reduced the number of unmarked walleyes in the single-census calculation by 10 fish to adjust for sub-legal fish that grew over the minimum size limit during the fishing season. We should note here that the low number of fish observed by the angler survey clerk is potentially due to inadvertent omission of data from interview forms. Although we could not confirm this, we find it difficult to believe that no walleyes were observed in May, perhaps the best month of the year for walleye fishing. The ramifications of this data-recording problem are described later in the **Discussion** section.

The angler survey clerk did not observe any fish that had a fin clip but no tag. However, due to the low number of fish that the angler survey clerk sampled, we used an average tag retention rate of 0.95, based on calculations from nine other large lakes we have surveyed to date, in order to adjust the abundance estimate. We believe this estimate of tag loss is reasonable.

During the spring 2003 egg-take collection, we observed a total of 507 male walleyes, of which 50 were marked, and 375 female walleyes, of which 38 were marked. We reduced the number of male and female unmarked walleyes by 75 and 0, respectively to adjust for sub-legal fish that grew over the minimum size limit during the year. We reduced the number of male and female marked fish at large by 71 and 58, respectively for tagged fish that were reported harvested during the first year. We also used an average tag retention rate of 0.95, based on calculations from nine other large lakes we have surveyed to date.

The estimated number of legal-size walleyes spawning in the Muskegon Lake System was 14,532 using the multiple-census method, 99,506 using the first single-census method (angler survey recaptures), and 37,851 (22,253 males and 15,598 females) using the second single-census method (2003 egg-take recaptures). The CVs were 0.31, 0.49, and 0.10 for the multiple-, first single-, and second single-census estimate, respectively (Table 6).

The estimated number of adult walleyes was 17,372 using the multiple-census method, 99,678 using the first single-census method (angler survey recaptures), and 37,890 (22,292 males and 15,598 females) using the second single-census method (2003 egg-take recaptures). The CVs were 0.28, 0.49, and 0.10 for the multiple-, first single-, and second single-census estimate, respectively (Table 6).

Mean lengths at age.–For walleyes, there was 54% agreement between the first two spine readers. For fish that were aged by a third reader, agreement was with first reader 72% of the time and with second reader 28% of the time; thus, there appeared to be bias among readers. Only 4% of samples were discarded due to poor agreement, thus at least two out of three readers agreed 96% of the time. Our reader agreement for walleye spines was similar to other studies. Clark et al. (2004) achieved 53% reader agreement, Hanchin et al. (2005a) found 68%, Isermann et al. (2003) achieved 55%, and Kocovsky and Carline (2000) achieved 62% reader agreement.

Female walleyes had higher mean lengths at age than males across all ages (Table 7). This dimorphic growth is typical for walleye populations (Colby et al. 1979; Carlander 1997; Kocovsky and Carline 2000). Females were generally 2 to 4 in longer than males from ages 4 through 12 (Table 7).

We calculated a mean growth index for Muskegon System walleyes of 3.4 in 2002. Thus, walleyes from this system grow much faster than most other walleyes across Michigan (greater than 3 in). It is impressive that the growth index is so high in spite of potential biases between aging methods. State average mean lengths were estimated by scale aging, which likely underestimates ages as compared to estimates from spines for the same fish (Kocovsky and Carline 2000). If so, this would cause estimated mean lengths at age of scale-aged fish to be larger than spine-aged fish. Eventually, the Large Lakes Program will obtain enough data to recalculate new statewide averages based on spines, which will improve future comparisons.

Mean length at age data for male, female, and all walleyes were fit to a von Bertalanffy growth curve. Male, female, and all walleyes had L_∞ values of 24.9, 29.9, and 27.0 in, respectively.

Mortality.–For walleyes, we estimated catch at age for 2,840 males, 1,762 females, and 4,631 total walleyes, including those fish of unknown-sex (Table 8). Note that the age frequency for total walleyes is rather different from that for males plus females across some ages. This is due to large variation in lengths at age (i.e., age-5 fish from 14–25 in), and the resulting changes in proportions at age in the age-length key when males, females, and unknown sex fish are added together.

We used ages 7 and older in the catch-curve analysis to represent the legal-size population (Figure 4). We chose age 7 because: 1) average length of walleyes at age 7 was 22.5 in for males and 25.6 in for females (Table 7), so likely all age-7 fish were legal-size at the beginning of fishing season; and 2) relative abundance of fish younger than age 7 do not appear to be represented in proportion to their true abundance (Figure 4; Table 8), suggesting that all walleyes (males and females) are not mature at age 6.

The catch-curve regressions for walleyes were all significant ($P < 0.05$), and produced total instantaneous mortality rates for legal-size fish of 0.498 for males, 0.578 for females, and 0.476 for all fish combined (Figure 4). These instantaneous rates correspond to annual mortality rates of 39% for males, 44% for females, and 38% for all walleyes combined.

Anglers extracted a total of 141 tags in the year following tagging (Table 9). Anglers voluntarily returned 139 of those tags to the central office (80 reward and 59 non-reward), and the angler survey clerk observed 2 tagged fish (1 reward and 1 non-reward) in the possession of anglers that were not reported to the central office by the anglers. Based on these tag returns, annual exploitation of walleyes was estimated to be 3.3%. After adjusting for 5% tag loss, this estimate increased slightly to

3.5%. Anglers reported both reward and non-reward tags at a similar rate (3.0% versus 2.3%), but they likely did not fully report either one.

Angler exploitation of walleyes was 12.5% based on dividing harvest by the multiple-census abundance estimate, 1.8% based on dividing harvest by the single-census angler survey abundance estimate, and was 4.8% based on dividing harvest by the single-census egg-take abundance estimate (Table 6). The harvest estimate used was not adjusted for non-surveyed months using tag returns because no tags were reported from Muskegon Lake during non-surveyed months. The harvest used in the latter two exploitation estimates was adjusted for the proportion of harvested fish that were not of legal size at the time of tagging.

Recruitment.–Variability in walleye year-class strength was relatively high in the Muskegon System spawning population, based on the statistics of the catch-curve regression. Residual values were large (Figure 4) and the amount of variation explained by the age variable (RCD) was low (R^2 = 0.80). The Muskegon System apparently had higher recruitment variability than Burt Lake (R^2 = 0.93; Hanchin et al. 2005c), Crooked and Pickerel lakes (R^2 = 0.94; Hanchin et al. 2005b), Houghton Lake (R^2 = 0.86; Clark et al. 2004), and Michigamme Reservoir (R^2 = 0.87; Hanchin et al. 2005a). Crooked, Pickerel, and Houghton lakes are also stocked with walleyes.

We tested for relationships between the residuals from the catch-curve regressions and data taken from the United States Historical Climatology Network (USHCN) weather station in Hart, Michigan. Variables that we tested included average monthly: air temperature, minimum air temperature, maximum air temperature, and precipitation. We also examined possible relationships with streamflow data taken from the USGS gauging station at Newaygo, Michigan. We did not find any environmental or climatic variables that were significantly related to walleye year-class strength, though water temperature and water quality data specific to the lake and weather data specific to the region are lacking. However, there was a weak positive relationship (R^2 = 0.58, F = 4.0538, P = 0.0789) between March precipitation and the residuals from the catch curve regression. There was no relationship (R^2 = 0.25, F = 0.6248, P = 0.4496) between the residuals from the catch-curve regression and the number of walleyes stocked in the Muskegon System.

Movement.–Based on tag returns, there was rapid movement of some walleyes downriver following tagging. For example, six walleyes were caught in Muskegon Lake within two days of being tagged in the river. Additionally, nine walleyes were reported caught in Lake Michigan in the month of April, and one walleye was caught in the Pere Marquette River on April 8. There were no tag returns from the Muskegon River after July 1, indicating that most fish have returned to Muskegon Lake or Lake Michigan by this point.

Based on voluntary tag returns during the year following tagging, there was significant movement of walleyes from the Muskegon System to other waters connected to Lake Michigan (Table 10). Of walleyes that were tagged in the lower Muskegon River, 58 (43% of total returns) were reported caught in Muskegon Lake or the channel, 27 (20%) were reported caught in Lake Michigan, 27 (20%) were reported caught in Lake Macatawa, and 10 (7%) were reported from the Muskegon River. These four locations accounted for about 90% of the first-year tag returns.

Some of the farthest recapture locations were Grand Traverse Bay and the Menominee River of Green Bay. The two walleye tag returns from Grand Traverse Bay were captured in October of 2003 and October of 2004, and represent movement of at least 250 miles in the most direct path. The walleyes caught in the Menominee River of Green Bay were collected during a spawning run survey in April of 2004 and represent movement of at least 250 miles.

Female walleyes apparently moved more readily than male walleyes. The M:F sex ratio in our spring survey was 1.6 compared to the M:F sex ratio of 0.9 for walleyes recaptured in Lake Michigan or other connected waters, not including Muskegon Lake.

Angler Survey

Summer 2002.–The angler survey clerk interviewed 830 boating anglers during the summer 2002 survey on Muskegon Lake. All but one interview were access type (completed-fishing trip). Anglers fished an estimated 97,171 angler hours and made 24,991 angler trips (Table 11).

The total harvest from Muskegon Lake was 88,583 fish, consisting of 17 different species (Table 11). Yellow perch were most numerous with an estimated harvest of 35,807, and 18,226 reported releases. Harvest of bluegill was similar at 35,153 with 25,101 releases. Anglers harvested 1,780 walleyes and 626 northern pike, and reported releasing 654 walleyes (27% of total catch) and 2,503 (80% of total catch) northern pike. Anglers harvested 169 smallmouth bass and 118 largemouth bass, and reported releasing 2,772 smallmouth bass (94% of total catch) and 4,219 largemouth bass (97% of total catch). We do not know what proportion of the released fish was legal size.

Winter 2003.–The angler survey clerk interviewed 155 open ice anglers and 340 shanty anglers on Muskegon Lake. While this survey was designed to collect roving interviews, all interviews were access type (completed trip). Open ice and shanty anglers fished 82,893 angler hours and made 20,828 trips on Muskegon Lake (Table 12).

A total of 95,577 fish were harvested and composed of eight species. Anglers harvested 302 walleyes, and reported releasing none. Anglers harvested 1,206 northern pike and released 2,543 (68% of total catch). Anglers also harvested 50,337 yellow perch and 40,144 bluegills. A total of 49,439 fish were caught and released, 94% of which were panfish species.

Annual totals for summer 2002 through winter 2003.–From April 27 2002 through March 23, 2003, anglers fished 180,064 hours and made 45,819 trips to Muskegon Lake (Tables 11 and 12). Of the total annual fishing effort, 54% occurred in the open-water summer period and 46% occurred during ice-cover winter period.

Bluegill and yellow perch were the most numerous species caught (harvested and released) in Muskegon Lake at 126,105 and 124,338, respectively. Resulting catch rates (catch per hour) for bluegill and yellow perch were 0.7003 and 0.6905, respectively. A total of 2,735 walleyes were caught, resulting in a catch rate of 0.0152. A total of 6,878 northern pike were caught, resulting in a catch rate of 0.0382. Anglers caught 3,007 smallmouth bass and 4,422 largemouth bass, resulting in catch rates of 0.0167 and 0.0246, respectively. It should be noted that catch rates were calculated with general effort, not targeted effort, and were therefore not necessarily indicative of the rate that an angler targeting one species may experience.

The total annual harvest in Muskegon Lake was 184,161 fish. Yellow perch were the most commonly harvested species at 86,144, followed by bluegill at 75,297. Panfish species together (yellow and white perch, bluegill, black crappie, pumpkinseed, and rock bass) accounted for 97% of the number of fish harvested. Panfish were harvested readily throughout the year, with peaks in the summer and late winter (Tables 11 and 12). Walleyes accounted for a relatively small proportion (1%) of the fish harvested, though they were the most commonly harvested large piscivore species. The remainder of the annual harvest was composed mostly of Chinook salmon and northern pike.

Throughout the year, anglers reported releasing 31% of all yellow perch caught, 40% of bluegill, 24% of walleyes, 73% of northern pike, 94% of smallmouth bass, 97% of largemouth bass, and 1% of Chinook salmon. Although we did not differentiate between sub-legal and legal released fish, we assumed that a large proportion of these released fish were sub-legal, or of a size unacceptable to anglers. The exception would be for the black basses, which often have high release rates.

We did not survey in December, because we thought that relatively little fishing occurred during that time of year. This assumption was reinforced as no walleye tag returns were reported caught during this time (Table 9). Thus, it appears that we adequately surveyed the entire year, and accurately characterized the fishery throughout the year. However, Muskegon Lake can occasionally provide a significant winter, open-water fishery. This occurred in 2004 when there was a significant amount of walleye tags reported caught in December (Figure 5).

Discussion

Fish Community

As previously stated in the **Results** section, our sampling effort was directed at spawning walleyes in the lower Muskegon River, and we did not adequately survey Muskegon Lake. Thus, the catch and associated CPUE (Table 4) does not provide an accurate reflection of the fish community in the lower river or the lake.

Walleye

Size structure.–The spawning population of walleyes in the Muskegon River contained relatively large fish compared to other Michigan populations. Males averaged 22.5 in and females averaged 26.6 in. Eschmeyer (1950) reported lower mean lengths of 19.1 in and 23.3 in for males and females, respectively in 1947. In 1948 mean lengths were 19.0 and 23.2 in, respectively. Schneider and Leach (1979) reported average sizes of male and female walleyes spawning in the Muskegon River from 1947 through 1975. From 1947 to 1963, the average size of male and female walleyes was 18.2 and 22.2 in, respectively, while the average length during 1972–75 was 20.6 and 25.7 in, respectively. It appears that the average size of spawning fish may have increased over time. Reasons for this are uncertain, but may be related to walleye population abundance or changes in the biological communities that have occurred during the past 50 years in the Muskegon System and Lake Michigan.

Based on the length-frequency distributions alone, the growth potential of walleyes spawning in the Muskegon System appears above average for large lakes in Michigan. As we will discuss later, this is likely due to its connectivity to Lake Michigan. Walleyes spawning in the Muskegon System are likely to attain lengths near 30 in. We discuss possible reasons for this growth in the *Mean lengths at age* section.

Sex composition.–Male walleyes outnumbered females in our survey, though not to the extent usually observed for walleyes. We collected about 60% males and 40% females. In past collections of spawning walleyes in the Muskegon System, females have actually outnumbered males. In 1947 and 1948, female walleyes made up 58% and 72% of the dip net catches below Newaygo Dam (Eschmeyer 1950). Eschmeyer (1950) suggested that the abnormal sex ratio in the Muskegon System was possibly due to selectivity of the dip nets, the Newaygo Dam barrier affecting sexes differently, or that it was a true representation of the migrating population, which differed from other waters for unknown reasons. More recently, the spring egg-take collections in 1998 and 2003 were composed of 60% and 57% males, and 40% and 43% females, which is almost identical to what we saw in 2002.

For walleyes from other lakes in Michigan and elsewhere, males consistently dominate sex composition in samples taken during spawning (Clark et al. 2004). This is likely due to males maturing at earlier sizes and ages than females and to males having a longer presence on spawning grounds than females (Carlander 1997).

Abundance.–Our success obtaining abundance estimates for walleyes spawning in the Muskegon System was mixed (Table 6). For the multiple-census estimate, we obtained the minimum number of recaptures; however, we may have violated some conditions for an unbiased estimate that are discussed later. For the single-census estimate using the angler survey for recaptures, we did not have sufficient numbers of fish observed for marks. Assuming that the legal walleye population was approximately 50,000 fish, and based on tagging around 5,000 fish, the recommended recapture sample to observe for marks in management studies (α = 0.05, p = 0.25; where: p denotes the level of accuracy, and 1-α the level of precision) is approximately 600 fish (Robson and Regier 1964). Our corrected recapture sample from the angler survey of 67 fish was well short of this recommendation, and the recommendation (200 fish) for preliminary studies and management surveys (α = 0.05, p = 0.50). However, our single-census estimate using the 2003 egg-take survey had a recapture sample of 807 fish, which exceeded the recommended recapture sample to observe for marks in management studies.

We think the single-census estimate from the angler survey is the least reliable estimate due to the low number of fish observed for marks. In comparing the other single-census estimate (egg-take survey) and the multiple-census estimate, it is helpful to see how they compare to the independently-derived estimates of harvest and exploitation. Our estimate of angler exploitation from tag returns was 3.3%, which should be considered a minimum. The estimated exploitation calculated by dividing harvest by abundance, is 12.5% based on the multiple-census abundance estimate and is 4.8% based on the single-census abundance estimate from the egg-take (Table 6). Hence, the independently-derived harvest estimate results in an exploitation rate that is more similar to that derived from tag returns when paired with the single-census estimate from the egg-take survey. Thus, we consider the estimate of 37,851 legal-size walleyes as the best estimate.

The multiple-census estimates were lower than the single-census estimates for both legal-size and adult walleyes (Table 6), though there was considerable overlap of the confidence limits between the two types of estimates. Precision varied among the various estimates (Table 6). Confidence limits were within 68%, 98%, and 19% for the multiple-census, single-census (angler survey), and single-census (egg-take) estimates, respectively.

There are several potential sources of error in our multiple-census estimates of walleye abundance. One assumption of the method is that marked fish become randomly mixed with unmarked fish. Over the course of our spring survey, marked fish were probably not mixing completely with the total population at large. An alternative description of this condition is that fishing effort is randomly distributed over the population being sampled (Ricker 1975). As fish moved off the spawning grounds and were excluded from our sampling gear, we violated this assumption. In contrast to the problems associated with the multiple-census method, the single-census estimates from the angler survey, and 2003 egg-take survey are likely to be more accurate because they allow sufficient time for the marked fish to fully mix with unmarked fish. Additionally, it does not matter if all spawning congregations are sampled in the initial tagging operation.

Our multiple-census estimates were 55–63% lower than single-census estimates for legal-size and adult walleyes. Our results were similar to those of Pierce (1997) who found that multiple-census methods underestimated abundance. He compared multiple-census estimates of northern pike abundance made with a single gear type (trap nets) to single-census estimates made with two gear types (marking with trap nets and recapturing several weeks later with experimental gill nets). He found that multiple-census estimates averaged 39% lower than single-census estimates. Pierce concluded that gear size selectivity and unequal vulnerability of fish to near shore netting make multiple-census estimates consistently low. He also concluded that recapturing fish at a later time with a second gear type resulted in estimates that were more valid. Clark et al. (2004) and Hanchin et al. (2005a, 2005b, 2005c) also found that multiple-census methods underestimated walleye and northern pike abundance relative to single-census methods.

All of our abundance estimates were higher than the predicted abundance from our Michigan models (Table 6). However, the Muskegon System is unique in that we actually estimated the abundance of the adfluvial Muskegon River spawning run, while the Michigan models were based on lakes with non-migratory populations. Since the walleye population has access to the productive waters of Lake Michigan and to the Muskegon River, the model's biological basis of lake area relating to available habitat and forage may not be applicable in the Muskegon System. Tagging studies have consistently shown substantial migrations from Muskegon System into Lake Michigan, and adult walleyes also known to reside in both Muskegon lake and river throughout the year (O'Neal 1997).

Our best estimate of walleye abundance was similar to the most recent estimates made for the Muskegon System. Day (1991) estimated 43,222 walleyes in 1986, and most recently, the MDNR estimated 46,479 adult walleyes in 1998. Day used a method similar to our single-census estimate from the egg-take, and the MDNR in 1998 made a single-census estimate during the spawning run, with separate marking and recapture periods. It appears that the population size has stabilized since its low point in the 1970s.

The accessibility that walleyes have to Lake Michigan also makes it difficult to interpret the true population density in Muskegon Lake System. If we assume that walleyes spawning in the Muskegon River reside in Muskegon Lake during the year, the density of legal-size walleyes would be 9.2 per acre. This density would be considered high compared to other lakes in Michigan and elsewhere. Walleye density estimated recently for other large lakes in Michigan has ranged from 0.8 to 2.9 per acre (R. N. Lockwood, unpublished data; Clark et al. 2004; Hanchin et al. 2005a, 2005b, and 2005c). Actually, many walleyes spawning in the Muskegon River migrate through Muskegon Lake into Lake Michigan and others remain in the river year round, and thus do not contribute to the density in Muskegon Lake throughout the year.

Mean lengths at age.–Mean lengths at age for walleyes in the Muskegon Lake System were more similar to Great Lakes walleye populations than to inland lake populations (Table 13). This, along with the high tag return rate from outside the system, suggests that virtually all the fish in this population spend at least part of their time in Lake Michigan.

Mean lengths at age for walleyes from our survey were larger than those from the 1998 survey and were more similar to the 1986 and 1987 surveys (Table 14). In the past, walleye growth of the Muskegon River population appeared to be density dependent (Schneider et al. 1991), and the population estimates mentioned in the previous section suggest walleye density was somewhat higher in 1998 than 1986 or 2002.

Walleye mean lengths at each age in 2002 were also much higher than the state averages (Tables 7 and 14). These differences were impressive considering the differences in aging techniques as explained earlier.

The L_∞ values for male, female, and all walleyes were 24.9, 29.9, and 27.0 in, respectively, which indicates tremendous growth potential. Day (1991) estimated similar L_∞ values of 25.2 and 28.7 in for male and female Muskegon River walleyes, respectively in 1986–87. For comparison, L_∞ values for walleyes in Houghton Lake were considerably lower at 17.7 in for males, 26.8 in for females, and 24.6 in for all walleyes (MDNR, unpublished data).

Mortality.–We estimated total mortality of walleyes in the Muskegon System to be 38%, with 16 year classes represented (Table 8). Mortality was similar between males and females, as was longevity. Our estimate was similar to the 1998 total annual mortality estimate of 35%, which was made using ages 10–15 and the Robson-Chapman method (MDNR, unpublished data). Additionally, the age distribution was similar between 1998 and 2002, with a high proportion of old (>age 10) fish (Table 15). Day (1991) estimated 80% total annual mortality of all Muskegon System walleyes using mark-recapture methods. He reported similar estimates of annual mortality for males and females, though when further separated by length, he found that large males had relatively lower mortality (53%). The large difference between our estimates and those of Day (1991) may be attributed to his use of mark and recapture data to estimate rates, which may not be most suitable for populations with high rates of movement in and out of the sampling area. In addition, his data also indicated higher than normal mortality among females used for egg-take in his tagging studies.

Compared to total mortality estimates for walleyes from other lakes in Michigan and elsewhere, our estimate of 38% for all walleyes is relatively low. Total mortality rates from other large lakes in Michigan have ranged from 37% to 51% (Clark et al. 2004; Hanchin et al. 2005a). Schneider (1978) summarized available estimates of total annual mortality for adult walleyes in Michigan. They ranged from 20% in Lake Gogebic to 65% in the bays de Noc, Lake Michigan. Schneider also presented estimates from lakes throughout Midwestern North America, other than Michigan. They ranged from 31% in Escanaba Lake, Wisconsin to 70% in Red Lakes, Minnesota. Colby et al. (1979) summarized total mortality rates for walleyes from a number of lakes across North America. They ranged from 13% to 84% for fish age 2 and older, with the majority of lakes between 35% and 65%.

Our estimates of the annual exploitation rate of walleyes ranged from 1.8% to 12.5%. All estimates were in a reasonable range lower than the estimates of total mortality. We consider the tag return estimate to be a minimum because we did not adjust for tagging mortality, or non-reporting, and if these occurred to any degree, we would have underestimated exploitation (Miranda et al. 2002). We did adjust for tag loss, which resulted in a 6% increase from the unadjusted estimate. Kallemeyn (1989) reported a 27% increase in an estimate for exploitation of walleyes when adjusting for loss of Carlin tags. We did not estimate tagging mortality and did not make a true estimate of non-reporting.

We attempted to measure non-reporting of tags by offering a $10 reward on about half of the tags and comparing return rates of reward to non-reward tags. We found that reporting rate was similar between reward and non-reward tags in Burt Lake. Clark et al. (2004) used the same tags and reward amount in Houghton Lake and did not observe much difference in return rates of reward and non-reward tags. Our reward amount was relatively low compared to those used by other authors (Miranda et al. 2002).

Due to the extensive movement that we observed, we decided to derive a fifth estimate of exploitation based on adjusting the walleye harvest in the lake by the observed tag return data. Given that approximately 43% of the walleye were harvested in the lake, the true harvest of the spawning population was actually about 2.3 times higher. Thus, the estimated walleye harvest (adjusted for the proportion of harvested fish that were not of legal size at the time of tagging) of 1,811 should be adjusted upwards to 4,212 to represent fish that were harvested in areas not covered by the angler survey. By dividing this adjusted harvest by our best estimate of legal walleye abundance (37,851), we came up with an exploitation estimate of 11.1%. We consider this to be our best estimate of the exploitation rate because: 1) it is slightly higher than the tag-return estimate, which we considered a minimum; 2) it is based on the most precise, and likely most accurate, abundance estimate; and 3) it is based on the most reasonable estimate of the number of walleye harvested from the 2002 spawning population. It is likely that exploitation is somewhat higher during some years because the intensive spring and fall fisheries vary annually with weather conditions.

Our estimates of angler exploitation were similar to previous estimates. MDNR previously estimated walleye exploitation of the Muskegon River spawning run from reward ($3) tag returns in 1986 and 1987. In addition to the $3 reward, names were entered in a drawing for $10, $25, and $50 prizes. They had respective return rates of 7.7% and 5.4%. In 1948, 11.0% of 292 walleyes released below Newaygo Dam were returned in the first year, and in 1950, 2.3% of 473 walleyes were returned in the first year.

Compared to exploitation rates for walleyes from other lakes in Michigan and elsewhere, our estimate of 11.1% for the Muskegon System is relatively low. For example, Thomas and Haas (2000) estimated angler exploitation rates from western Lake Erie at 7.5% to 38.8% from 1989 through 1998. Serns and Kempinger (1981) reported average exploitation rates of 24.6% and 27.3% for male and female walleyes respectively in Escanaba Lake, Wisconsin during 1958–79. Schneider (1978) gave a range of 5% to 50% for lakes in Midwestern North America, and Carlander (1997) gave a range of 5% to 59% for a sample of lakes throughout North America.

Recruitment.–We collected walleyes from 16 year classes in the Muskegon River (ages 3 through 18). Year-class strength was somewhat inconsistent from 1985 through 1995, the years included in our catch-curve regression. This was largely due to poorly represented year classes in 1987 and 1988. We found no relationship between catch-curve regression residuals and numbers stocked.

Movement.–The movement patterns that we observed following the spring tagging confirm that Muskegon River walleyes move considerable distances into Lake Michigan and connected waters. We noted rapid (within 1 month) movement both to Lake Michigan and even to other tributary rivers of Lake Michigan. Eschmeyer (1950) also noted rapid downstream movement in the Muskegon River. One walleye of 292 tagged during April 17–22, 1948 was taken near the City of Muskegon in Lake Michigan on May 20. He noted another fish recovered near the mouth of the St. Joseph River on May 31. This individual moved a distance of 115 miles, at an average rate of 3 miles per day. The average movement rate of 12 recovered walleyes in 1948 was 0.9 miles per day. We had no tag recoveries from the Muskegon River after July 1, suggesting that most walleyes had moved downstream by that point. Eschmeyer (1950) had similar results from 1948; their last tag return from the river was June 1.

We also noted movement over large distances (250 miles), such as to the Menominee River and Grand Traverse Bay. Previous walleye tagging studies on the Muskegon River (Eschmeyer 1950; MDNR, unpublished data) also found movement throughout Lake Michigan. Among the largest documented movement were returns from Porter Beach, Indiana; mouth of the Manistee River; mouth of Kalamazoo River; mouth of St. Joseph River; mouth of White River; Betsie Bay; Pentwater Lake; mouth of Pere Marquette River; and Good Harbor Bay. To our knowledge, this is the first time that Muskegon River walleyes were captured while spawning in another river (Menominee).

In the past, spawning walleyes were transferred from below Newaygo Dam to upstream impoundments. It is interesting to note that fish readily passed through dams (Eschmeyer 1950), and were recovered downstream, possibly indicating a propensity to migrate downstream. In 1947 and 1948, a total of 43% and 40% of the first-year returns, respectively, had moved downstream through one or more impoundments.

Our estimate of the scope of walleye movement was higher than what Day (1991) found, but was similar to what Eschmeyer (1950) found. Only 3.3% of Day's tag returns came from outside of the Muskegon System; 40% of Eschmeyer's and 50% of ours came from outside the system. Even if a large proportion of our tag returns reported caught in Lake Michigan were taken just outside of the Muskegon Lake System, our long-distant returns would still be at least 30%, higher than reported by Day. Day suggested that the lower rate of long-distance movement he observed was possibly due to lower walleye density in the Muskegon System or reduced commercial exploitation occurring in Lake Michigan between the time of his and Eschmeyer's work. Our results do not support either of Day's suggestions, because both walleye density and commercial fishing effort were similar in 2002 and 1986, and our results were more similar to Eschmeyer's.

Schneider et al. (1991) suggested that the magnitude of movement from the Muskegon Lake System was affected by density. That is, walleyes were more likely to move out of the system when the density was higher as in the 1940s and 1950s compared to when the density was lower as in the 1980s. Our results do not support this theory. Currently the density is only about one-third of what it was in the 1950s (Schneider and Leach 1979) but movement to areas outside the system is about the same as it was then.

Our study also confirmed the high fidelity of homing behavior of Muskegon River walleyes. Crowe (1962) previously reported homing to spawning areas in the Muskegon River. He reported that no walleyes tagged in the Muskegon System had been recaptured in other areas during the spawning season. While homing is still extensive, we apparently noted the first straying of a Muskegon River walleyes to another river (Menominee) during the spawn. The question remains whether it was a Muskegon River walleye that strayed to the Menominee, or a Menominee River walleye that had strayed to the Muskegon River. Similarly, Schneider and Crowe (1977) reported that a walleye first tagged in the Big Sable River was found one year later in the Muskegon River spawning run. Other Michigan river-spawning populations have been shown to have strong homing tendencies (Thomas 1995; Leonardi and Thomas 2000).

Angler Survey

The fishery of Muskegon Lake is dominated by panfish species, which comprised 97% of the total annual harvest and are caught throughout the year. The next most numerous species caught were black bass, northern pike, and walleye. Black basses are not readily harvested throughout the year, though many were reported released. We are unsure if this high release rate for bass was due to mandatory release of sublegal fish (<14 in) or voluntary release of legal-size fish. Northern pike were harvested mostly in winter months, though some harvest occurred throughout the summer. Northern pike also had a high release rate, which, because of the relatively high minimum size limit for them (24 in), may suggest that many released fish were sub-legal. Walleye harvest showed peaks in July, September, and November, corresponding with higher catch rates. The highest walleye harvest occurred in November, which had the second lowest angling effort of any month. Catch rate for walleyes was highest in November (0.149/h), followed by July (0.034/h), and September (0.023/h).

There are other species that provide significant angling opportunity, but were more seasonal in nature. Chinook and coho salmon, for example, were caught primarily in the fall, while brown trout were caught in the spring and early summer.

Comparison to other large lakes.–In general, surveys conducted in Michigan in the past 10 years used the same methods we used on Muskegon Lake, but most of them differed from our survey in seasonal time frame. For example, few other surveys were done in consecutive summer and winter periods. Regardless, for comparison, we used recent angler survey results for Michigan's large inland lakes from 1993 through 1999, compiled by Lockwood (2000b), and results for Michigan's Great Lakes waters in 2001, compiled by Rakoczy and Wesander-Russell (2002).

We estimated 180,064 angler hours occurred on Muskegon Lake during the year from April 27, 2002 through March 31, 2003. The number of hours fished per acre was higher than any other lake we used for comparison (Table 16). The number of fish harvested per acre was also higher than any other lake, and was actually greater than twice that of Houghton Lake.

For walleyes, our estimated annual harvest from Muskegon Lake was 0.5 fish per acre. This harvest is below average relative to other waters in Michigan. The average harvest of six other large Michigan lakes (>1,000 acres) reported by Lockwood (2000b) was 0.9 walleyes per acre, ranging from 0.1 per acre in Brevoort Lake, Mackinac County to 2.4 per acre in Chicagon Lake, Iron County. These Michigan lakes were all subject to similar gears and fishing regulations, including a 15-in minimum size limit. The harvest per hour of walleyes was 0.0116 in Muskegon Lake. This is low compared to harvest per hour in four other large lakes in Michigan, which ranged from 0.0366 to 0.0596 walleyes per hour. As noted previously, catch rates are calculated with general effort, not targeted effort, and are therefore not necessarily indicative of the rate that an angler targeting one species may experience. Since much of the angler effort in Muskegon Lake is for panfish, the harvest rate for walleyes is likely underestimated.

The total catch (harvest and release) of black bass in Muskegon Lake was 7,429, which was high compared to the total annual catch of black bass in Houghton Lake (4,314; Clark et al. 2004), Crooked and Pickerel lakes (1,463; Hanchin et al. 2005b), and Burt Lake (1,405; Hanchin et al. 2005c).

The estimated annual harvest per acre of yellow perch was 20.4 for Muskegon Lake. In comparison, harvest per acre of yellow perch was 2.5 in Houghton Lake (Clark et al. 2004), 1.8 in Crooked and Pickerel lakes (Hanchin et al. 2005b), and 3.4 for Burt Lake (Hanchin et al. 2005c). The associated harvest rate for yellow perch in Muskegon Lake was 0.4784, compared to 0.4401 per hour for Burt Lake, 0.0988 per hour for Houghton Lake, and 0.1129 per hour for Crooked and Pickerel lakes. In terms of both catch rate and total harvest, the yellow perch fishery in Muskegon Lake appears to be relatively good. Seasonal movement of yellow perch from Lake Michigan into Muskegon Lake may be a factor contributing to the high harvest and catch rates.

Management Implications

The current walleye population that spawns in the Muskegon River can be characterized as one with average to high density, fast growth, low total mortality, and low angler harvest. Walleyes up to age 13 were well represented in our sample, with a few fish up to age 18, which indicates the production of relatively consistent year classes that persist to older ages. The population density was nearly identical for adult and legal-size walleyes because of the extremely large sizes of age-3 and older fish and our inability to capture fish younger than age 3. Due to the extensive movements of this population, density estimates in Muskegon Lake are problematic, but are likely not more than 4.6 per acre most of the year. The annual harvest was 0.5 walleyes per acre and harvest per hour was 0.0116 within Muskegon Lake. Compared to other walleye fisheries in Michigan and elsewhere, these harvest estimates were relatively low. The annual exploitation rate was approximately 5% in Muskegon Lake and 11% overall. These exploitation rates are low compared to walleye fisheries in other inland lakes, but are similar to other walleye fisheries in the Great Lakes. The total annual mortality rate for the Muskegon walleye population was 38%, which is relatively low compared to populations elsewhere. Considering these rapid growth and low mortality rates, current fishing regulations for walleyes in the Muskegon Lake System adequately protect this population.

The abundance of the Muskegon River spawning population declined during the 1960s and 1970s due to low natural recruitment (Schneider and Leach 1979). Today, the Muskegon River walleye population is used as a broodstock source for stocking other waters in the state, but primarily within the Lake Michigan Basin.

The overall fishery in Muskegon Lake is relatively good. The number of fish harvested per hour (1.02), and number of fish harvested per acre (43.5) was the highest of any large lake surveyed under similar methods. Muskegon Lake has considerable angling opportunity for panfish, and a high diversity of other species in lower abundance.

Methods used for harvest, abundance, age and growth, and mortality estimates for walleyes performed fairly well. However, data-recording problems encountered in the angler survey precluded us from obtaining a reliable single-census abundance estimate for comparison. As a substitute, recaptures were taken during the following year's egg-take to make another single-census abundance estimate, which we think was reliable. We are not yet able to determine which of the different methods for estimating abundance (multiple- or single-census) and fishing mortality (tag returns or harvest/abundance) are best for long-term use. Comparisons must be repeated on more lakes before conclusions can be made. Thus, the overall approach used in this study should be continued on other large lakes before significant changes are made.

Our estimates of walleye abundance were much higher than the estimate made a priori with the recently derived Michigan regression equations. The Michigan regression equations were developed for inland lake non-migratory stocks and may not be appropriate for a population with extensive migrations like the Muskegon River population

Acknowledgements

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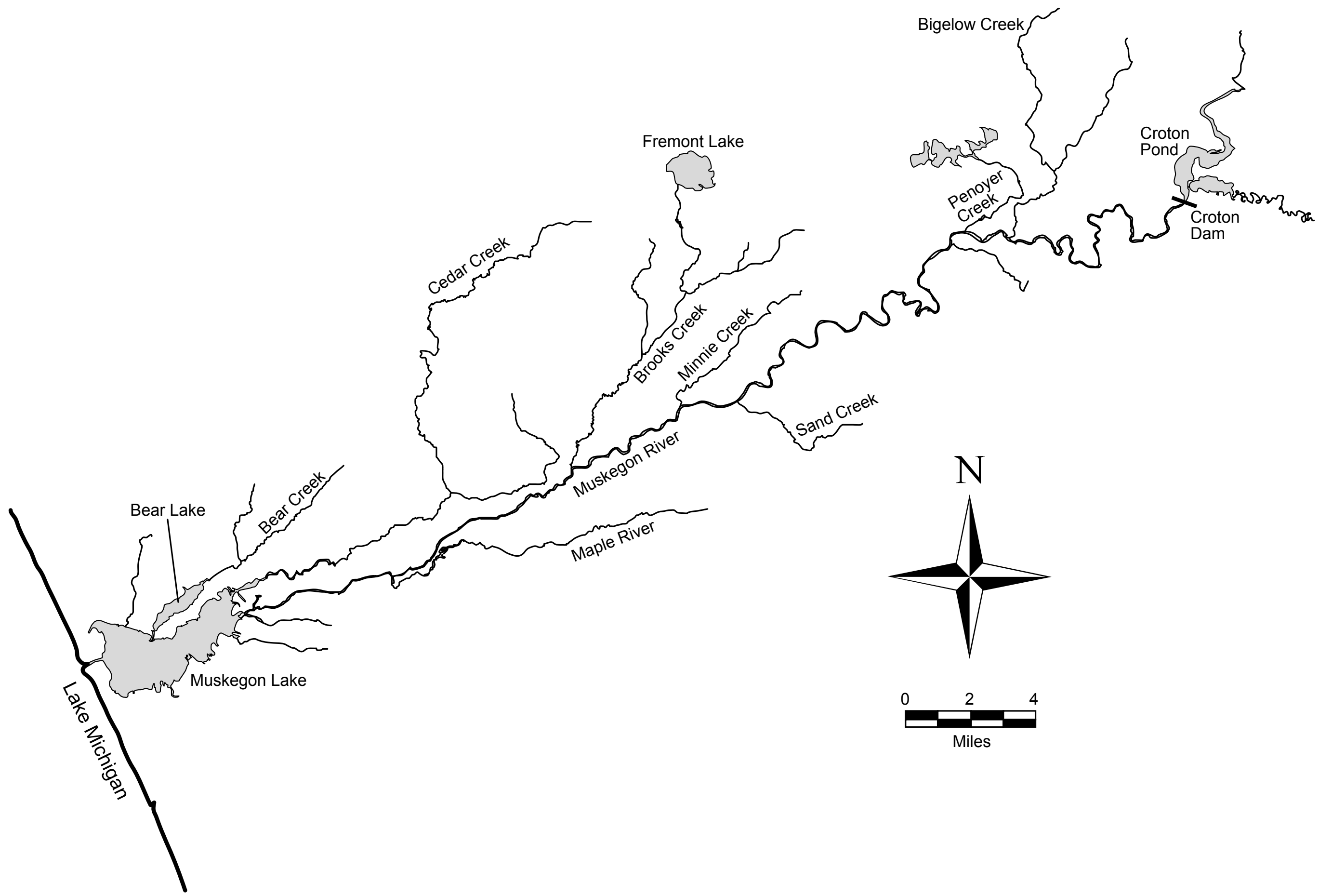

Figure 1.–Map of the Muskegon Lake System, Muskegon and Newaygo counties, Michigan.

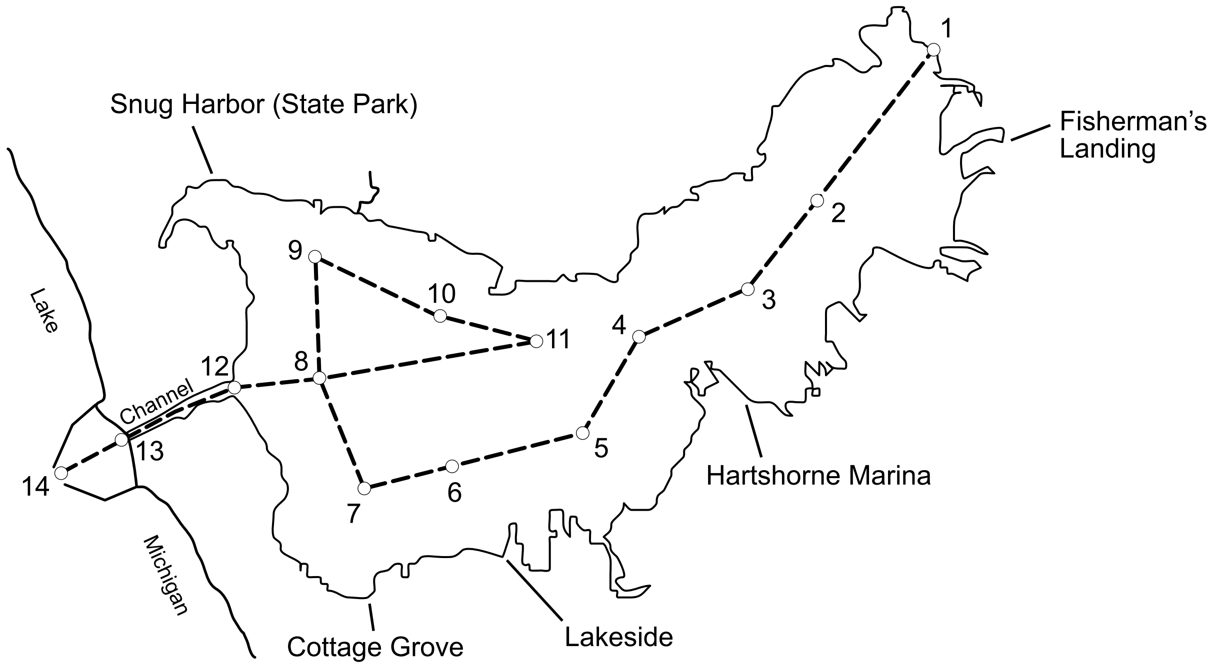

Figure 2.–Counting path, associated count path way points, and interview locations for Muskegon Lake, summer 2002. Roving interviews were collected from shore anglers fishing the channel and access interview were collected from boat anglers as they returned to the five named access sites. Latitude and longitude for points 1–14 are given in Table 2.

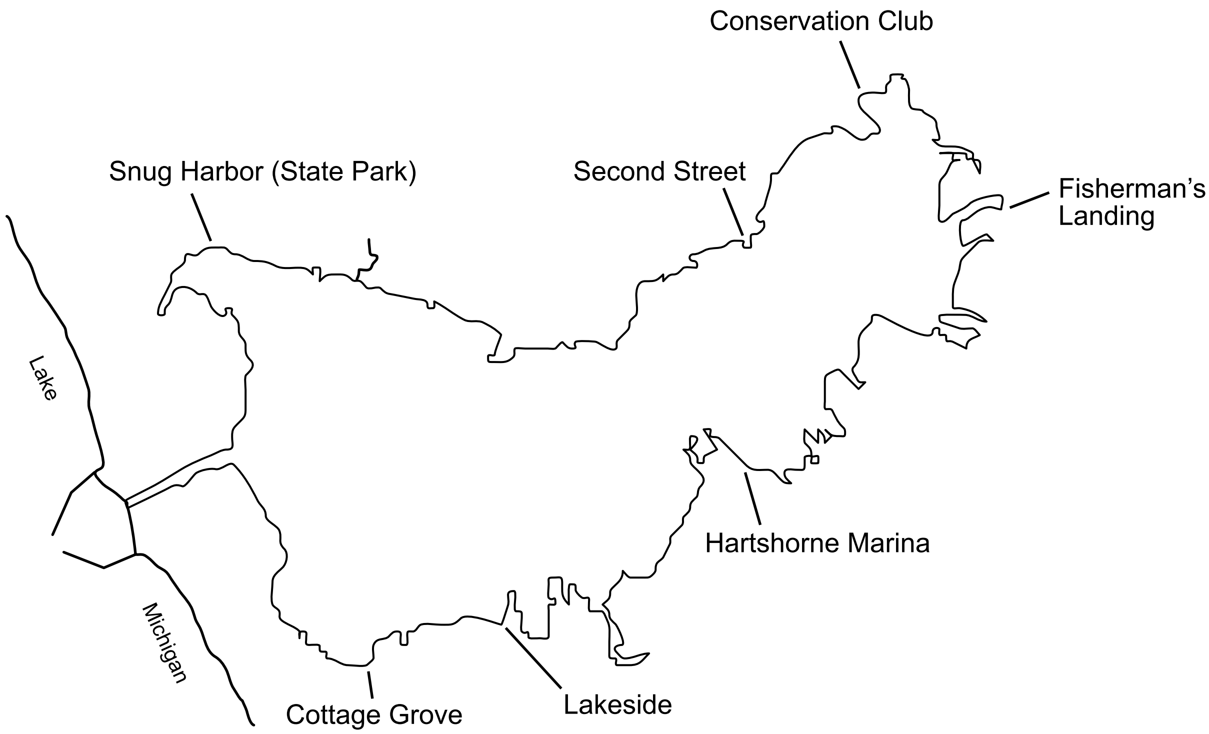

Figure 3.–Counting and interviewing locations for Muskegon Lake, winter 2003.

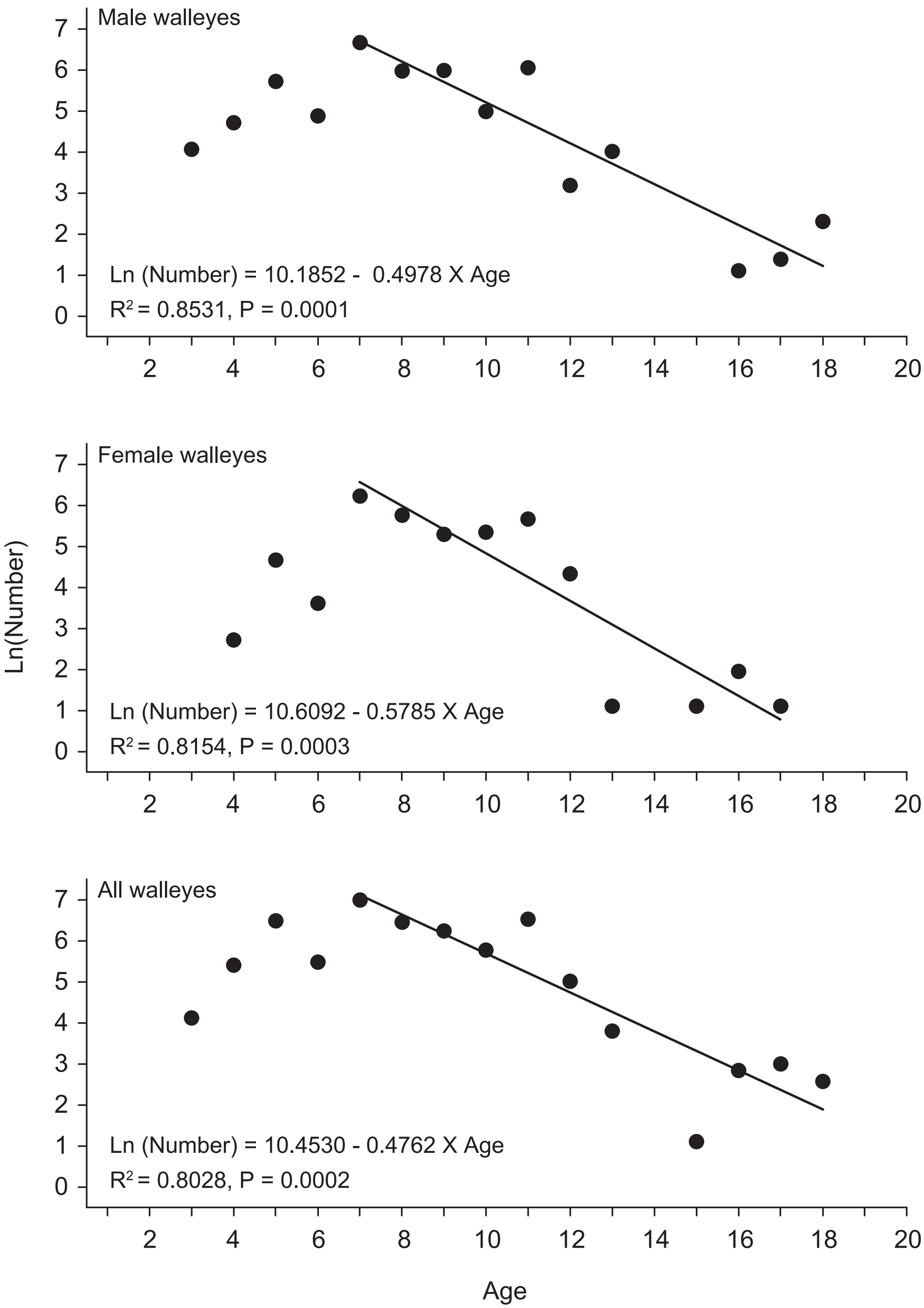

Figure 4.–Plots of observed ln(number) versus age for male, female, and all (including males, females, and unknown sex) walleyes in the Muskegon River. Lines are plots of regression equations given with each graph.

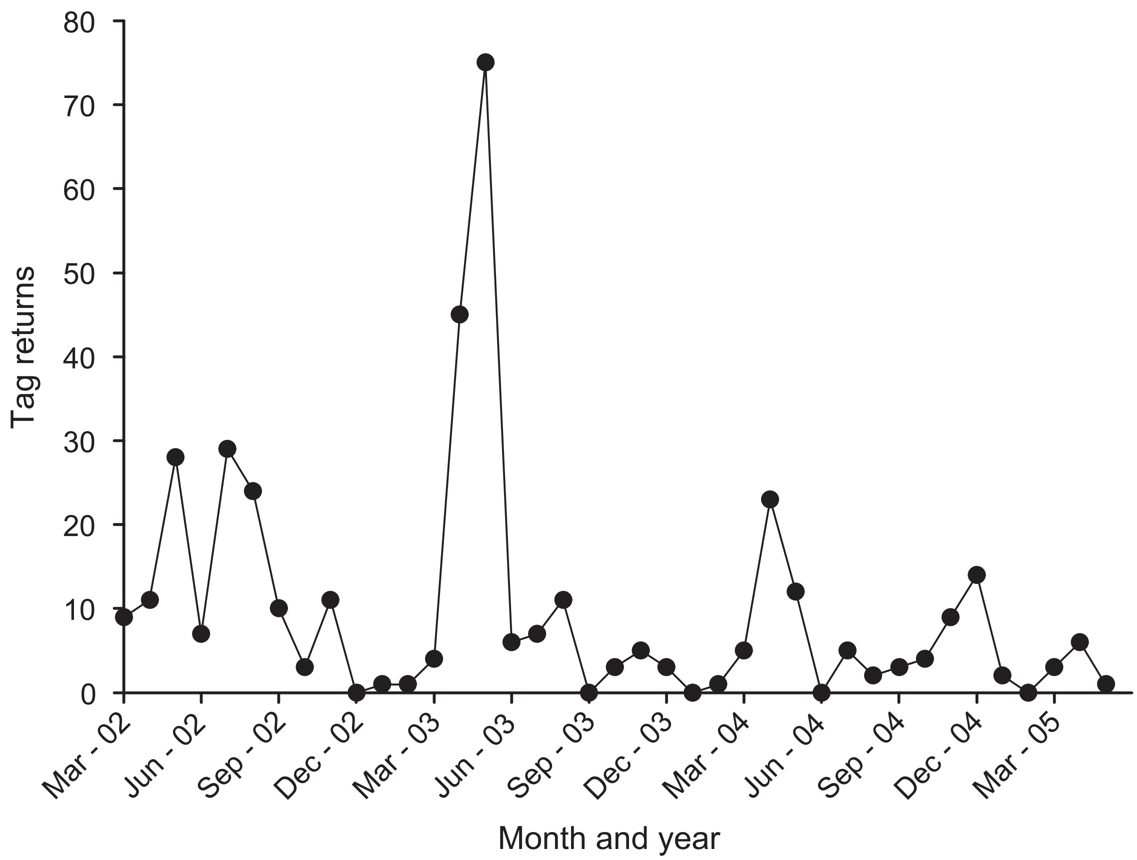

Figure 5.–Walleye tag returns (reward and non-reward) by month and year for walleyes tagged during the spawning run (March 4–29, 2002) in the Muskegon Lake System.

Table 1.–Number of walleyes stocked into the Muskegon Lake System from 1978 through 2002.

Year	Number of fingerlings	Number of fry
1978	123,353	
1979	114,362	
1980	155,664	
1981	8,000	
1982	0	
1983	71,000	
1984	82,026	
1985	191,556	
1986	207,898	
1987	18,765	
1988	73,910	
1989	799	
1990	46,766	99,000
1991	520,056	
1992	392,841	
1993	550,579	
1994	585,800	2,300,000
1995	588,971	500,000
1996	388,124	
1997	568,785	
1998	406,714	
1999	594,588	
2000	549,753	
2001	69,113	
2002	351,885	

Table 2.–Latitude and longitude for numbered markers on count path used in summer 2002 Muskegon Lake angler survey (See Figure 2).

Marker	Latitude	Longitude
1	43°15.66' N	86°14.88' W
2	43°14.80' N	86°15.72' W
3	43°14.43' N	86°16.19' W
4	43°14.19' N	86°16.92' W
5	43°13.69' N	86°17.30' W
6	43°13.56' N	86°18.23' W
7	43°13.42' N	86°18.82' W
8	43°13.99' N	86°19.05' W
9	43°14.57' N	86°19.16' W
10	43°14.28' N	86°18.27' W
11	43°14.13' N	86°17.54' W
12	43°13.92' N	86°19.66' W
13	43°13.67' N	86°20.39' W
14	43°13.52' N	86°20.76' W

Table 3.–Survey periods, sampling shifts, and expansion value “F” (number of fishing hours within a sample day) for the Muskegon Lake angler survey, spring 2002 through winter 2003.

Survey period	Sample shifts			F
May 15–November 30	0600–1430 h	1000–1830 h	1530–2400 h	19
January 1–March 31	0700–1530 h	1100–1930 h		13

Table 4.–Fish collected from lower Muskegon River and Muskegon Lake using a total sampling effort of 9 trap-net lifts, 5 fyke-net lifts, and 35 electrofishing runs from March 4 to March 29, 2002. Electrofishing runs targeted walleyes; other species were not collected during these runs.

Species	Total catch [a]	Percent by number	Mean CPUE [b]		Length (in)		Number measured
			Trap-net	Fyke-net	Range	Average	
Walleye	5,573	97.8	0.5	0.2	13.2–31.6	24.1	4,635
Rock bass	58	1.0	6.0	0	4.7–7.6	6.0	58
White sucker	35	0.6	1.4	1.4	5.9–21.6	17.7	35
Northern pike	15	0.3	0.1	0	13.6–38.5	26.9	13
Golden redhorse	8	0.1	0.3	0.4	10.8–24.7	16.4	8
Gizzard shad	3	<0.1	0.3	0	17.0–19.0	17.8	3
Quillback	3	<0.1	0.3	0	20.0–21.1	20.5	3
Yellow perch	1	<0.1	0.1	0	–	6.6	1
Bowfin	1	<0.1	0.1	0	–	26.8	1

[a] Includes recaptures.
[b] Number per trap-net or fyke-net night.

Table 5.–Number of fish per inch group measured in spring netting and electrofishing operations on lower Muskegon River and Muskegon Lake, March 4 to March 29, 2002.

	Species								
Inch group	Walleye	Rock bass	White sucker	Northern pike	Golden redhorse	Gizzard shad	Quillback	Yellow perch	Bowfin
3	–	–	–	–	–	–	–	–	–
4	–	1	–	–	–	–	–	–	–
5	–	28	1	–	–	–	–	–	–
6	–	24	–	–	–	–	–	1	–
7	–	5	–	–	–	–	–	–	–
8	–	–	–	–	–	–	–	–	–
9	–	–	–	–	–	–	–	–	–
10	–	–	–	–	1	–	–	–	–
11	–	–	–	–	–	–	–	–	–
12	–	–	–	–	–	–	–	–	–
13	1	–	1	1	–	–	–	–	–
14	7	–	–	–	–	–	–	–	–
15	11	–	3	–	4	–	–	–	–
16	35	–	4	–	1	–	–	–	–
17	48	–	9	2	1	2	–	–	–
18	46	–	6	–	–	–	–	–	–
19	86	–	3	–	–	1	–	–	–
20	272	–	6	–	–	–	2	–	–
21	512	–	2	–	–	–	1	–	–
22	708	–	–	1	–	–	–	–	–
23	616	–	–	1	–	–	–	–	–
24	565	–	–	–	1	–	–	–	–
25	511	–	–	1	–	–	–	–	–
26	436	–	–	1	–	–	–	–	1
27	308	–	–	–	–	–	–	–	–
28	243	–	–	–	–	–	–	–	–
29	146	–	–	1	–	–	–	–	–
30	69	–	–	–	–	–	–	–	–
31	15	–	–	–	–	–	–	–	–
32	–	–	–	2	–	–	–	–	–
33	–	–	–	–	–	–	–	–	–
34	–	–	–	1	–	–	–	–	–
35	–	–	–	1	–	–	–	–	–
36	–	–	–	–	–	–	–	–	–
37	–	–	–	–	–	–	–	–	–
38	–	–	–	1	–	–	–	–	–
39	–	–	–	–	–	–	–	–	–
40	–	–	–	–	–	–	–	–	–
Total	4,635	58	35	13	8	3	3	1	1

Table 6.–Estimates of abundance, angler exploitation rates, and instantaneous fishing mortality rates for lower Muskegon River spawning walleyes using the different methods described in text. Symmetrical 95% confidence intervals for estimates are given in parentheses, along with coefficient of variation (CV) where applicable. The best estimates in each category in our opinion are shaded.

Parameter	Estimate	CV
Number tagged	4,620	
Total tag returns	141	
Number of legal-size fish [a]		
Multiple-census method	14,532 (4,582–24,481)	0.31
Single-census method (angler survey)	99,506 (2,387–196,624)	0.49
Single-census method (egg-take)	37,851 (30,545–45,157)	0.10
Michigan model prediction [b]	6,511 (1,379–30,729)	
Number of adult fish [c]		
Multiple-census method	17,372 (6,945–27,799)	0.28
Single-census method (angler survey)	99,678 (2,391–196,964)	0.49
Single-census method (egg-take)	37,890 (30,576–45,203)	0.10
Michigan model prediction [d]	8,657 (2,047–36,607)	
Annual exploitation rates		
Based on reward tag returns	3.5%	
Based on harvest/abundance [e]	12.5% (3.2–21.8%)	0.37
Based on harvest/abundance [f]	1.8% (0–3.7%)	0.53
Based on harvest/abundance [g]	4.8% (2.6–6.9%)	0.22
Instantaneous fishing rates (F)		
Based on reward tag returns	0.0428	
Based on harvest/abundance [e]	0.1601	
Based on harvest/abundance [f]	0.0234	
Based on harvest/abundance [g]	0.0615	

[a] Fish ≥15 in.
[b] Michigan model prediction of legal walleye abundance based on lake area.
[c] All legal-size fish and sublegal-size fish that are sexually mature.
[d] Michigan model prediction of adult walleye abundance based on lake area.
[e] Multiple-census estimate of legal-size walleye abundance.
[f] Single-census estimate of legal-size walleye abundance from angler survey.
[g] Single-census estimate of legal-size walleye abundance from egg-take survey.

Table 7.–Weighted mean lengths and sample sizes (number aged) by age and sex for walleyes collected from the Muskegon Lake System, March 4 to 29, 2002. Standard deviations for mean lengths are in parentheses.

	Mean length (SE)						Number aged		
Age	Males		Females		All [a]		Males	Females	All [a]
3	17.2	(1.3)	–		17.1	(1.3)	28		35
4	18.5	(1.6)	22.4	(0.6)	20.6	(2.3)	39	7	48
5	20.8	(1.3)	24.0	(1.2)	22.0	(1.7)	31	23	60
6	21.8	(1.3)	23.4	(0.5)	22.5	(1.2)	7	9	17
7	22.5	(1.2)	25.6	(1.0)	23.7	(1.9)	38	41	82
8	22.2	(1.4)	26.2	(1.3)	24.1	(2.3)	23	26	50
9	23.1	(1.5)	27.1	(1.3)	24.7	(2.5)	24	17	42
10	24.3	(1.2)	27.8	(1.3)	26.6	(2.0)	11	21	35
11	24.2	(1.2)	28.4	(1.5)	26.2	(2.3)	33	39	76
12	26.3	(1.1)	28.7	(1.4)	27.9	(1.7)	8	13	24
13	24.5	(0.0)	30.5	(0.0)	24.9	(1.5)	3	1	4
14	–		–		–				
15	–		30.2	(0.0)	30.2	(0.0)		1	1
16	26.9	(0.0)	29.5	(0.0)	27.8	(1.3)	1	1	2
17	27.0	(1.5)	30.2	(0.0)	27.7	(1.7)	2	1	3
18	25.8	(0.0)	–		25.8	(0.0)	1		1

[a] Includes fish of unknown sex.

Table 8. Catch-at-age estimates (apportioned by age-length key) for walleyes collected with trap and fyke nets and electrofishing gear from the lower Muskegon River and Muskegon Lake, March 4 to 29, 2002. See **Discussion** section for interpretation of differences in proportions at age among sexes.

Age	Year-class	Walleyes		
		Males	Females	All [a]
3	1999	58	–	61
4	1998	111	15	221
5	1997	303	106	651
6	1996	131	37	238
7	1995	785	502	1082
8	1994	390	317	628
9	1993	397	197	508
10	1992	145	209	319
11	1991	424	287	677
12	1990	24	76	149
13	1989	55	3	44
14	1988	–	–	–
15	1987	–	3	3
16	1986	3	7	17
17	1985	4	3	20
18	1984	10	–	13
Totals		2,840	1,762	4,631

[a] Includes fish of unknown sex.

Table 9.–Tags returned by anglers (reward and non-reward) from walleyes tagged during the spawning run (March 4–29, 2002) in the lower Muskegon River in the year following tagging. The harvest season was April 27, 2002–March 15, 2003 in the Muskegon Lake System, however walleyes are incidentally caught preseason by steelhead anglers in the system and in Lake Michigan, which has no closed season. Percent of total tag returns (harvested + released) is in parentheses.

Year	Number of tag returns			
Month	Harvested		Released	
2002				
March	0	(0.0)	9	(6.4)
April	10	(7.1)	1	(0.7)
May	28	(19.8)	0	(0.0)
June	7	(5.0)	0	(0.0)
July	31	(22.0)	0	(0.0)
August	24	(17.0)	0	(0.0)
September	10	(7.1)	0	(0.0)
October	3	(2.1)	0	(0.0)
November	11	(7.8)	0	(0.0)
December	0	(0.0)	0	(0.0)
2003				
January	1	(0.7)	0	(0.0)
February	2	(1.4)	0	(0.0)
March	2	(1.4)	2	(1.4)
Totals	129	(100.0)	12	(100.0)

Table 10.–Location of walleye capture for tags (reward and non-reward) returned in the year following tagging from walleyes tagged during the spawning run (March 4–29, 2002) in the lower Muskegon River.

Recapture location	Tag returns	Percent of total
Muskegon Lake and channel	58	42.6
Lake Macatawa	27	19.9
Lake Michigan	27	19.9
Muskegon River	10	7.4
Grand River	8	5.9
Kalamazoo River	1	0.7
Manistee Lake	1	0.7
Pere Marquette River	1	0.7
Spring Lake (Ottawa Co.)	1	0.7
White Lake channel	1	0.7
Port Sheldon Lake	1	0.7
Totals	136	100.0

Table 11.–Angler survey estimates for summer 2002 from Muskegon Lake. Survey period was April 27 to November 30, 2002. Two standard errors are given in parentheses.

Species	Catch/hour		Apr–May		Jun		Jul		Aug		Sep		Oct		Nov		Season	
			Number harvested															
Coho salmon	0.0010	(0.0013)	0	(0)	0	(0)	0	(0)	0	(0)	85	(121)	7	(15)	0	(0)	92	(122)
Chinook	0.0102	(0.0088)	81	(90)	0	(0)	0	(0)	0	(0)	871	(825)	0	(0)	41	(83)	993	(834)
Rainbow trout	0.0001	(0.0003)	0	(0)	0	(0)	0	(0)	0	(0)	14	(27)	0	(0)	0	(0)	14	(27)
Brown trout	0.0029	(0.0051)	32	(47)	245	(491)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	278	(493)
Smallmouth bass	0.0017	(0.002)	0	(0)	0	(0)	161	(192)	0	(0)	0	(0)	7	(15)	0	(0)	169	(192)
Walleye	0.0183	(0.0086)	65	(83)	147	(254)	489	(377)	72	(102)	415	(498)	37	(47)	554	(329)	1,780	(763)
Yellow perch	0.3685	(0.1335)	3,288	(2,327)	15,313	(7,820)	5,354	(2,130)	5,026	(3,638)	5,872	(6,020)	418	(554)	536	(462)	35,807	(11,005)
Northern pike	0.0064	(0.0036)	225	(249)	0	(0)	0	(0)	36	(71)	167	(154)	45	(47)	154	(132)	626	(332)
Muskellunge	0.0002	(0.0004)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	20	(40)	20	(40)
Black crappie	0.0217	(0.0152)	32	(65)	600	(685)	205	(275)	0	(0)	27	(41)	769	(1,071)	472	(564)	2,105	(1,419)
Bluegill	0.3618	(0.1231)	2,277	(1,562)	7,727	(4,070)	9,622	(4,101)	4,554	(2,367)	7,214	(7,174)	3,448	(2,123)	310	(380)	35,153	(9,876)
Largemouth bass	0.0012	(0.0015)	0	(0)	60	(119)	0	(0)	36	(71)	0	(0)	22	(34)	0	(0)	118	(143)
Pumpkinseed	0.1063	(0.0399)	995	(1,033)	3,856	(2,260)	3,098	(1,710)	1,002	(827)	289	(577)	1,073	(983)	21	(41)	10,333	(3,330)
Rock bass	0.0065	(0.0068)	149	(299)	98	(196)	0	(0)	36	(72)	347	(539)	0	(0)	0	(0)	631	(650)
Channel catfish	0.0032	(0.0028)	0	(0)	196	(237)	71	(101)	0	(0)	41	(52)	0	(0)	0	(0)	308	(263)
Freshwater drum	0.0014	(0.0017)	0	(0)	74	(111)	0	(0)	0	(0)	58	(116)	0	(0)	0	(0)	131	(160)
White sucker	0.0003	(0.0005)	0	(0)	25	(49)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	25	(49)
Total harvest	0.9116	(0.2353)	7,145	(3,016)	28,341	(9,150)	19,000	(4,954)	10,762	(4,422)	15,398	(9,451)	5,828	(2,633)	2,109	(901)	88,583	(15,296)
			Number released															
Chinook salmon	0.0001	(0.0003)	0	(0)	0	(0)	0	(0)	0	(0)	14	(27)	0	(0)	0	(0)	14	(27)
Smallmouth bass	0.0285	(0.0112)	489	(433)	425	(352)	955	(636)	499	(312)	343	(288)	30	(48)	31	(45)	2,772	(949)
Largemouth bass	0.0434	(0.0189)	1,316	(1,000)	401	(402)	848	(630)	935	(818)	619	(676)	60	(94)	41	(82)	4,219	(1,644)
Walleye	0.0067	(0.0042)	0	(0)	49	(71)	347	(328)	35	(71)	112	(145)	38	(77)	72	(70)	654	(387)
Northern pike	0.0258	(0.0108)	556	(553)	278	(293)	498	(408)	143	(175)	384	(329)	263	(219)	381	(343	2,503	(929)

Table 11.–Continued.

Species	Catch/hour		Apr–May		Jun		Jul		Aug		Sep		Oct		Nov		Season	
White sucker	0.0006	(0.0013)	0	(0)	60	(121)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	60	(121)
Rock bass	0.0221	(0.0143)	219	(375)	194	(193)	153	(191)	897	(1,024)	153	(161)	507	(685)	20	(40)	2,144	(1,327)
Bowfin	0.0031	(0.0024)	16	(32)	134	(150)	41	(82)	35	(71)	71	(119)	0	(0)	0	(0)	298	(222)
Bluegill	0.2583	(0.0955)	4,740	(3,523)	6,435	(3,241)	4,359	(2,642)	1,863	(1,205)	3,946	(4,711)	3,758	(3,063)	0	(0)	25,101	(7,933)
Pumpkinseed	0.0585	(0.0272)	1,506	(1,450)	1,462	(1,129)	2,059	(1,339)	0	(0)	58	(115)	577	(775)	20	(40)	5,681	(2,405)
Yellow perch	0.1876	(0.0643)	2,122	(1,640)	6,733	(3,340)	3,346	(1,454)	1,971	(1,184)	3,234	(2,967)	615	(746)	204	(252)	18,226	(5,175)
Total released	0.6347	(0.1601)	10,964	(4,341)	16,170	(4,835)	12,605	(3,465)	6,379	(2,170)	8,934	(5,632)	5,848	(3,328)	770	(445)	61,671	(10,096)
Total (harvest and release)	1.5463	(0.3516)	18,109	(5,285)	44,511	(10,349)	31,606	(6,046)	17,142	(4,926)	24,332	(11,002)	11,676	(4,244)	2,879	(1,005)	150,255	(18,328)
			Fishing effort															
Angler hours			6,918	(2,713)	17,470	(5,543)	24,720	(5,737)	17,265	(4,120)	22,893	(15,978)	3,706	(1,447)	4,198	(1,486)	97,171	(18,643)
Angler trips			1,683	(671)	4,423	(1,439)	6,368	(1,506)	4,360	(1,078)	5,968	(4,402)	1,126	(493)	1,062	(387)	24,991	(5,072)

Table 12.–Angler survey estimates for winter 2003 from Muskegon Lake. Survey period was January 4 to March 23, 2003. Two standard errors are given in parentheses.

Species	Catch/hour		January		February		March		Season	
			Number harvested							
Walleye	0.0036	(0.0036)	127	(155)	98	(197)	76	(150)	302	(292)
Yellow perch	0.6073	(0.1931)	10,015	(5,331)	29,184	(9,456)	11,138	(5,923)	50,337	(12,366)
White perch	0.0002	(0.0004)	17	(34)	0	(0)	0	(0)	17	(34)
Northern pike	0.0145	(0.0085)	302	(356)	290	(310)	613	(467)	1,206	(664)
Black crappie	0.0009	(0.0013)	76	(109)	0	(0)	0	(0)	76	(109)
Bluegill	0.4843	(0.222)	6,102	(4,798)	6,670	(5,817)	27,372	(14,705)	40,144	(16,526)
Pumpkinseed	0.0177	(0.017)	443	(561)	0	(0)	1,029	(1,254)	1,471	(1,373)
Rock bass	0.0244	(0.0298)	254	(352)	1,771	(2,407)	0	(0)	2,025	(2,432)
Total harvest	1.1530	(0.3427)	17,336	(7,214)	38,013	(11,366)	40,228	(15,910)	95,577	(20,841)
			Number released							
Smallmouth bass	0.0008	(0.0012)	21	(43)	44	(88)	0	(0)	66	(98)
Largemouth bass	0.0010	(0.0015)	86	(127)	0	(0)	0	(0)	86	(127)
Northern pike	0.0307	(0.017)	479	(492)	955	(683)	1,109	(1,011)	2,543	(1,316)
White bass	0.0018	(0.0021)	0	(0)	148	(171)	0	(0)	148	(171)
Rock bass	0.0030	(0.0043)	208	(338)	44	(88)	0	(0)	252	(349)
Bluegill	0.3101	(0.1563)	2,492	(1,711)	6,964	(6,676)	16,250	(9,667)	25,707	(11,872)
Pumpkinseed	0.0081	(0.0101)	460	(707)	0	(0)	210	(422)	670	(824)
Yellow perch	0.2409	(0.0911)	5,957	(4,055)	9,855	(4,072)	4,156	(2,786)	19,968	(6,386)
Total released	0.5964	(0.2033)	9,703	(4,499)	18,010	(7,852)	21,726	(10,120)	49,439	(13,576)
Total (harvest and release)	1.7494	(0.4635)	27,039	(8,502)	56,023	(13,815)	61,953	(18,856)	145,016	(24,873)
			Fishing effort							
Angler hours			22,940	(10,523)	38,993	(10,807)	20,960	(7,253)	82,893	(16,737)
Angler trips			6,133	(2,748)	9,781	(2,835)	4,914	(1,749)	20,828	(4,318)

Table 13.–Mean lengths of walleyes from the 2002 survey of the Muskegon System compared to other Great Lakes river-spawning populations and inland lake populations sampled under the Large Lakes Program. All populations were sampled in the spring. Number aged is given in parentheses.

		Mean lengths															
Age	State average [a]	Muskegon River [b]		Grand River [c]		Cedar River [d]		Tittabawassee River [e]		Huron River [f]		South Lake Leelanau [g]		Houghton Lake [h]		Crooked-Pickerel Lake [i]	
2	10.4	–		–		–		–		13.7	(7)	9.9	(7)	11.0	(17)	12.1	(2)
3	13.9	17.1	(35)	16.4	(28)	–		–		16.2	(21)	13.3	(21)	13.6	(102)	12.5	(23)
4	15.8	20.6	(48)	18.2	(48)	19.6	(62)	20.6	(18)	19.0	(283)	14.9	(31)	14.5	(36)	13.7	(61)
5	17.6	22.0	(60)	20.5	(58)	20.6	(12)	20.8	(10)	20.2	(151)	15.0	(42)	15.8	(30)	14.9	(92)
6	19.2	22.5	(17)	22.2	(36)	22.7	(7)	21.3	(16)	21.7	(609)	15.9	(53)	16.8	(50)	15.8	(58)
7	20.6	23.7	(82)	23.6	(23)	23.8	(27)	23.2	(28)	22.5	(128)	17.0	(58)	17.6	(35)	16.4	(76)
8	21.6	24.1	(50)	24.3	(24)	23.9	(16)	24.4	(40)	23.2	(124)	17.3	(38)	18.1	(49)	17.3	(50)
9	22.4	24.7	(42)	26.3	(9)	24.2	(5)	24.7	(32)	24.6	(148)	18.3	(35)	18.4	(43)	17.1	(14)
10	23.1	26.6	(35)	27.4	(24)	26.1	(10)	24.9	(60)	24.5	(33)	17.4	(18)	18.9	(46)	18.4	(7)
11		26.2	(76)	28.3	(13)	25.1	(16)	25.7	(46)	25.2	(23)	20.8	(32)	19.4	(33)	18.8	(5)
12		27.9	(24)	29.7	(5)	26.8	(19)	–		26.6	(19)	21.1	(26)	19.9	(11)	18.8	(3)
13		24.9	(4)	–		27.5	(4)	–		26.5	(6)	22.7	(2)	25.7	(7)	–	
14		–		31.1	(1)	27.4	(2)	–		24.6	(3)	–		26.8	(4)	–	
15		30.2	(1)	–		–		–		–		–		26.0	(1)	19.7	(1)
16		27.8	(2)	–		–		–		24.7	(2)	–		–		–	
17		27.7	(3)	–		–		–		25.1	(1)	–		–		–	
18		25.8	(1)	–		–		–		–		–		–		–	
Mean growth index [j]		+3.4		+3.1		+2.9		+2.8		+2.3		-2.9		-2.2		-3.1	

[a] Jan–May averages from Schneider et al (2000), aged using scales.
[b] Fish collected in 2002 and aged using spines.
[c] Fish collected in 1997 and aged using scales.
[d] Fish collected in 2002 and aged using spines.
[e] Fish collected in 2002 and aged using scales (Fielder and Thomas In press).
[f] Fish collected in 2005 and aged using scales.
[g] Fish collected in 2002 and aged using spines.
[h] Fish collected in 2001 and aged using spines.
[i] Fish collected in 2001 and aged using spines.
[j] The mean deviation from the statewide average, where N ≥ 5.

Table 14.–Mean lengths for walleyes from the Muskegon Lake System from our survey compared to previous surveys. Number aged is given in parentheses.

Age	State average [a]	Mean lengths from survey years							
		2002 [b]		1998 [c]		1987 [c, d]		1986 [c, d]	
3	13.9	17.1	(35)	16.1	(6)	16.3	(1)	14.6	(7)
4	15.8	20.6	(48)	16.9	(35)	17.4	(13)	17.4	(77)
5	17.6	22.0	(60)	18.1	(34)	19.2	(46)	18.8	(168)
6	19.2	22.5	(17)	19.8	(49)	20.5	(41)	22.1	(153)
7	20.6	23.7	(82)	21.0	(71)	23.0	(70)	24.0	(296)
8	21.6	24.1	(50)	22.9	(74)	25.0	(87)	25.4	(306)
9	22.4	24.7	(42)	24.1	(60)	26.2	(71)	26.1	(107)
10	23.1	26.6	(35)	26.0	(50)	26.8	(20)	26.6	(20)
11		26.2	(76)	26.3	(41)				
12		27.9	(24)	27.6	(30)				
13		24.9	(4)	28.7	(16)				
14				28.7	(13)				
15		30.2	(1)	29.6	(15)				
16		27.8	(2)						
17		27.7	(3)						
18		25.8	(1)						
Mean growth index [e]		3.4		1.3		2.5		2.6	

[a] Jan–May averages from Schneider et al. (2000).
[b] Fish aged with spines.
[c] Fish aged with scales.
[d] Weighted length at age was calculated from male and female length at age data from Day (1991).
[e] The mean deviation from the statewide average. Only age groups with $N \geq 5$ were used.

Table 15.–Age frequency distribution (percent) of mature walleyes in the Muskegon River spawning run, 1947–2002. Data for 1947–75 were from Eschmeyer (1947) and Schneider and Leach (1979). Data for 1998 were from unpublished MDNR records.

	Year and (in parentheses) number of fish aged											
Age group	1947 (125)	1955 (153)	1956 (101)	1957 (151)	1958 (103)	1960 (101)	1962 (163)	1972 (51)	1974 (57)	1975 (133)	1998 (495)	2002 (480)
2	–	–	–	–	–	–	–	4	–	–	–	–
3	2	3	–	1	–	–	25	10	8	15	1	1
4	8	9	–	3	6	6	11	25	16	16	7	5
5	16	29	4	2	7	31	3	12	23	13	7	14
6	31	15	8	4	15	14	5	18	5	6	10	5
7	21	15	30	29	17	20	22	21	16	13	14	23
8	15	12	49	48	26	24	26	8	23	20	15	14
9	6	11	9	11	15	5	4	–	5	12	12	11
10	1	5	–	1	7	–	2	2	2	5	10	7
>10	–	1	–	1	7	–	2	–	2	–	23	20

Table 16.–Comparison of recreational fishing effort and total harvest on Muskegon Lake to those of selected other Michigan lakes. Lakes are listed from highest to lowest total fishing effort. Lake sizes are from Michigan Digital Water Atlas (Breck 2004), except where specified.

Lake and County	Size (acres)	Survey period	Total fishing effort (hrs)	Fish harvested number	Fish harvested per hr	Hours fished per acre	Fish harvested per acre
Michigan [a], many	–	Jan–Nov, 2001	2,684,359	677,360	0.25	–	–
Huron [a], many	–	Jan–Oct, 2001	1,807,519	1,057,819	0.59	–	–
Houghton, Roscommon (all year)	20,075	Apr 2001–Mar 2002	499,048	386,287	0.77	24.9	19.2
Erie [a], Wayne and Monroe	–	Apr–Oct, 2001	490,807	378,700	0.77	–	–
Superior [a], many	–	Apr–Oct, 2001	180,428	60,947	0.34	–	–
Muskegon Lake, Muskegon	4,232	April 2002–Mar 2003	180,064	184,161	1.02	42.5	43.5
Fletcher Pond, Alpena and Montmorency	8,970 [b]	May–Sep, 1997	171,521	118,101	0.69	19.1	13.2
Burt, Cheboygan	17,394	April 2001–Mar 2002	134,205	68,473	0.51	7.8	4.0
Gogebic, Ontonagon and Gogebic	13,127	May 1998–Apr 1999	121,525	26,622	0.22	9.1	2.0
Mullett, Cheboygan	16,704	May–Aug, 1998	87,520	18,727	0.21	5.3	1.1
Crooked and Pickerel, Emmet	3,434	April 2001–Mar 2002	55,894	13,665	0.24	16.3	4.0
Michigamme Reservoir, Iron	6,400	May 2001–Feb 2002	52,686	10,899	0.21	8.2	1.7

[a] Does not include charter boat harvest or effort.
[b] Lake size from Laarman (1976).

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Appendix.–Fish species captured in Muskegon Lake from 1948 through 2002 by MDNR crews using various gear types. Asterisk (*) indicates the species is not indigenous to Muskegon Lake.

Common name	Scientific name
Species we collected in 2002 with trap nets, fyke nets, and electrofishing gear	
Bowfin	*Amia calva*
Gizzard shad*	*Dorosoma cepedianum*
Golden redhorse	*Moxostoma erythrurum*
Northern pike	*Esox lucius*
Quillback	*Carpiodes cyprinus*
Rock bass	*Ambloplites rupestris*
Walleye	*Sander vitreus*
White sucker	*Catostomus commersonii*
Yellow perch	*Perca flavescens*
Additional species collected or observed in previous surveys of Muskegon Lake	
Alewife*	*Alosa pseudoharengus*
Black buffalo*	*Ictiobus niger*
Black bullhead	*Ameiurus melas*
Black crappie	*Pomoxis nigromaculatus*
Blacknose shiner	*Notropis heterolepis*
Bluegill	*Lepomis macrochirus*
Bluntnose minnow	*Pimephales notatus*
Brook silverside	*Labidesthes sicculus*
Brown bullhead	*Ameiurus nebulosus*
Brown trout*	*Salmo trutta*
Central mudminnow	*Umbra lima*
Channel catfish	*Ictalurus punctatus*
Chestnut lamprey	*Ichthyomyzon castaneus*
Chinook salmon*	*Oncorhynchus tshawytscha*
Coho salmon*	*Oncorhynchus kisutch*
Common carp*	*Cyprinus carpio*
Common shiner	*Luxilus cornutus*
Emerald shiner	*Notropis atherinoides*
Flathead catfish	*Pylodictis olivaris*
Freshwater drum	*Aplodinotus grunniens*
Golden shiner	*Notemigonus crysoleucas*
Goldfish*	*Carassius auratus*
Grass pickerel	*Esox americanus*
Iowa darter	*Etheostoma exile*
Johnny darter	*Etheostoma nigrum*
Lake chubsucker	*Erimyzon sucetta*
Lake herring	*Coregonus artedi*
Lake sturgeon	*Acipenser fulvescens*
Lake trout	*Salvelinus namaycush*
Lake whitefish	*Coregonus clupeaformis*
Largemouth bass	*Micropterus salmoides*
Longnose gar	*Lepisosteus osseus*
Longnose sucker	*Catostomus catostomus*
Northern brook lamprey	*Ichthyomyzon fossor*

Appendix.–Continued.

Common name	Scientific name
Northern hog sucker	*Hypentelium nigricans*
Northern logperch	*Percina caprodes semifasciata*
Pumpkinseed	*Lepomis gibbosus*
Quillback	*Carpiodes cyprinus*
Rainbow smelt*	*Osmerus mordax*
Rainbow trout*	*Oncorhynchus mykiss*
Round goby*	*Neogobius melanostomus*
Sauger	*Stizostedion canadense*
Sea lamprey*	*Petromyzon marinus*
Shorthead redhorse	*Moxostoma macrolepidotum*
Silver redhorse	*Moxostoma anisurum*
Smallmouth bass	*Micropterus dolomieu*
Spottail shiner	*Notropis hudsonius*
Spotted sucker	*Minytrema melanops*
Tadpole madtom	*Noturus gyrinus*
Trout perch	*Percopsis omiscomaycus*
Warmouth	*Chaenobryttus gulosus*
Western banded killifish	*Fundulus diaphanous menona*
White bass	*Morone chrysops*
White perch*	*Morone americana*
White crappie	*Pomoxis annularis*
Yellow bullhead	*Ameiurus natalis*