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The Fish Community and Fishery of North Manistique Lake, Luce County, Michigan in 2003–04 with Emphasis on Walleyes

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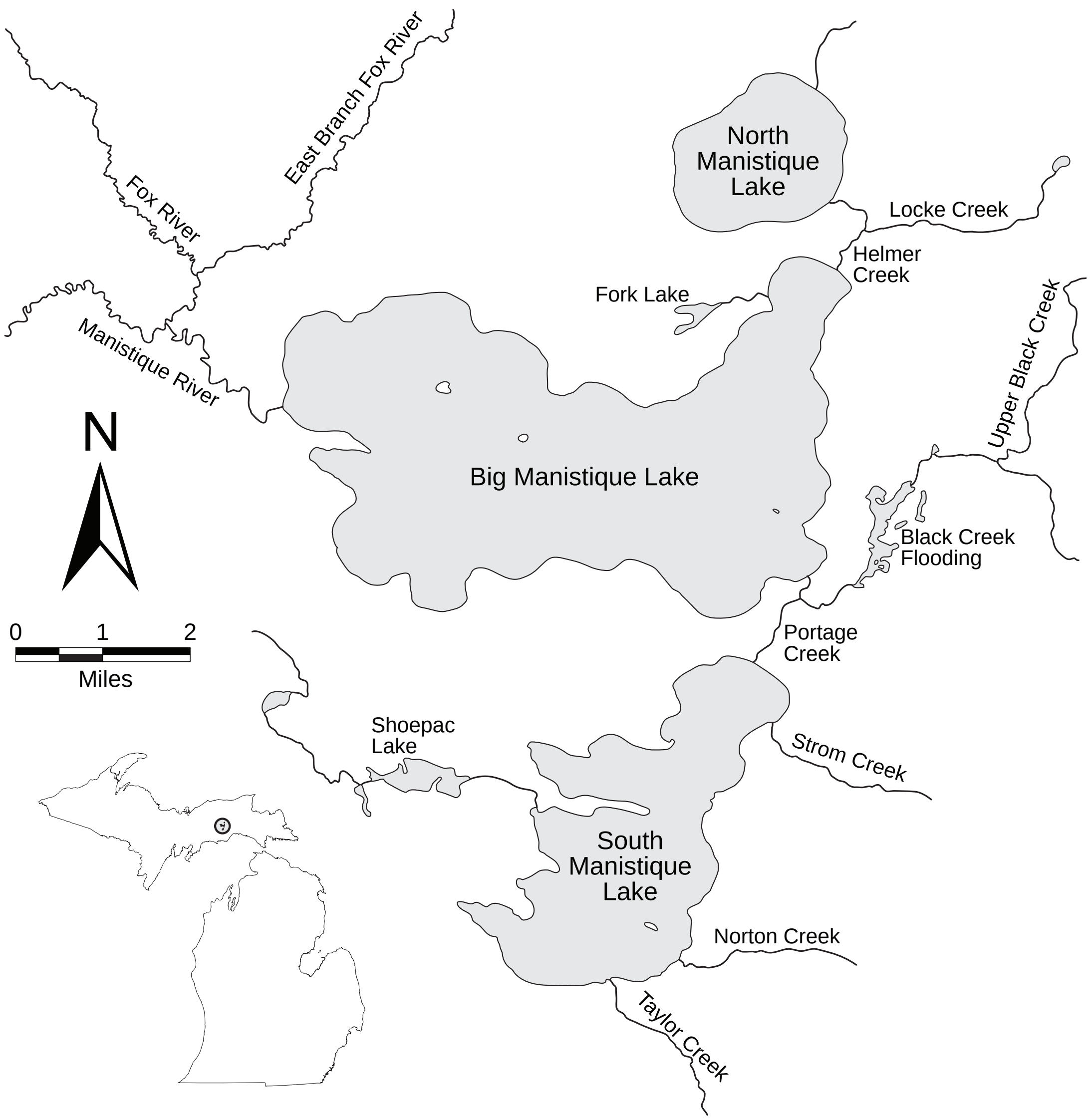

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The Fish Community and Fishery of North Manistique Lake, Luce County, Michigan in 2003–04 with Emphasis on Walleyes

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Introduction

The Michigan Department of Natural Resources (MDNR), Fisheries Division surveyed fish populations and angler catch and effort at North Manistique Lake, Luce County, Michigan from April 2003 through March 2004. This work was part of the Large Lake Program, which is designed to improve assessment and monitoring of fish communities and fisheries in Michigan's largest inland lakes (> 1,000 acres; Clark et al. 2004).

The Large Lake Program has three primary objectives. First, we want to produce consistent indices of abundance, generally describe the dynamics of the fish populations, and estimate harvest and fishing effort for target species. In this case, target species were defined as those susceptible to trap or fyke nets and/or those readily harvested by anglers. We selected walleyes *Sander vitreus* and northern pike *Esox lucius* as target species in this survey of North Manistique Lake. Consistent indices of abundance are important for detecting major changes in populations over time and among lakes. Second, we want to generate growth and mortality statistics to evaluate effects of fishing on species which support valuable fisheries. Methods to achieve this goal involve targeted sampling to collect, sample, and mark sufficient numbers of fish. Finally, we want to evaluate the suitability of various statistical estimators for describing fish populations in large lakes. For example, we applied and compared three types of abundance and three types of exploitation rate estimators in this survey.

The Large Lake Program maintains consistent sampling methods over lakes and time. This allows us to build a body of fish population and harvest statistics to directly evaluate differences among lakes or changes within a lake over time. North Manistique Lake is the ninth lake to be surveyed under the protocols of the program; thus, we were somewhat limited in our ability to make valid comparisons among lakes. As the program progresses, we will eventually have a large body of netting data collected under the same conditions that will facilitate comprehensive analyses.

Study Area

The surface area of North Manistique Lake is approximately 1,700 acres, with sources disagreeing only slightly on size. Humphrys and Green (1962) estimated 1,722 surface acres for North Manistique Lake by taking measurements from United States Geological Survey (USGS) maps using hand-held drafting tools. Breck (2004) estimated 1,709 acres as the surface area for North Manistique Lake; this estimate was derived from digital analysis of USGS topographical maps.

Boundaries of the lake polygon from the Michigan Digital Water Atlas Geographical Information System and aerial photos of the lake showed good agreement when compared using ArcView© (ESRI, Inc., Redlands, California, http://www.esri.com/software/arcgis/index.html). In the Large Lake Program, we compare various measures of productivity among lakes, such as number of fish per acre or harvest per acre, so an accurate measure of lake size is important. Therefore, we will use the more modern estimate of 1,709 acres as the size of North Manistique Lake in our analyses.

North Manistique Lake is fed by several springs on the northern and eastern shores and a small inlet on the west shore. The only outlet, Helmer Creek, flows south into Big Manistique Lake (Figure 1). The shoreline is extensively developed with private and commercial residences, though some public land exists in the form of a county park and boat launch. The maximum depth is about 50 feet. The bathymetry is mainly bowl-shaped, with both shallow flats and a deep central area in the lake (Michigan Digital Water Atlas). Approximately 48% of the lake area is less than 15 feet deep (Figure 2), and 81% of the lake volume is contained in waters greater than or equal to 15 feet (Figure 3).

Substrate in the shallow areas is sand and marl, with substrate in deeper areas consisting of pulpy peat. There is a shallow rock reef on the western shoreline. Aquatic vegetation is mostly sparse, consisting of rushes, Chara, and Potomageton. The fish community of North Manistique Lake includes species typical of inland lakes in Michigan, Minnesota, and Wisconsin. Common and scientific names of all fish species captured during this and previous studies of North Manistique Lake are listed in the Appendix; we refer to fishes only by common name in the text.

Fish stocking in North Manistique Lake has involved a variety of species, ages, and sizes, dating back over 80 years. More recent (1985–2003) stocking efforts have included walleyes, northern pike, lake trout, splake, and smallmouth bass (Table 1). Walleye fry were stocked from the mid-1930’s to early 1940’s; yellow perch were stocked sporadically during the same time period. Rainbow trout were stocked annually from 1947 to 1961 and again in 1982. Northern pike were stocked most years from 1962 to 1977, and in 1988, 1989, 1991, 1993, 1998, and 2000. Brown trout were stocked from 1980 to 1984; the brown trout program was discontinued after 1984. Walleye fry and fingerlings were again stocked from the late 1970’s to the present. Adult lake trout were stocked when available from 1982 to 1999.

There have been 11 State of Michigan Master Angler awards (rock bass and smallmouth bass) caught in North Manistique Lake from 1994 to 2000.

Methods

Fish populations in North Manistique Lake were sampled with trap nets and fyke nets from April 24 to May 6, 2003. We used one boat daily to work nets, with a three-person crew. Fyke nets were 6 ft x 4 ft with 2-inch stretch mesh and 70- to 100-ft leads. Trap nets were 8 ft by 6 ft by 3 ft with 2-inch stretch mesh and 70- to 100-ft leads. Nets were located to target walleyes and northern pike (nonrandom), though we also made an effort to cover the entire lake. Duration of net sets ranged from 1–2 nights, but most were 1 night. Latitude and longitude were recorded for all net locations using hand-held global positioning systems (GPS). Concurrent with our survey of North Manistique Lake, we surveyed Big (Hanchin and Kramer 2007) and South Manistique (Hanchin and Kramer 2008) lakes using identical methods. Additionally, we conducted a standardized survey using multiple gears (Wehrly et al. in press) from June 9 to 13 on the Manistique lakes.

Fish Community

We described the status of the overall fish community in terms of species present, catch per unit effort, percent by number, and length frequencies. Total lengths of all walleyes, northern pike, and smallmouth bass were measured to the nearest 0.1 inch. For other fish, lengths were measured to the nearest 0.1 inch for a subsample of up to 200 fish. We ensured that lengths were taken over the course of the survey to account for any temporal trends in the size structure of fish collected. Reported size distributions for target species (walleyes, northern pike, and smallmouth bass) only include fish on their initial capture occasion. Walleyes and northern pike with flowing gametes were identified as male or female; fish with no flowing gametes were identified as unknown sex. For smallmouth bass, sex determination was usually not possible because we were collecting them several weeks prior to their spawning time.

We used Microsoft Access© to store and retrieve data collected during the tagging operation. We calculated mean catch per unit effort (CPUE) in fyke nets as an indicator of relative abundance; CPUE is reported as the number of fish per net night (including recaptures) for all net lifts that were determined to have fished effectively (i.e., without wave-induced rolling or human disturbance).

Schneider et al. (2000a) cautioned that trap-net and fyke-net collections provide "imperfect snapshots" of fish community composition in lakes. Yet, with proper consideration of gear biases and sampling time frames, some indices of species composition provide useful insight into fish community dynamics. We calculated the percent by number of fish collected in each of three feeding guilds: 1) species that are primarily piscivores; 2) species that are primarily pelagic planktivores and/or insectivores; and 3) species that are primarily benthivores. These indices will be used to compare fish communities among lakes or within the same lake over time, especially in the future when more large lake surveys using similar methods are available for comparison. Of the species we collected, we classified walleyes, northern pike, and smallmouth bass as piscivores; rock bass, bluegill, yellow perch, and spottail shiners as pelagic planktivores-insectivores; and white and redhorse suckers as benthivores.

Abundance.–We estimated the abundance of legal-size walleyes and northern pike using mark-and-recapture methods. Walleyes (≥15 inches) and northern pike (≥24 inches) were fitted with monel-metal jaw tags upon initial capture in fyke and trap nets. To assess tag loss, tagged fish were double-marked by clipping the left pelvic fin. An approximate 1:1 ratio of $10-reward : nonreward tags was maintained. We did not think that an exact ratio was important, and maintaining an exact ratio would have been more difficult, given the multiple crews working simultaneously and numbers of fish tagged. Large tags (size 16) that were used on large northern pike (≥36 inches) were all nonreward.

Short-term 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 netting-induced tag loss. All fish that lost tags during netting recapture were retagged, and so were accounted for in the total number of marked fish at large.

We generated and contrasted two different abundance estimates from mark-and-recapture data, one derived from marked-unmarked ratios during the spring (trap/fyke net) survey (multiple census) and the other derived from marked-unmarked ratios from a creel survey (single census; creel survey methods described below). For the multiple-census estimate, we used the Schumacher-Eschmeyer formula for daily recaptures during the tagging operation. Fish recaptured with nets were recorded as either tagged (numbers recorded) or fin-clipped. The minimum number of recaptures necessary for an unbiased estimate was set a priori at four. We used the following formula from Ricker (1975):

$$N_1 = \frac{\sum_{d=1}^{n} C_d M_d^2}{\sum_{d=1}^{n} R_d M_d}$$

where N_1 = multiple-census population estimate (number of legal-sized fish); $C_d = U_d + R_d$ = total number of fish caught during day *:* U_d = number of unmarked fish caught during day d; R_d = number of recaptures during day d; M_d = number of marked fish available for recapture at start of day d; and d = day (ranging from d_1 to d_n).

The variance formula was,

$$Var(N_1) = \frac{\sum_{d=1}^{n}\left(\frac{R_d^2}{C_d}\right) - \left[\frac{\left(\sum_{d=1}^{n} R_d M_d\right)^2}{\sum_{d=1}^{n} C_d M_d^2}\right]}{m-1},$$

where m = number of days in which fish were actually caught.

Variance of $1/N_1$ is:

$$\frac{Var(N_1)}{\sum_{d=1}^{n} C_d M_d^2}.$$

Asymmetrical 95% confidence limits were computed as $1/N_1 \pm t$ (Standard error). Because we clipped fins and recorded recaptures of all walleyes, we were also able (for comparison) to make a direct multiple-census estimate of adult walleyes on the spawning grounds using the Schumacher-Eschmeyer formula by including all mature (sublegal and legal) fish that were marked and recaptured. Adult walleyes were defined as all sexable walleyes and walleyes of. unknown sex greater than or equal to 15 inches in length.

For the single-census estimate, the recapture sample was comprised of the number of marked and unmarked fish observed by the creel clerk in the companion creel survey, and by technicians during the standard summer netting survey of North Manistique Lake. We used the Chapman modification of the Petersen method (Ricker 1975) to generate population estimates and the minimum number of recaptures necessary for an unbiased estimate was set a priori at three (Ricker 1975). We used the following formula from Ricker (1975):

$$N_2 = \frac{(M+1)(C+1)}{R+1},$$

where N_2 = single-census population estimate (numbers of legal-sized fish); M = number of fish caught, marked and released in first sample; C = total number of fish caught in second sample (unmarked + recaptures); and R = number of recaptures in second sample.

We calculated the variance as:

$$Var(N_2) = \frac{N^2(C-R)}{(C+1)(R+2)},$$

Asymmetrical 95% confidence limits were calculated using the Poisson distribution for the 95% confidence limits on the number of recaptured fish (R), which were substituted into the equation for N_2 above (Ricker 1975). We estimated numbers of adult walleyes from the single-census estimate by dividing the estimate of walleyes 15 inches or larger by the proportion of walleyes 15 inches or larger on the spawning grounds. That is, N_3 and N_a should be comparable where:

$$N_a = \frac{N_{leg} + N_{sub}}{N_{leg}} \times N_2,$$

and, N_a = estimated number of adult walleyes; N_{sub} = number of sublegal (<15 inches) mature fish caught; N_{leg} = number of legal fish caught.

We calculated the variance as:

$$Var(N_a) = \left(\frac{N_{leg} + N_{sub}}{N_{leg}}\right)^2 \times Var(N_2).$$

Similar to walleyes, we defined adult northern pike as those 24 inches or larger or less than 24 inches, but of identifiable sex. We estimated adult northern pike using the multiple-census and adjusted single-census methods as was done for walleyes.

No prior abundance estimates existed for walleyes or northern pike in North Manistique Lake to help us gauge how many fish to mark. For walleyes, we used two regression equations (referred to as Michigan model) developed for Michigan lakes for a priori estimates of abundance. These regressions predict legal and adult walleye abundance based on lake size. These equations were derived from historic abundance estimates made in Michigan over the past 20 years (Hanchin, unpublished data), and include naturally-reproducing and stocked walleye populations. The following equation for adult walleyes was based on 35 abundance estimates:

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

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

where N is the estimated number of adult walleyes and A is the surface area of the lake in acres. For North Manistique Lake, the equation gives an estimate of 3,273 adult walleyes, with a 95% prediction interval (Zar 1999) of 785 to 13,641.

The equation for legal walleyes was based on 21 estimates:

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

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

where N is the estimated number of legal walleyes and A is the surface area of the lake in acres. The equation gives an estimate of 2,601 legal walleyes, with a 95% prediction interval (Zar 1999) of 560 to 12,083. Based on these a priori abundance estimates, we thought that marking approximately 300 legal-size walleyes (≈10% of the population) would be sufficient.

For the single-census estimate, we accounted for fish that recruited to legal size during the creel survey based on the estimated weighted average monthly growth for fish of slightly sublegal size. That is, because we were estimating the abundance of legal-sized walleyes (≥15 inches) and northern pike (≥24 inches) at time of marking (spring) and growth of fish occurred during the recapture period, it was necessary to reduce the number of unmarked fish by the estimated number that recruited to legal size during the recapture period. For example, to make this adjustment for walleyes we determined the annual growth of slightly sublegal fish (i.e., 14.0–14.9-inch fish) from mean length-at-age data. We then divided it by the length of the growing season in months (6) and rounded to the nearest 0.1 inch. This average monthly growth was then used as the criteria to remove unmarked fish that were observed in the creel. The largest size of a sublegal fish at tagging was 14.9 inches; thus, an average monthly growth of 0.2 inches would result in all unmarked fish less than or equal to 15.1 inches caught during the first full month (June) after tagging to be removed from analysis. Adjustments were made for each month of the creel survey resulting in a final ratio of marked to unmarked fish. This final ratio was used to make the single-census population estimate.

We calculated the coefficient of variation (CV) for each abundance estimate (single- and multiple-census) and considered estimates with a CV less than or equal to 0.40 to be valid (Hansen et al. 2000).

Growth.–We used dorsal spines to age walleyes and dorsal fin rays to age northern pike. 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. We considered ease of collection important because our spring netting survey occurs during cold, windy conditions, and personnel are tagging large numbers of fish in addition to measuring and collecting structures. Otoliths have been shown to be the most accurate and precise ageing structure for older walleyes (Heidinger and Clodfelter 1987; Koscovsky and Carline 2000; Isermann et al. 2003) and otoliths or cleithra for northern pike (Casselman 1974; Harrison and Hadley 1979), but collecting these structures requires killing the fish and we were tagging and releasing fish for later recapture. Results from several studies comparing ageing structures for walleyes agreed that spines were quicker to remove than scales, but they do not agree that spines are more accurate than scales (Campbell and Babaluk 1979; Kocovsky and Carline 2000; Isermann et al. 2003). Errors in ages from spines were often related to misidentifying the first annulus in older fish (Ambrose 1983; Isermann et al. 2003). There is also considerable disagreement as to whether spines or scales were more precise for walleye age estimation. Erickson (1983) and Campbell and Babaluk (1979) found that spines were more precise, Belanger and Hogler (1982) found spines and scales were equally precise, and Kocovsky and Carline (2000) found scales were more precise. Since northern pike older than 6 years are notoriously difficult to age with scales (Carlander 1969), in recent years, field technicians and biologists in MDNR have been using dorsal fin rays instead. They are as quick and easy to remove in the field as spines for walleyes. Studies have demonstrated that fin rays are a valid ageing structure for a number of species (Skidmore and Glass 1953; Ambrose 1983), including northern pike (Casselman 1996), but no comparisons have been made to statistically compare accuracy and precision of fin rays to other ageing structures for northern pike. Our sample size goal was to collect 20 male and 20 female fish per inch group for walleyes and northern pike.

Spine and fin ray samples were sectioned using a table-mounted high-speed 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 were photographed with a digital camera. The digital image was archived for multiple reads. Two technicians independently aged samples, and ages were considered final when independent estimates were in agreement. Samples in dispute were aged by a third technician. Disputed ages were considered final 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 ages assigned to older fish (≥age 10) were within ±10% of each other (e.g., assigned ages of 12, 13, and 14 results in average age of 13).

After a final age was identified for all samples, we calculated weighted mean lengths-at-age and age-length keys (Devries and Frie 1996) for male, female and all (males, females, and fish of unknown sex) walleyes and northern pike. Given that our collection took place in the early spring, we considered the length at capture equal to the length at annulus formation. We compared the mean lengths-at-age to those from previous surveys of North Manistique Lake and to other large lakes. We also computed a mean growth index to compare the data to Michigan state averages, as described by Schneider et al. (2000b). The mean growth index is the average of deviations (by age group) between the observed mean lengths and statewide seasonal average lengths. In addition, we fit mean length-at-age data to a von Bertalanffy growth equation using nonlinear regression (Slipke and Maceina 2000), and calculated the total length-at-infinity ($L\infty$) for use as an index of growth potential. All growth curves were forced through the origin (data point added for age = 0 and length = 0).

Mortality.–We calculated catch-at-age for males, females, and all fish (including males, female, and those of unknown sex), and estimated instantaneous total mortality and total annual mortality rates using catch-curve analyses with assumptions described by Ricker (1975). Our goal was to estimate total mortality for fish of legal size for comparison with annual angler exploitation, which was only estimated for fish of legal size. When choosing age groups to be included in the analyses, we considered several potential problems. First, an assumption of catch-curve analysis is that the mortality rate is uniform with age over the full range of age groups in analysis. Fish were collected with gears different from those used in the fisheries and the size (age) of recruitment in the fisheries was controlled by minimum-size-limit regulations. For fish smaller than the minimum size limit, mortality is $M + H$; for fish larger, mortality is $M + H + F$, where M, H, and F are natural, hooking (from catch and release), and fishing mortality, respectively. Thus, from the standpoint of uniformity in mortality, age groups used in a single catch curve should contain fish that are either all smaller than, or all larger than the minimum size limit in the fishery. Second, walleyes and northern pike exhibit sexual dimorphism (Carlander 1969 and 1997), which could lead to differences in mortality between sexes. Thus, when sufficient data were available, we computed separate catch curves for males and females to determine if total mortality differed with sex. A catch curve was also computed for all fish that included males, females, and fish of unknown sex. Third, walleyes and northern pike were collected in the act of spawning, so we needed to be sure that fish in each age group were sexually mature and represented on the spawning grounds in proportion to their true abundance in the population. Thus, we included in the analyses only age groups with fish that we judged to be mostly mature. We based this judgment on a combination of information, including relative abundance and mean size by age and percent maturity by size.

We estimated angler exploitation rates using three methods. In the first method, exploitation rate was estimated as the fraction of reward tags returned by anglers, adjusted for tag loss. For this method, we made the assumption that tagging mortality was negligible, and that near 100% of reward tags on fish caught by anglers would be returned. Voluntary tag returns were encouraged with a monetary reward ($10) denoted on approximately 50% of the tags. Tag return forms were made available at boater access sites, at MDNR offices, and from creel clerks. Additionally, tag return information could be submitted on-line at the MDNR website. All tag return data were entered into the database so that it could be efficiently linked to and verified against data collected during the tagging operation. We developed linked documents in Microsoft Word® so that payment vouchers and letters to anglers were automatically produced with relevant information from the database. Letters (for both reward and nonreward tags) sent to anglers described information regarding the length and sex of the tagged fish, and the location and date of tagging. Return rates were calculated separately for reward and nonreward tags. In addition to data on harvested fish, we estimated the release rate of legal fish. We did this by adding a question to the tag return form asking if the fish was released.

Probability of long-term tag loss was calculated as the number of fish in the recapture sample (creel survey) that had lost tags (fin clip 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). Although we did not truly assess nonreporting, we did compare the actual number of tag returns to the expected number (X), based on the ratio:

$$\frac{N_t}{N_C} = \frac{X}{H}$$

where N_t = Number of tags observed in creel, N_c = Number of fish observed in creel, H = Total expanded harvest of species.

Additionally, we checked individual tags observed by the creel clerk to see if they were subsequently reported by anglers. This last step is also not a true estimate of nonreporting because there is the possibility that anglers believed the necessary information was obtained by the creel clerk, and further reporting to the MDNR was unnecessary.

In the second and third methods, we calculated exploitation as the estimated annual harvest from the creel survey (see below) divided by the multiple- and single-census abundance estimates for legal-sized fish. For proper comparison with the single-census abundance of legal fish as existed in the spring, the estimated annual harvest was adjusted for fish that would have recruited to legal size over the course of the creel survey based on the percentage of fish observed in the creel survey that were determined to have been sublegal at the time of the spring survey (See Abundance subsection of the **Methods** section). We calculated 95% confidence limits for these exploitation estimates assuming a normal distribution, and summing the variances of the abundance and harvest estimates.

Recruitment.–We considered the coefficient of determination from catch curve regressions (RCD) to be an index of recruitment variability (Isermann et al. 2002). We also considered relative year-class strength as an index of recruitment. As Maceina (2003), we assumed the residuals of the catch-curve regressions were indices of year-class strength. We explored relationships among year-class strength and various environmental variables by using correlation analyses. The significance levels (α = 0.10) were adjusted with a Bonferroni correction of alpha for multiple comparisons (Sokal and Rohlf 1995) to limit overall experimentwise error. Historic weather data were obtained from the National Weather Service observation station in Newberry, Michigan (Station 205816). Variables that we tested included: average monthly air temperature, average monthly minimum air temperature, minimum monthly air temperature, average monthly maximum air temperature, maximum monthly air temperature, and average monthly precipitation. We did not have any historic water quality data specific to the lake; analyses were limited to correlation with weather data. Additionally, we tested for a relationship between the residuals and the number of spring fingerling walleyes stocked. The number of walleye fry stocked was converted to spring fingerling equivalents, using a survival of 10%.

Movement.–Fish movements were assessed by comparing 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 conspicuous movement, such as to another lake or connected river.

Creel Survey

Fishing harvest seasons for walleyes, northern pike, and muskellunge during this survey were May 15, 2003–February 28, 2004. Minimum length limits were 15 inches for walleyes and 24 inches for northern pike. Daily bag limit was 5 fish in any combination of walleyes, northern pike, smallmouth bass, largemouth bass, or flathead catfish, with no more than two northern pike. Fishing harvest seasons for smallmouth bass and largemouth bass were May 24 through December 31, 2003. Minimum length limit was 14 inches for both smallmouth bass and largemouth bass.

Harvest was permitted all year for all other species present. No minimum length limits were imposed for other species. Bag limit for yellow perch was 50 per day. Bag limit for “sunfishes”, including black crappie, bluegill, pumpkinseed, and rock bass was 25 per day in any combination. Bag limit for lake herring was 12 in combination with lake whitefish.

Direct contact angler creel surveys were conducted during one spring-summer period of May 8 to October 15, 2003 and one winter period of December 27, 2003 through March 28, 2004. Concurrent with the creel survey of North Manistique Lake, we surveyed Big and South Manistique lakes using identical methods.

Summer.–We used an aerial-roving design for the summer survey (Lockwood 2000a) of the three Manistique lakes. Fishing boats were counted by aircraft, and one clerk working from a boat collected angler interview data. Both weekend days and three randomly selected weekdays were selected for counting and interviewing during each week of the survey season. No interview data were collected on holidays; however, aerial counts were made on holidays. Holidays during the survey period were Memorial Day (May 26, 2003), Independence Day (July 4, 2003), and Labor Day (September 1, 2003). Counting and interviewing were done on the same days (with exception to previously discussed holidays), and one instantaneous count of fishing boats was made per day.

Two different directions of an aerial counting path were flown (Figure 4), selection of which was randomized. Counting began at Marker 1 and proceeded along the flight path ending at Marker 23; or counting began at Marker 23 and proceeded along the flight path ending at Marker 1. The pilot flew one of the two randomly selected predetermined routes using GPS coordinates. Each flight was made at 500–700 ft altitude and took approximately 20 min to complete with an air speed of about 100 mph. Counting was done by a contracted pilot, 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 included: date, count time, and number of fishing boats in each lake.

This survey was designed to collect roving (incomplete-trip) interviews. One of two shifts (A or B) was selected each sample day for interviewing (Table 2). Interview starting location (Table 3, Figure 4) and direction were randomized daily. Minimum fishing time prior to interview (incomplete-trip interview) was one hour (Lockwood 2004). Access interviews include information from complete trips and are appropriate standards for comparison. All roving interview data were collected by individual angler, to avoid party-size bias (Lockwood 1997). The clerk occasionally encountered anglers as they completed their fishing trips. The clerk was instructed to interview these anglers and record the same information as for roving interviews, noting that the interview was of a completed trip.

Interview information collected included: date, lake, fishing mode, 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, northern pike, smallmouth bass, and muskellunge, and tag number (where applicable). Number of anglers in each party was recorded on one interview form for each party.

The creel clerk also recorded presence or absence of jaw tags and fin clips, tag numbers, and lengths of all walleyes, northern pike, smallmouth bass, and muskellunge. These data were used to estimate tag loss and to determine the ratio of marked-unmarked fish for single-census abundance estimates.

*Winter.–*We used a progressive-roving design for winter surveys (Lockwood 2000a). One clerk working from a snowmobile 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 the winter sampling period were: New Year's Day (January 1, 2004), Martin Luther King Day (January 19, 2004), and President's Day (February 16, 2004). The clerk followed a randomized count and interview schedule. One of two shifts was selected each sample day (Table 2). Starting location (Figure 5) and direction of travel were randomized for both counting and interviewing.

Progressive (instantaneous) counts of open-ice anglers and occupied shanties were made once per day. Count information collected included: date, lake, fishing mode (open ice or shanty), count time, and number of units (anglers or occupied shanties) counted. No anglers were interviewed while counting (Wade et al. 1991). Similar to summer interview methods, minimum fishing time prior to interviewing was one hour. Additional interviewing instructions and interview information collected followed methods for the summer survey period.

*Estimation methods.–*Catch and effort estimates were made using a multiple-day method (Lockwood et al. 1999). Expansion values (number of hours within sample days, or "F" in Lockwood et al. 1999) are given in Table 2. Monthly effort is the product of mean counts, day type (weekday or weekend), days within the month, and the expansion value for that month. Thus, the angling effort and catch reported here are for those time periods sampled; i.e. no expansions were made to include periods not sampled (e.g., 0100 to 0400 hours).

Most interviews (>80%) collected during summer and winter were of a single type (access or roving). When 80% or more of interviews within a time period (weekday or weekend day within a month and section) were of an interview type, the appropriate catch-rate estimator for that interview type (Lockwood et al. 1999) was used on all interviews. When less than 80% of interviews were of a single interview type, a weighted average R_w was used:

$$R_w = \frac{\left(\hat{R} \cdot n_1\right) + \left(\overline{R} \cdot n_2\right)}{\left(n_1 + n_2\right)},$$

where $\hat{R}$ is the ratio-of-means estimator for n_1 completed-trip interviews and $\overline{R}$ the mean-of-ratios estimator for n_2 incompleted-trip interviews. Estimated variance s_w^2 was calculated as:

$$s_w^2 = \frac{\left(s_{\hat{R}}^2 \cdot n_1^2\right) + \left(s_{\overline{R}}^2 \cdot n_2^2\right)}{\left(n_1 + n_2\right)^2},$$

where $s_{\hat{R}}^2$ is the estimated variance of $\hat{R}$ and $s_{\overline{R}}^2$ is the estimated variance of $\overline{R}$.

From the angler creel data collected, catch and harvest by species were estimated and angling effort expressed as both 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 anglers make on average 1.2 trips per day (R. N. Lockwood, MDNR, personal communication).

All creel estimates are reported as $X \pm 2$ *SE*. Error bounds provided a measure of statistical significance, assuming a normal distribution shape and $N \geq 10$ (per month), of 75 to 95% (Dixon and Massey 1957). All count samples exceeded minimum sample size (10 counts per day type per month) and effort estimates approximated 95% confidence limits. Most error bounds for catch-and-release and harvest estimates also approximated 95% confidence limits. However, coverage for rarely caught species is more appropriately described as 75% confidence limits due to severe departure of catch rates from normality.

Results[1]

Fish Community

We collected a total of 1,844 fish of 9 species (Table 4). Total sampling effort was 28 trap-net lifts, and 50 fyke-net lifts. Species collected in order of abundance of total catch were: white sucker, walleyes, rock bass, northern pike, yellow perch, smallmouth bass, redhorse sucker, spottail shiner, and bluegill. White suckers comprised 68% of the catch by number and walleyes comprised 24%. Mean length of this species was 16.8 inches. Rock bass comprised 5% of the catch by number, and mean length was 4.8 inches (Table 4). Besides white suckers, walleyes, and rock bass, the remaining species comprised less than one percent each of the total catch. The overall fish community composition in North Manistique Lake was 26% piscivores, 5% pelagic planktivores-insectivores, and 69% benthivores.

The percentage of walleyes and northern pike that were legal size was 99.8% and 88%, respectively (Table 5). The population of spawning walleyes was dominated by 18- to 24- inch walleyes, with only two fish greater than or equal to 25 inches. Northern pike were widely distributed

[1] We provide confidence limits for estimates in relevant tables, but not in the text.

among 16- to 40-inch groups. Large pike (≥30 inches) were relatively common, making up 41% of the total catch. We did not catch any legal smallmouth bass.

Male walleyes outnumbered females in our spring survey, which is typical for spawning aggregations of walleyes (Carlander 1997). Of all walleyes captured, 59% were male, 40% were female, and 1% were of unknown sex. The sex ratio for northern pike was more balanced than walleyes. Of all northern pike captured, 47% were male, 47% were female, and 6% were unknown sex. The composition was identical for legal-size northern pike.

Abundance.–We tagged 393 legal-sized walleyes (212 reward and 181 nonreward tags) and clipped the fin of one sublegal walleye. No walleyes were observed to have died, or lost their tag during the spring netting survey.

The creel survey clerk observed a total of 16 walleyes on North Manistique Lake, of which four were tagged. In our summer netting survey we observed an additional 15 walleyes, of which three were tagged. None of the unmarked fish were deemed to have been sublegal fish that grew over the minimum size limit during the fishing season. The creel clerk did not observe any fish that had a fin clip, no tag, and were determined to have been legal size at the time of tagging; thus, no evidence of tag loss was detected.

The estimated number of legal-sized walleyes was 1,827 using the multiple-census method, 1,576 using the single-census method, and 2,601 using the Michigan model (Table 6). Both the multiple-census and single-census estimates of adult walleyes were identical to the estimates of legal walleyes. The coefficient of variation (CV = standard deviation/estimate) was 0.11 for the two multiple-census estimates, and was 0.29 for the single-census estimates.

We tagged 15 legal-sized northern pike in North Manistique Lake (8 reward and 7 nonreward tags) and clipped fins of two sublegal northern pike. No fish were observed to have died, or lost tags during the spring netting survey. The creel clerk did not observe any northern pike during the year, though during the summer netting survey we observed three northern pike, of which one was tagged. Neither of the unmarked fish was deemed to have been a sublegal fish that recruited to legal size during the fishing season, and neither had lost a tag. We could not make multiple- or single-census estimates of legal or adult northern pike abundance, since the minimum number of recaptures was not reached for either method.

Growth.–For walleye, there was 84% agreement between the first two spine readers. For the 16 fish that were aged by a third reader, agreement was with first reader 31% of the time and with second reader 69% of the time; thus, there appeared to be some bias among readers. Four percent of samples were discarded due to poor agreement, and an average age was used 1% of the time when ages assigned to older fish (≥age 10) were within ±10% of each other. At least two out of three readers agreed 96% of the time. Our reader agreement for walleye spines (84%) was somewhat higher than other studies, which ranged from 53–82% (Clark et al. 2004, Hanchin et al. 2005a, Isermann et al. 2003, Kocovsky and Carline 2000).

Female walleyes had higher mean lengths at age than males in North Manistique; females were 1.4 inches longer than males at age 8 (Table 7). This sexually-dimorphic growth is typical for walleye populations (Colby et al. 1979, Carlander 1997, Kocovsky and Carline 2000). Walleye mean lengths-at-age for North Manistique Lake were about equal to the state average; the mean growth index was +0.2. Based on the fit of mean total length at age data to a von Bertalanffy growth curve, male, female, and all walleyes had L_∞ values of 22.2, 25.0, and 24.0 inches, respectively.

For northern pike, there was 88% agreement between the first two fin ray readers. For the two fish that were aged by a third reader, agreement was with the first reader 50% of the time and with the second reader 50% of the time. No samples were discarded due to poor agreement, and at least two out of three readers agreed 100% of the time. Clark et al. (2004) found 72% agreement, and Hanchin et al. (2005a) reported 82% agreement between the initial two readers of northern pike fin rays. Female northern pike were generally larger than males, but we did not have a large enough sample to compare mean lengths-at-age between sexes (Table 8). Females averaged 32.0 inches, with a range of

16.3 to 40.0 inches. Males averaged 27.1 inches, with a range of 22.1 to 29.8 inches. As with walleyes, sexually-dimorphic growth is typical for northern pike populations in general (Carlander 1969; Craig 1996). We calculated a mean growth index for northern pike of +4.2, which was based on a single age group. The length-at-infinity for all northern pike was 33.3 inches.

Mortality.–For walleyes, we estimated mortality using data from 239 males, 165 females, and 405 total walleyes, including those fish of unknown-sex (Table 9). We netted 404 individual walleyes, though a rounding error in the age-length key resulted in 405 walleyes projected for all age groups. We used ages 4 and older in the catch-curve analysis to represent the legal-size walleye population (Figure 6). We chose age 4 as the youngest age because: 1) average length of male, female, and all walleyes at age 4 was greater than legal size, so most age-4 fish were likely legal size at the beginning of fishing season; and 2) relative abundance of fish younger than age 4 did not appear to be represented in proportion to their true abundance (Figure 6; Table 9). We considered the number of age-5 fish to be an outlier (extremely weak year class) and did not include them in any regressions. The removal of age groups in catch-curve regressions that are inconsistent with the apparent mortality trend for the majority of the adult age groups was also reported by Cortes and Parsons (1996). Although the existence of this weak year class violates the assumption of constant recruitment, this assumption is often violated in walleye populations. While the catch of age groups 4 through 7 appeared low, and perhaps too low to include in the catch curve, we believe that the low relatively abundance of these age groups is a result of not stocking walleyes during these years (1998–99).

We considered using age groups 8 through 14 in the catch-curve regression, which would have resulted in an annual mortality of 51%. Although this is a reasonable mortality estimate, it is not consistent with our estimate of walleye abundance. For example, when the descending limb of this catch curve is extrapolated backwards to attain estimates of the age groups (legal size) not included in the regression (Clarke et al. 2005, Sparre et al. 1999), we estimate that 2,681 age-4 to -7 walleyes could have been caught in our nets (assuming they were sexually mature and on spawning grounds). Given that we tagged approximately 25% of the walleye population (number tagged/single-census abundance estimate), the abundance of age-4 to -7 walleyes alone would have been 10,724 fish, or 6.3 per acre. Although the age groups in question (ages 4–7) may not be fully mature or represented on the spawning grounds, they are large enough to be fully-recruited to our sampling gear. Thus, an annual mortality rate of 51% appears to overestimate the mortality that the adult walleye population experienced during the years 1989–99.

The catch-curve regressions for walleyes were all significant ($P < 0.05$), and produced total instantaneous mortality rate estimates for legal-size fish of 0.459 for males, 0.347 for females, and 0.443 for all fish combined (Figure 6). These instantaneous rates corresponded to annual mortality rates of 37% for males, 29% for females, and 36% for all walleyes combined.

Anglers returned a total of 29 tags (16 reward and 13 nonreward) from harvested walleyes, and no tags from released walleyes, in North Manistique Lake in the year following tagging. The creel clerk did not observe any tagged fish in the possession of anglers that were not subsequently reported by the anglers. The reward tag return estimate of annual exploitation of walleyes was 7.9%, which incorporated an average tag loss rate (5%) derived from previous Large lake surveys. Although we did not detect long-term tag loss on walleyes, we used the average rate since our sample size for detection was quite low. Anglers reported reward and nonreward tags at a similar rate (7.5% versus 7.2%). The reporting rate of nonreward tags relative to reward tags (λ *in* Pollock et al. 1991) was 95%. Based on angler reports of tagged walleyes caught, the reported release rate was 0%. Additional estimates of the exploitation rate for walleyes were 18.3% (CV = 0.47) based on dividing harvest by the multiple-census abundance estimate, and 21.3% (CV = 0.54) based on dividing harvest by the single-census creel survey abundance estimate (Table 6).

For northern pike, we aged every fish that we collected; there were eight males, eight females, and one fish of unknown sex (Table 9). Although this sample is rather small to estimate mortality, we used ages 6 and older in the catch-curve analyses to represent the northern pike population (Figure 7). We chose age 6 as the youngest age because the average length of northern pike at age 6 was greater than legal size, and the relative abundance of age-6 and older fish appears to be representative of their expected abundance (Figure 7; Table 9). The catch-curve regression was significant (P <0.05), and resulted in a total instantaneous mortality rate of 0.443 for all fish combined. This instantaneous rate corresponds to an annual mortality rate of 36%.

Anglers returned a total of 2 tags (1 reward and 1 nonreward) from harvested northern pike, and no tags from released northern pike, in North Manistique Lake in the year following tagging. The creel clerk did not observe any tagged fish in the possession of anglers surveyed. The reward tag return estimate of annual exploitation of northern pike was 14.0%, which incorporated an average tag loss rate of 5%. Similar to walleyes, we did not detect long-term tag loss on northern pike, but we used the average rate since our sample size for detection of tag loss was low. Anglers reported reward tags at a similar rate to nonreward tags (12.5% versus 14.3%); the reporting rate of nonreward tags relative to reward tags (λ *in* Pollock et al. 1991) was 114%. No tagged northern pike were reported as being released. We could not estimate an exploitation rate for northern pike by dividing harvest by the abundance estimates, since there was no estimated harvest of northern pike in North Manistique Lake.

Recruitment.–For walleyes in North Manistique Lake, variability in year-class strength (based on catch-at-age of adult walleyes) was relatively high. Residual values from the catch curve regression were large (Figure 6) and the amount of variation explained by the age variable (R^2) was 0.80. We did not find any relationships between climatological variables and walleye year-class strength in North Manistique Lake. Additionally, there was no relationship between the residuals from the catch curve regression and the number of walleyes stocked. For northern pike, the amount of variation explained by the age variable (R^2) was 0.79. Due to the low sample size, we did not test for relationships between climatological variables and northern pike year-class strength in North Manistique Lake.

Movement.–Based on 40 recaptures during the spring survey and 29 voluntary tag returns by anglers, no movement of walleyes out of North Manistique Lake was evident. There was no between-lake movement of northern pike detected during our spring survey, or from angler tag returns throughout the year following tagging.

Creel Survey

Summer.–The clerk interviewed 371 boat anglers during the summer 2003 survey on North Manistique Lake. Most interviews (84%) were roving (incomplete-fishing trip). Anglers fished an estimated 9,515 hours and made 4,656 trips (Table 10).

The total estimated harvest of 5,677 fish consisted of three different species (Table 10). Yellow perch were most numerous with an estimated harvest of 5,355 fish. Anglers harvested 318 walleyes and reported releasing no walleyes. Anglers also harvested 3 rock bass. Anglers reported releasing 87 smallmouth bass, 612 rock bass, and 25,075 yellow perch. Although we did not detect any harvest of northern pike, we know from tag returns that two northern pike were harvested during the summer period.

Winter.–The clerk interviewed 23 open ice anglers and 38 shanty anglers during the winter survey period. Most open ice (87%) and shanty (74%) interviews were roving type. Open ice and shanty anglers fished 1,099 hours and made 361 trips on North Manistique Lake (Table 11). A total of 1,927 fish (yellow perch and walleyes) were harvested. Anglers also reported releasing 574 yellow perch.

Annual totals for summer and winter.–In the annual period from May 15 through October 15, 2003 and December 27, 2003 through March 31, 2004, anglers fished 10,614 hours and made 4,997 trips to North Manistique Lake (Table 12). Of the total annual fishing effort, 90% occurred in the open-water (summer) period and 10% occurred during the ice-cover (winter) period. The total annual harvest was 7,603 fish. Total annual harvest of yellow perch was 7,265 (96% of the total harvest) and estimated total annual harvest of walleyes was 335 (4% of the total harvest).

Yellow perch were the predominant species caught (harvested + released) at 32,914, with a resulting catch rate (catch per h) of 3.10. Yellow perch were caught throughout the year, with catch peaking in August. The total catch of walleyes was 335, with a catch rate of 0.032. Walleye catch peaked in July, and they were caught in only five months during the creel survey. Anglers did not report releasing any walleyes; thus, the catch must have been dominated by legal-size fish. We did not detect any catch of northern pike during the survey, a testament to their low density. As stated previously, we did have two tag returns from northern pike during the year, so there is some harvest of northern pike in North Manistique Lake. Estimated total annual catch of smallmouth bass was 87 (catch rate = 0.008) and total annual catch of rock bass was 615 (catch rate = 0.058). It should be noted that 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.

We did not survey from mid October through December, because we thought that relatively little fishing occurred during that time of year. In fact, no walleye tag returns were reported from mid-October through December (Table 13). Thus, we consider the estimate of total annual walleye harvest to be representative of the entire year. Similarly, no northern pike tag returns were reported as caught during the nonsurveyed months (Table 13). April was not surveyed because walleyes, northern pike, muskellunge, and smallmouth bass seasons are closed at that time.

Six species that we captured during spring netting operations were not detected in the angler harvest - bluegill, smallmouth bass, redhorse sucker, white sucker, and spottail shiner. However, smallmouth bass were at least caught and released. No species were caught by anglers that were not also collected in our spring survey.

Discussion

Fish Community

Because of the seasonal bias, we likely captured more large, mature fish of several species than would normally be captured during surveys that have historically been conducted later in the spring or summer. This includes spring spawning species such as walleyes, northern pike, white sucker, and smallmouth bass.

The seasonal and gear biases associated with our survey preclude comparisons of population and community indices to most other surveys of Michigan lakes. Because of the mesh-size bias, smaller fish are not represented in our sample in proportion to their true abundance in the lake. This includes juveniles of all species, as well as entire populations of smaller fishes known to exist in North Manistique Lake such as various species of shiners, darters, and minnows. For example, 14 species of fish have been collected or observed in North Manistique Lake in previous surveys that were not collected in 2003 (see Appendix).

White suckers accounted for almost 69% of the total catch by number, compared to 40% and 8.1% at similar surveys on adjacent Big Manistique Lake (Hanchin and Kramer 2007) and South Manistique Lake (Hanchin and Kramer 2008), respectively. A less intensive fish community survey was done at North Manistique in the 1995 (MDNR files) using trap-nets, fyke nets, and gill nets (41 net nights). Nine species were collected during this survey, with walleyes, white sucker, and northern pike comprising 37% of the catch by number. Panfish were present in the current survey, but were not found in great numbers, with the exception of rock bass. While the low numbers of these fish in our netting survey may be due to the survey gear used and timing of the survey, the creel survey results also suggest that panfish densities are low.

As part of the Large Lake Program, the MDNR also surveyed Big Manistique Lake (Hanchin and Kramer 2007) and South Manistique Lake (Hanchin and Kramer 2008) using methods and gears similar to this survey. Thus, it should be reasonable to compare fish community composition indices for North Manistique Lake to these other lakes. The proportion of piscivores in North Manistique Lake was lower than of nearby Big Manistique Lake and South Manistique Lake. In fact, the community composition among the three lakes was rather different. We observed 26% piscivores, 5% pelagic planktivores-insectivores, and 69% benthivores in North Manistique Lake versus 45% piscivores, 11% pelagic planktivores-insectivores, and 44% benthivores in Big Manistique Lake and

72% piscivores, 18% pelagic planktivores-insectivores, and 9% benthivores in South Manistique Lake. One large difference between the communities is that Big and South Manistique lakes have larger number of predators due to the quantity and quality of spawning habitat, which supports good natural reproduction. The lower predator density in North Manistique Lake also may allow white suckers to reach higher relative abundance, hence the greater proportion of benthivores in North Manistique Lake.

The size structure of walleyes in our spring survey was above average, largely due to the absence of sublegal walleyes. In eleven populations surveyed under the Large Lake Program, 71% of walleyes were legal size in spring surveys, compared to 99.8% for North Manistique Lake. In spring surveys of North Manistique Lake conducted in 1983 and 1995, the percentages of legal-size walleyes were 54% and 98%, respectively. There is no evidence of truncation in the length-frequency distribution as a result of angler harvest. However, the size structure does appear to show the effects of recent poor year classes. The low number of fish in the 15- to 17-inch range is likely a result of poor year classes and lack of stocking during the years from 1998 to 2000. Although growth of walleyes in North Manistique Lake is acceptable, it is apparent from the size structure that they are unlikely to attain lengths much greater than 25 inches.

The size structure of the northern pike population in North Manistique Lake is also above average. In ten populations surveyed under the Large Lake Program, the average percentage of legal-size northern pike in spring surveys was 27%, compared to 88% in North Manistique Lake. While we did not collect a large number of northern pike, the number of large (≥30 inches) fish was impressive, and overall northern pike in North Manistique Lake have the potential to reach large size.

Male walleyes outnumbered females in our survey, both when all sizes, or when only legal-size fish were considered. The male : female ratio (1.5:1) was below the average (3.9:1) that we have observed in ten large lakes surveyed to date. 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).

There were equal numbers of male and female northern pike when all sizes were considered, and when only legal-size fish were considered. In most other spring samples observed in the Large Lake Program, males made up the largest proportion of adult northern pike, but females made up the largest proportion of legal-size northern pike. Along with Big Manistique Lake (Hanchin and Kramer 2007), North Manistique Lake was the second northern pike population that we have observed in the Large Lake Program that did not have fewer legal males than females. This may be due, in part, to the favorable growth that we observed for northern pike in North Manistique Lake. The male : female sex ratio for adult northern pike (1:1) was similar to the average (1.1:1) that we have observed in ten large lakes surveyed to date in Michigan. In other lakes, males have been shown to predominate in spawning-season samples, but not at other times of the year (Priegel and Krohn 1975, Bregazzi and Kennedy 1980).

Abundance.–We were successful in obtaining both multiple-census and single-census estimates of walleye abundance. For the multiple-census estimate, the minimum number of recaptures was obtained; however, some assumptions for an unbiased estimate may have been violated (see later discussion). For the single-census estimate, we marked enough fish, but did not have a satisfactory number of fish observed for marks in the recapture sample. Assuming that the legal walleye population was approximately 2,000 fish, and based on tagging 393 fish, the recommended recapture sample to observe for marks in management studies ($\alpha = 0.05$, $P = 0.25$; where P denotes the level of accuracy, and $1-\alpha$ the level of precision) is 250 fish (Robson and Regier 1964). Our recapture sample of 31 fish was well short of this recommendation. The CV's were 0.11 and 0.29 for the multiple-census and single-census estimates, respectively. Thus, based on this measure of precision alone, we considered both our multiple-census and single-census estimates to be reliable.

The multiple-census estimate for walleyes was higher than the single-census estimate for both legal-size fish and adult fish. In most other populations surveyed under the Large Lake Program, the multiple-census estimates have been lower than the single-census estimates (Clark et al. 2004, Hanchin et al. 2005a, 2005b, 2005c). In the present study, 95% confidence limits between the two types of estimates overlapped, and each individual estimate was contained within the other's confidence limit as well. Precision was higher for the multiple-census estimates. Confidence limits were within 37% of the multiple-census point estimates, but only within 110% of the single-census estimates. Our estimates of walleye abundance were lower (up to 52% lower) than the a priori Michigan model estimates (Table 6). This was to be expected, given that the walleye population in North Manistique is low-density and dependent on stocking as a recruitment source, while the Michigan regression includes data from high-density populations with considerable natural recruitment.

Population density of walleyes in North Manistique Lake was below average compared to other lakes in Michigan. Using the acreage of 1,709, our single-census estimate for 15-inch-and-larger walleyes in North Manistique Lake was 0.9 per acre. Density of legal-size walleyes estimated recently for eleven large lakes in Michigan averaged 2.2, and ranged from 0.4 to 4.6 per acre. The density of legal walleyes in nearby Big and South Manistique lakes was 1.1 and 1.6 per acre, respectively (Hanchin and Kramer 2007, 2008). Population density of adult walleyes from our single-census estimate was also 0.9 per acre. Adult walleye abundance has averaged 3.5 per acre in eleven large lakes surveyed thus far as part of the Large Lake Program. Nate et al. (2000) reported an average density of 2.2 adult walleyes per acre for 131 Wisconsin lakes having natural reproduction.

We had less success in obtaining abundance estimates for northern pike. We could not make any abundance estimates for northern pike since the minimum number of recaptures was not obtained for either method. This was largely due to the fact that we only tagged 15 northern pike. Despite the lack of reliable estimates, the population density of legal size northern pike in North Manistique Lake is low (likely less than 100 individuals) relative to other lakes in Michigan and elsewhere. The density of adult northern pike estimated recently for ten large lakes in Michigan has averaged 0.95, and has ranged from 0.02 to 2.9 per acre (MDNR, unpublished data). Craig (1996) gives a table of abundance estimates (converted to density) for northern pike from various investigators across North America and Europe, including one from Michigan (Beyerle 1971). The sizes and ages of fish included in these estimates vary, but considering only estimates including age 1 and older fish, the range in density was 1 to 29 fish per acre. Also, Pierce et al. (1995) estimated abundance and density of northern pike in seven small (<300 ha) Minnesota lakes, where density estimates ranged from 4.5 to 22.3 per acre for fish age 2 and older.

One assumption of the multiple-census method for estimating abundance that we may have violated for both species is the random mixing of marked fish with unmarked fish. Over the course of our netting operation, marked fish were probably not mixing completely with the total population at large, and we possibly did not sample all spawning congregations in this large lake. An alternative description of this assumption 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 multiple-census method, the single-census estimate from the creel survey is more likely to be accurate because it allows sufficient time for the marked fish to fully mix with unmarked fish. Additionally, for the single-census estimate it is not assumed that all spawning congregations are sampled in the initial tagging operation.

Pierce (1997) found that multiple-census methods severely underestimated abundance of northern pike. 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 (1997) concluded that 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. In contrast to Pierce (1997), our multiple-census estimates were 19% higher for walleyes. Considering reliable estimates, this is the first survey in the Large Lake Program where the multiple-census estimates were higher than the single-census estimates.

Growth.–Mean lengths at age for walleyes from our survey were similar to those from previous surveys of North Manistique Lake and Big Manistique Lake (Table 14). In the past, the mean growth index for walleyes in North Manistique Lake has been within the bounds of ±1.0 inch (Table 14). Schneider et al. (2000b) suggests that a growth index in the range of ±1.0 inch is satisfactory for game fish; based on this criteria, recent walleye growth in North Manistique Lake has been satisfactory. Walleyes appeared to grow better in North Manistique Lake than in nearby South Manistique Lake and about the same as walleyes in Big Manistique Lake (Table 14). Given that all of the Manistique lakes are at similar latitude, we would expect similar growth rates. Thus, the better growth observed in North Manistique is likely a result of the lower density. A typical walleye in North Manistique Lake reaches legal size by age 3, compared to age 3 and age 4 in Big and South Manistique lakes, respectively (Table 14).

The values we calculated for L_∞ provide some insight into the growth potential of individuals in this population. The L_∞ for male and female walleyes was 22.0 and 25.0 inches, respectively, which indicates normal to good growth potential. For comparison, L_∞'s for walleyes in neighboring Big Manistique Lake were 20.7 inches for males, 24.0 inches for females, and 23.3 inches for all walleyes. In South Manistique Lake, L_∞'s were 20.6 inches for males, 24.7 for females, and 23.1 inches for all walleyes.

Mean lengths-at-age for northern pike from our survey were similar to those from previous surveys of North Manistique Lake (MDNR, unpublished data). They were also similar to those for the northern pike population in adjacent Big Manistique Lake (Table 15). The northern pike population has been mostly sustained through stocking (Table 1). Subsequently, northern pike experienced above-average growth when introduced into North Manistique Lake due to ample forage resources. Based on the Statewide mean growth index, northern pike growth in North Manistique Lake is satisfactory or better. As with walleyes, state averages for northern pike were based entirely on scale ageing, which probably underestimates ages for older fish, resulting in overestimated mean lengths.

The length-at-infinity (L_∞) value (33.3 inches) for all northern pike suggests that growth potential is average for this species. Female pike typically attain legal size (24 inches) between ages 4 and 5, whereas males attain this size at older ages. Northern pike through age 10 were observed in the 2003 collections, indicating that these fish can survive for some years after recruiting to legal size.

Mortality.–Compared to total mortality estimates for walleyes from other lakes in Michigan and elsewhere, our estimate of 36% is about average. Overall, thirteen year classes were represented and the age structure showed no indications of severe mortality associated with attainment of legal size. The variation in catch at age was likely a result of varying year-class strength, which may have been affected by walleye stocking. Total mortality rates from eleven populations surveyed as part of the Large Lake Program in Michigan have ranged from 24 to 51%, with an average of 37%. In 2003, annual mortality rates for all walleyes in nearby Big and South Manistique lakes were 31% and 29%, respectively. Schneider (1978) summarized available estimates of total annual mortality for adult walleyes in Michigan and from lakes throughout Midwestern North America, other than Michigan. Michigan estimates ranged from 20% in Lake Gogebic to 65% in Bay de Noc, Lake Michigan. North American estimates 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. These estimates ranged from 13 to 84% for fish age 2 and older, with the majority of lakes between 35% and 65%.

Our three estimates of annual exploitation rate of walleyes were somewhat different; 7.9% from tag returns, 18.3% using harvest divided by the multiple-census abundance estimate, and 21.9% using harvest divided by the single-census abundance estimate. We consider the tag return estimate to be a minimum because we did not adjust for tagging mortality, or nonreporting. If these problems occurred to any degree, we would have underestimated exploitation (Miranda et al. 2002).

Because we believe the exploitation estimate from tag returns is a minimum, the estimates derived by dividing harvest by abundance were both possible, and are assumed to represent upper limits on the true exploitation rate. The major problem with estimating exploitation as harvest divided by abundance is that the error associated with two individual estimates is compounded. If our harvest estimate was biased high, and our abundance estimate was biased low, the exploitation estimate would include the error from both individual estimates in a single direction, resulting in a gross inaccuracy. We believe this error occurs to some degree, in that the harvest estimate was likely biased high. We do not think the disparity between the exploitation estimates can be attributed solely to nonreporting since we observed a relatively high return rate (26.1%) of reward tags in nearby South Manistique Lake in the same year (Hanchin and Kramer 2008). Since we believe that the estimates from harvest divided by abundance may be biased high, the true annual exploitation rate of walleyes in North Manistique Lake is likely in the 10–15% range.

The average exploitation rate for walleyes from eleven large lakes surveyed to date was 14.8%, with a range of 3.5 to 29.3%. In general, the range of exploitation for walleyes across its range is large. For example, 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. Additionally, exploitation can vary over time for a single waterbody; in western Lake Erie, estimates ranged from 7.5 to 38.8% from 1989 through 1998 (Thomas and Haas 2000).

In 2003, we added a question to the tag return form asking anglers if they released the tagged walleyes that they caught. The absence of any reported releases for walleyes of legal size is consistent with expectations, given that we only collected one sublegal walleye in spring netting. We believe the estimated release rate is a minimum, given that anglers releasing fish are less likely to remove tags, or record the tag number information. The reported release rates for walleyes of legal size in Big and South Manistique lakes were 0.4 and 0.8%, respectively, in 2003 (Hanchin and Kramer 2007, 2008).

Compared to total mortality estimates for northern pike from other lakes in Michigan and elsewhere, our estimate of 36% is below average. Total mortality rates from ten populations surveyed as part of the Large Lake Program in Michigan have ranged from 31 to 69%, with an average of 50%. Diana (1983) estimated total annual mortality for two other populations in Michigan, Murray Lake (24.4%) and Lac Vieux Desert (36.2%). Pierce et al. (1995) estimated total mortality for northern pike in seven small (<300 ha) lakes in Minnesota to be 36 to 65%. They also summarized total mortality for adult northern pike from a number of lakes across North America; estimates ranged from a low of 19% (Mosindy et al. 1987) to a high of 91% (Kempinger and Carline 1978), with the majority of populations between 35% and 65%.

We were only able to make one estimate of annual exploitation for northern pike, 14.0% from tag returns. Again, we consider the tag return estimate to be a minimum estimate, and unreliable. Due to the low sample size, the addition of a single additional tag return would have increased the estimate to 21.1%, a 51% increase. Compared to exploitation rates for northern pike from other lakes in Michigan and elsewhere, our tag return estimate of 14% for North Manistique Lake is a little below average. The average exploitation rate for northern pike from nine large lakes surveyed to date was 19.4%, with a range of 7.8 to 31.4%. Latta (1972) reported northern pike exploitation in two Michigan lakes, Grebe Lake (12–23%) and Fletcher Pond (38%). Pierce et al. (1995) reported rates of 8 to 46% for fish over 20 inches from seven lakes in Minnesota. Carlander (1969) gave a range of 14 to 41% for a sample of lakes throughout North America.

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; 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, but 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, 1996b; Nate, et al. 2000).

We obtained population data in North Manistique Lake 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 and northern pike. 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.

Walleyes in North Manistique Lake were represented by 13 year classes (ages 2 through 14) in our samples. Variability in year-class strength appeared high (R^2 = 0.80; Figure 6), though we did not include some age classes in the catch curve regression. When we included all age classes that were greater than legal size the catch curve regression had an R^2 value of 0.50, indicating highly variable recruitment. In eleven Michigan walleye populations surveyed as part of the Large Lake Program to date the R^2 has ranged from 0.50 to 0.98, with an average of 0.82. North Manistique Lake represents the highest recruitment variability that we have observed thus far in the Large Lake Program.

Although the number of walleyes stocked did not correlate with the residuals from the catch curve, stocking likely contributes to the population. The lowest residual that we observed (considered an outlier) corresponded with a year (1998) in which no walleyes were stocked. In contrast, the 1999 year class was well represented in our catch, and also occurred in a year when no walleyes were stocked. Thus, it appears that both natural reproduction and stocking may contribute to the walleye population in North Manistique Lake. The true contribution of each source would best be determined by marking spring fingerling walleyes stocked over several years. Additionally, following five years (1998–2002) of no stocking, it should be relatively easy to determine the contribution of natural reproduction by collecting adult fish from these year classes.

Northern pike were represented by seven year classes, but sample size was low. Variability in year-class strength was about average (R^2 = 0.79; Figure 7), but this was largely a result of there being only four age groups included in the regression. The low catch overall suggests that recruitment is low, and the absence of at least the 1999 and 2000 year classes suggests that recruitment is also variable. In ten Michigan northern pike populations surveyed as part of the Large Lake Program to date, the R^2 has ranged from 0.67 to 1.00, with an average of 0.86.

Movement.–We did not detect any movement of fish out of North Manistique Lake, or into the lake from Big or South Manistique lakes. It is possible that fish could move to or from the lake via Helmer Creek, and angler creel data from the 1940's showed that walleyes and suckers were occasionally caught in Helmer Creek (Madison and Lockwood 2004). Although walleyes could potentially migrate through Helmer Creek, low flow and shallow depth exist for the majority of the year, making it unlikely. Additionally, Tressler Dam would likely be a barrier, or deterrence for both upstream and downstream movement during most of the year.

Creel Survey

The fishery of North Manistique Lake is dominated by yellow perch and walleye harvest. These two species comprised nearly 100% of the total annual harvest. Harvest of yellow perch increased monthly from May to August, as did total catch. Walleyes were harvested most readily in June and July, though they were caught in three other months as well. Catch rate for walleyes was highest in September (0.045/hour), followed by June (0.041/hour). Yellow perch catch peaked in August, and the majority of harvest occurred from June through September. Twenty-six percent of the yellow perch harvest occurred during the ice-cover (winter) period. With an estimated harvest of only three fish, rock bass were the only other species harvested, and their presence in the angler harvest is likely small in most years. Although there was no estimated harvest of smallmouth bass, a relatively small number were caught and released.

Comparison to other large lakes.–Historical creel survey data was not available for North Manistique Lake. In general, surveys conducted in Michigan during the past 10 years used the same methods we used on North Manistique Lake, but most of them still differ from our survey in seasonality. For example, few other surveys were done in consecutive summer and winter periods. Regardless, for comparison to our results, we used recent creel survey results for Michigan's large inland lakes from 1993 through 1999 as compiled by Lockwood (2000b) and results for Michigan's

Great Lakes waters in 2001 compiled by Rakoczy and Wesander-Russell (2002). In addition, we compared results to nine other lakes that have been surveyed as part of the Large Lake Program to date.

We estimated 10,614 angler hours of effort on North Manistique Lake during the year from May 15 through October 15, 2003 and December 27, 2003 through March 28, 2004. The harvest per acre (all species) and hours fished per acre were below average, relative to other large lakes (Table 16), but the harvest per hour was above average. The waterbody is less productive than average, not as heavily fished, although angler success is relatively high.

For walleyes, our estimated annual harvest from North Manistique Lake was 0.20 fish per acre. This harvest is well below the average of other waters in Michigan. The average harvest of eleven large Michigan lakes was 0.71 walleyes per acre. These Michigan lakes all were subject to similar gears and fishing regulations, including a 15-inch minimum size limit. The harvest per acre was similar to nearby Big Manistique Lake (0.16), but rather different than South Manistique Lake which had the highest walleye harvest per acre (1.61) that we have observed thus far in the Large Lake Program (Hanchin and Kramer 2008). The catch per hour (harvest and released combined) of all walleyes (0.032) was also below average (0.118) for lakes surveyed in the Large Lake Program thus far.

We estimated no harvest of northern pike from North Manistique Lake, though there was obviously some low level of harvest given that we received tag returns. If we multiply our exploitation estimate (14.0%) by the abundance estimate (32) we get a harvest of four northern pike. This speculative harvest (0.003 per acre) would be well below average, compared to other large lakes surveyed in Michigan. The average harvest from seven other large Michigan lakes (> 1,000 acres) reported by Lockwood (2000b) was 0.2 northern pike per acre, ranging from less than 0.1 per acre in Bond Falls Flowage, Gogebic County to 0.7 per acre in Fletcher Pond, Alpena County. The average harvest from nine other lakes surveyed as part of the Large Lake Program thus far was 0.18 per acre. These Michigan lakes all were subject to similar gears and fishing regulations, including a 24-inch minimum size limit. Elsewhere, Pierce et al. (1995) estimated harvests from 0.7 to 3.6 per acre in seven, smaller Minnesota lakes. These lakes ranged from 136 to 628 acres in size and had no minimum size limits for northern pike.

The total catch (harvest + release) of smallmouth bass in North Manistique Lake was 87, which were all released fish. The catch per hour (0.008) was lower than the average (0.035) for eleven large lakes surveyed thus far. The total catch and harvest of yellow perch in North Manistique was impressive, with an estimated 4.3 yellow perch harvested per acre. In comparison, the harvest per acre of yellow perch in Big Manistique Lake, Burt Lake, Crooked and Pickerel lakes, and Muskegon Lake were 6.6, 3.4, 1.8, and 10.7, respectively. The catch rate of yellow perch in North Manistique Lake (3.10) was greater than that of Big Manistique (1.05 per hour), Muskegon Lake (0.69), Burt Lake (0.80), and Crooked and Pickerel lakes (0.22), indicating relatively high yellow perch abundance. The majority (78%) of yellow perch caught were reported as being released.

Summary

The current walleye density in North Manistique Lake is below average when compared to other large lakes in Michigan, but this is expected given that the lake has little spawning habitat, and the population is maintained primarily by stocking. Our estimates of legal and adult walleye abundance were lower than the estimates made a priori with the Michigan Model, but this is also expected for a stocked population in a low productivity system. Growth was satisfactory and size structure was favorable, with 99.8% of the spring spawning stock above the 15-inch minimum size limit.

Our estimate of exploitation for North Manistique Lake walleyes was below average for Michigan lakes. The annual harvest of 0.2 walleyes per acre matches the lowest we have seen so far in the Large Lake Program, and is about 30% of the average from nine large lakes. Catch per hour for walleyes of all sizes was 0.032, which is also well below average for large lakes in Michigan. While this catch rate indicates a poor walleye fishery, it is not always indicative of walleye density since we did not assess targeted effort. In fact, the low walleye catch rate is likely a result of the greater effort directed toward yellow perch.

Both natural reproduction and stocking contribute to the walleye population in North Manistique Lake, but a determination of the contribution by each source could not be accomplished with this study. We recommend marking spring fingerling walleyes over successive stocking years to identify the contribution of stocked fish. Although current walleye growth is satisfactory, it should not be compromised by introducing too many predators into the system. Although we did not collect many yellow perch in our spring survey, it appears from the high release rate in the creel survey that yellow perch size structure is relatively low, and density is high. If this is true, it would indicate that walleye density is not so high that it is having a negative effect on yellow perch density.

The density of northern pike in North Manistique is low relative to other large lakes in Michigan. The mean growth index (+4.2) for northern pike is the highest that we have observed thus far in ten populations surveyed under the Large Lake Program. This is likely a testament to the presence of ideal growing conditions (thermal refuge and abundant prey) for large pike. Size structure of northern pike is high, with 88% of the spring spawning stock above the 24-inch minimum size limit. The population is not adversely affected by angling, but is likely limited by the amount of available spawning habitat, which results in erratic recruitment, and low reproduction. Total mortality of northern pike is low, likely a result of low density, low angling pressure, and ideal growing conditions. Our estimate of northern pike exploitation was below average relative to other large lakes in Michigan.

Overall, the fishery in North Manistique Lake is not diverse, but the yellow perch and walleye fisheries provide reasonable fishing opportunity. The number of all fish species harvested per hour was above average, considering large lakes surveyed under similar methods. Fish harvested per acre was below average, but was greater than the median value from large lakes surveyed under similar methods. The harvest per acre of yellow perch (4.3) exceeded that for Burt Lake (3.4) which is a notable perch fishery.

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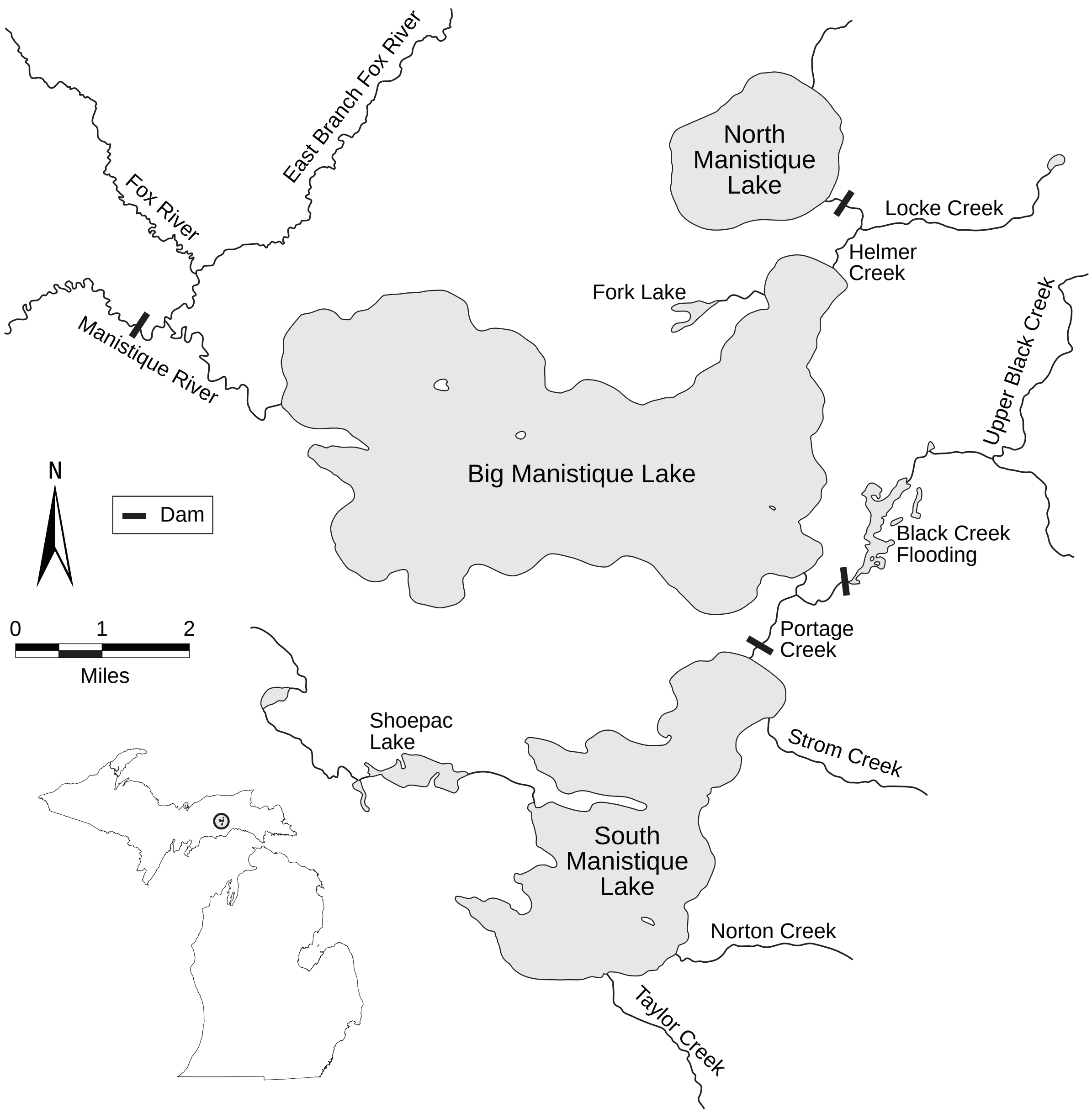

Figure 1.–Map of the Manistique lakes, Luce and Mackinac counties, Michigan. Solid black lines represent dams described in the text.

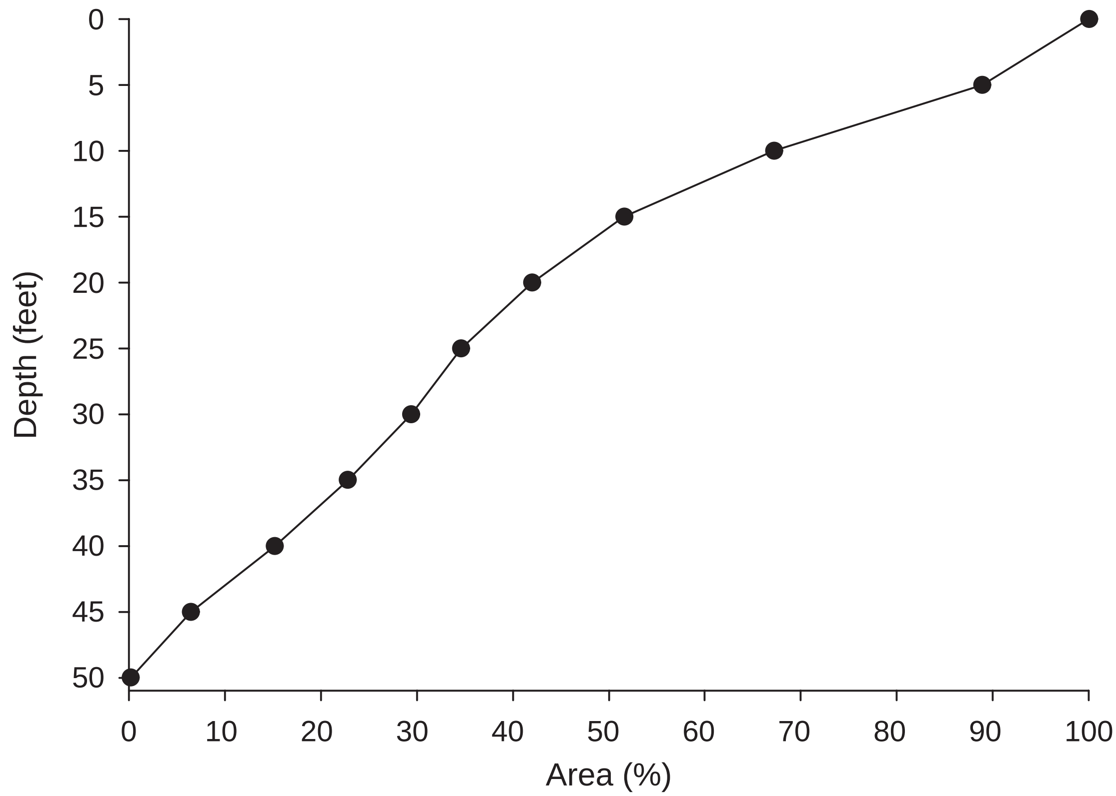

Figure 2.–Percent of area equal to or greater than a given depth for North Manistique Lake. Data taken from MDNR Digital Water Atlas.

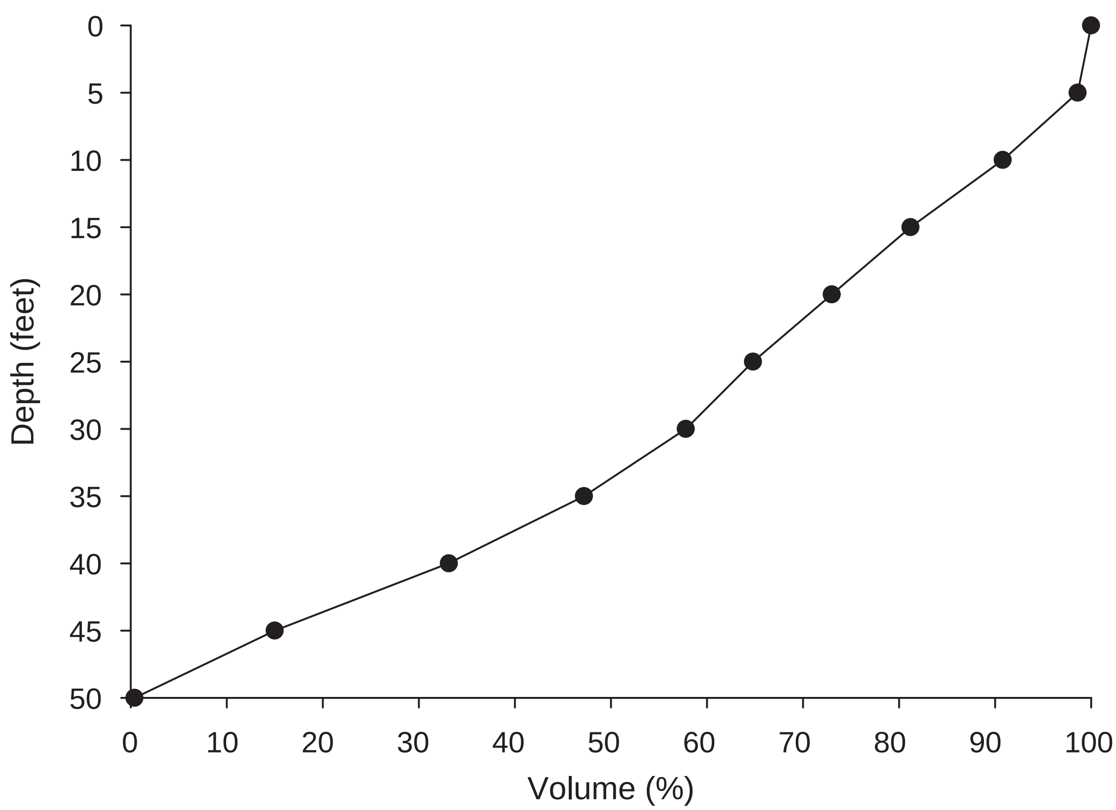

Figure 3.–Percent of volume equal to or greater than a given depth for North Manistique Lake. Data taken from MDNR Digital Water Atlas.

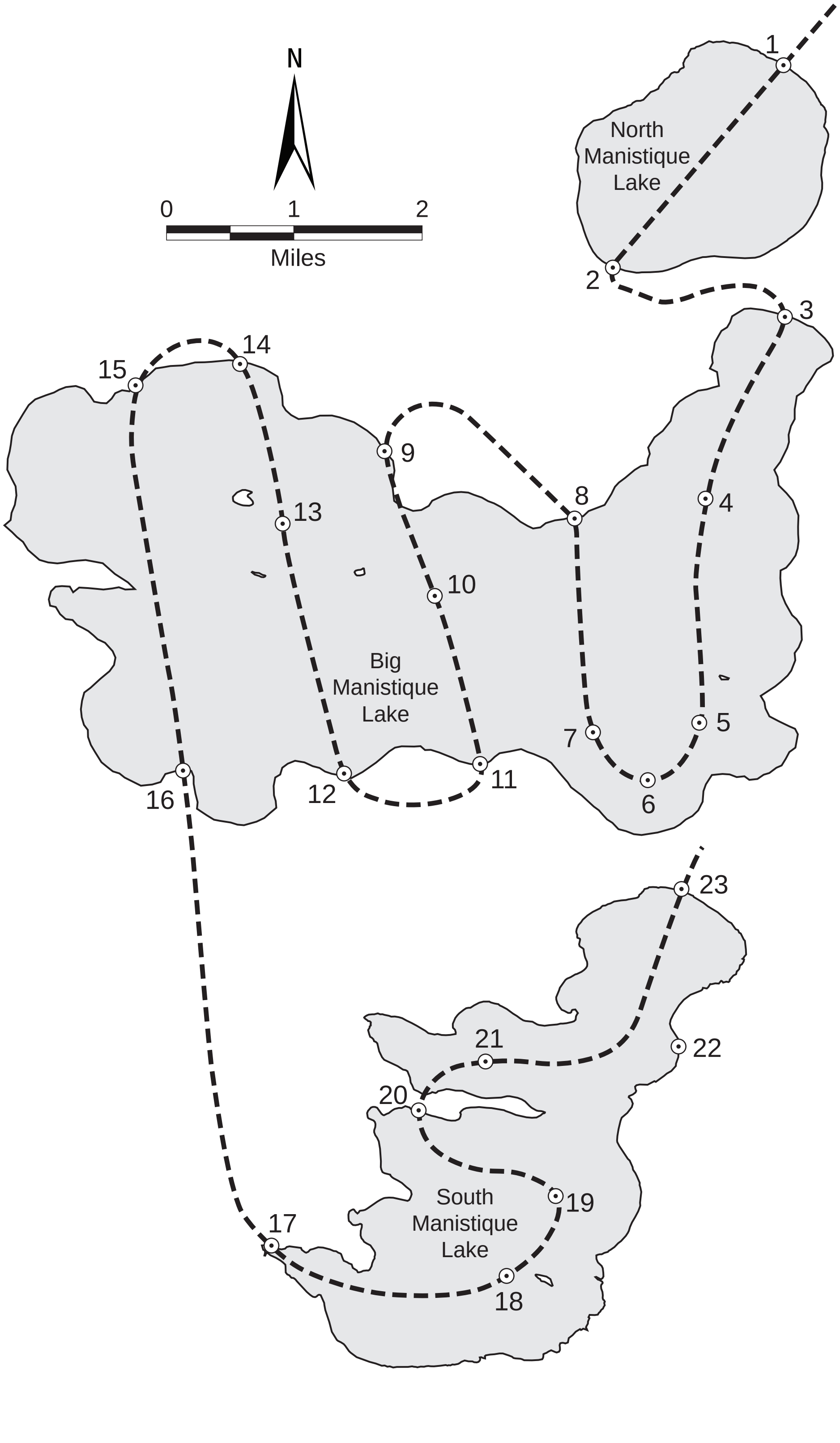

Figure 4.–Counting flight path, associated way points, and interview starting locations (points 1, 2, 3, 8, 11, 15, 17, and 23) for the Manistique lakes, summer 2003 survey. Latitude and longitude for points 1–23 are given in Table 3.

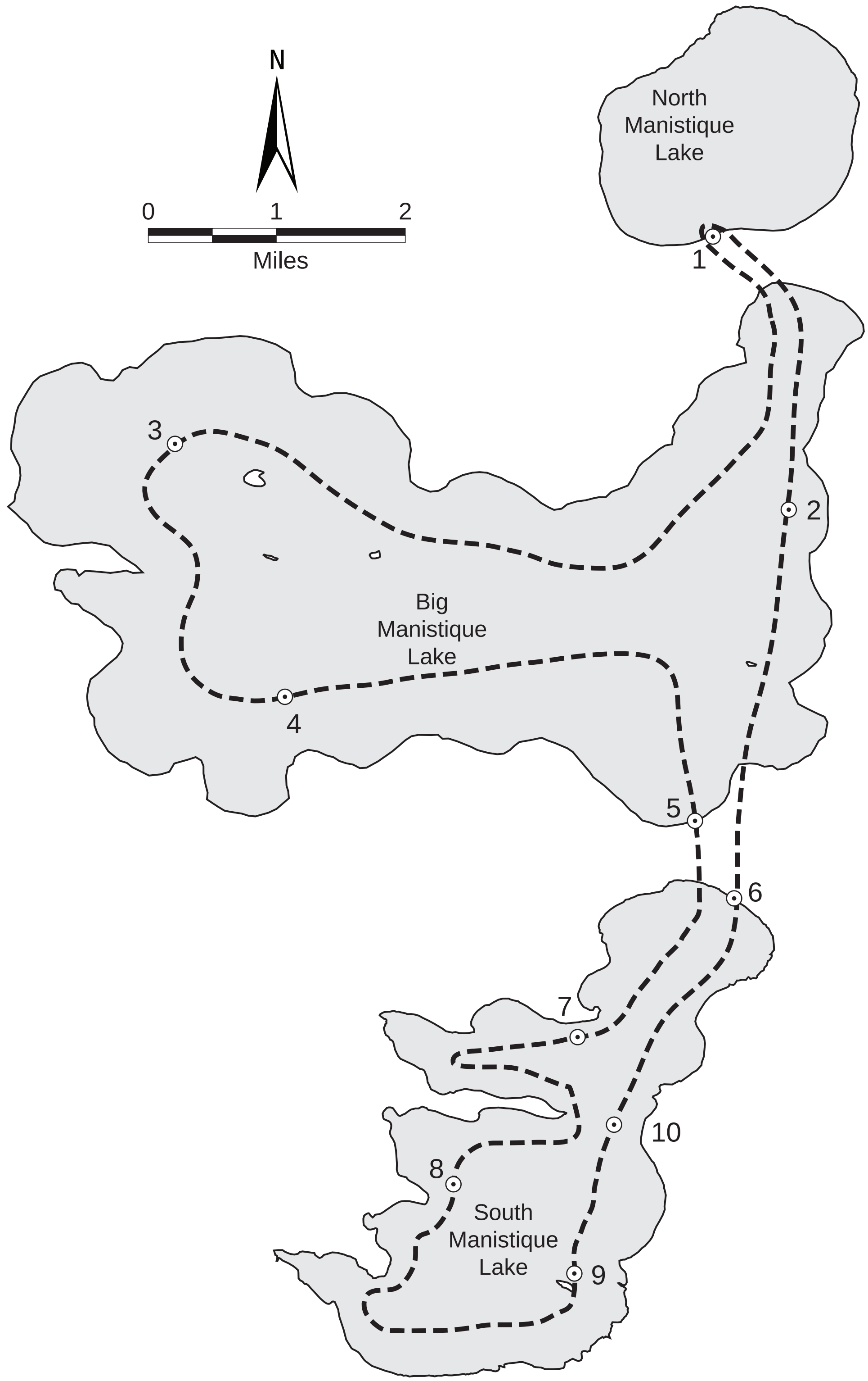

Figure 5.–Counting path, and approximate interview starting locations (1-10) for the Manistique lakes, winter 2003-04 survey.

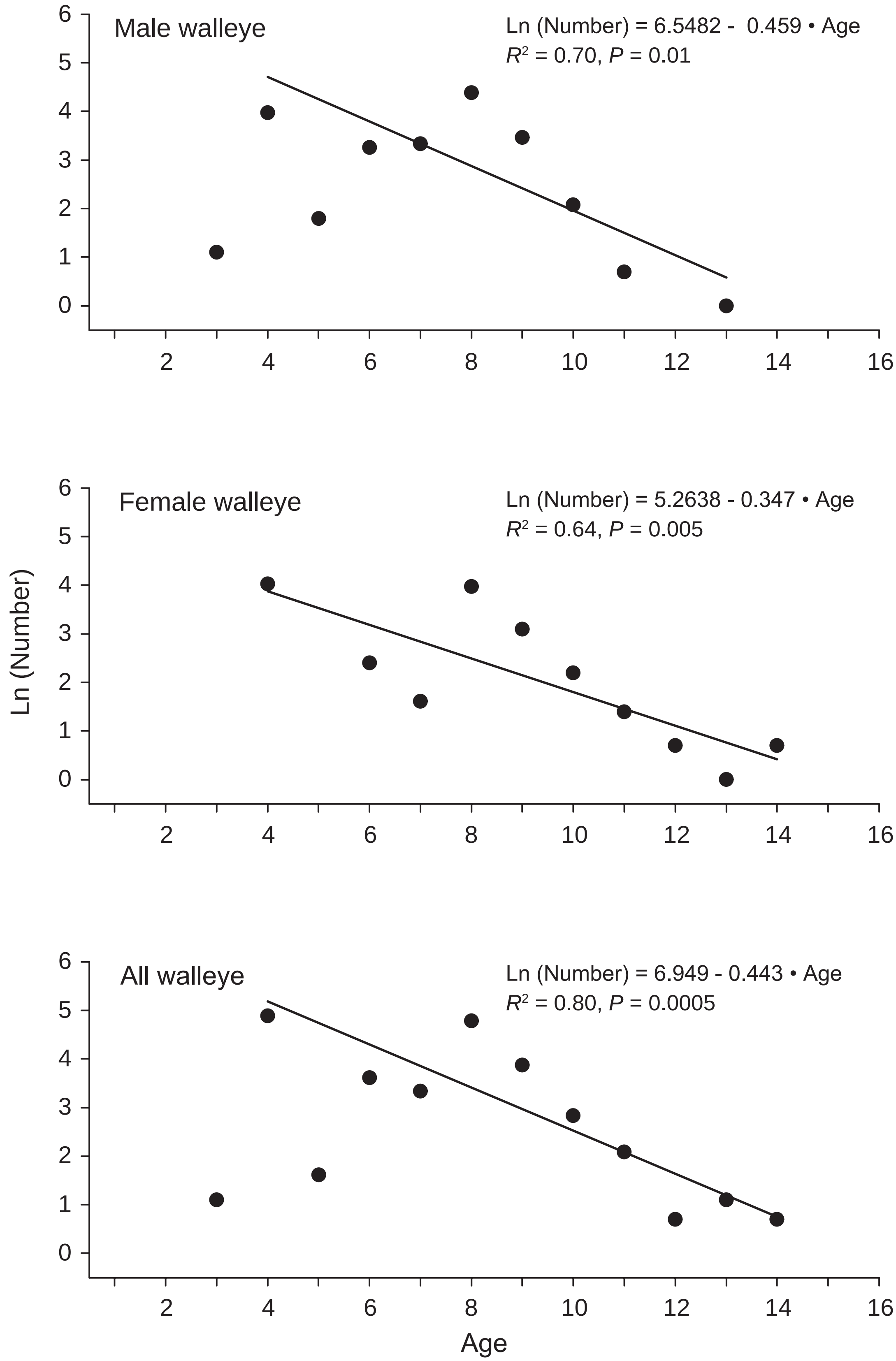

Figure 6.–Observed ln(number) versus age for male, female, and all (including males, females, and unknown sex) walleyes in North Manistique Lake. Lines are plots of the regression equations shown. Age-5 fish were considered outliers, and were not included in regressions.

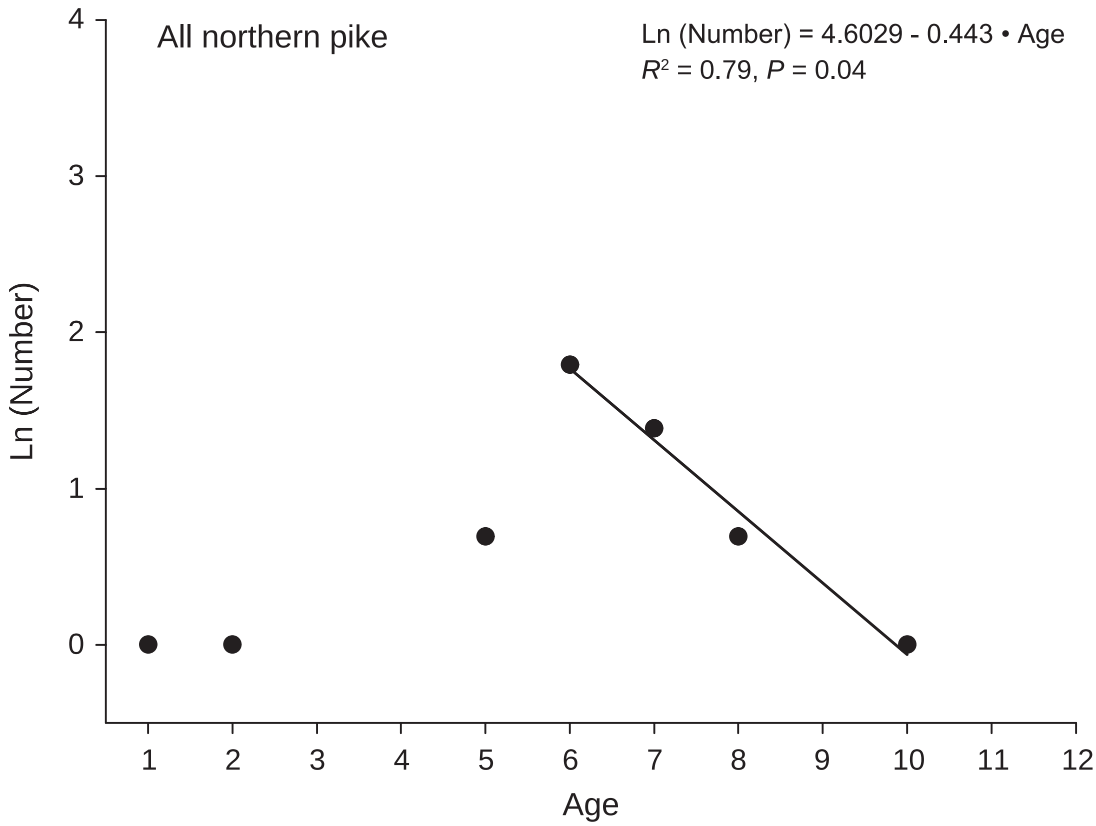

Figure 7.–Observed ln(number) versus age for all (including males, females, and unknown sex) northern pike in North Manistique Lake. Line is a plot of the regression equation shown.

Table 1.–Number and size of fish stocked in North Manistique Lake, 1985 through 2003.

Year	Species	Number	Weight (lbs)	Average size (in)
1985	Walleye	150,000	3	0.5
	Northern pike	15,000	110	3.4
	Lake trout	1,536	8,450	22.2
1986	Walleye	300,000	5	0.5
	Walleye	65,970	109	1.8
1987	Walleye	17,918	34	2.0
	Lake trout	200	757	22.9
	Lake trout	8,339	282	5.2
	Splake	36,000	1,226	5.2
1988	Northern pike	15,000	117	3.4
1989	Walleye	500,000	6	0.4
	Northern pike	11,500	179	4.3
1990	Walleye	34,247	33	1.6
1991	Walleye	974,000	13	0.2
	Northern pike	8,876	79	3.6
1992	Walleye	1,097,400	21	0.2
	Walleye	64,492	39	1.9
1993	Walleye	72	36	15.0
	Walleye	20,014	50	2.0
	Walleye	2,100,000	29	0.2
	Lake trout	90	99	16.6
1994	Walleye	101,226	115	1.7
1995	Walleye	70,368	147	2.1
1996	Walleye	67,730	42	1.3
	Lake trout	481	3,223	25.4
1997	Walleye	62,462	205	2.3
	Lake trout	470	188	11.5
	Smallmouth bass	1,301	13	3.0
1998	Smallmouth bass	7,154	34	2.4
	Lake trout	1,008	8,955	27.8
1999	Lake trout	250	913	24.0
	Lake trout	27,048	2,372	7.1
2000	Northern pike	96	211	22.4
2003	Walleye	38,519	84	1.8

Table 2.–Survey periods, sampling shifts, and expansion value “F” (number of fishing hours within a sample day) for the Manistique lakes creel survey, spring 2003 through winter 2004.

	Sample shifts (h)		
Survey period	A	B	F
Summer			
May 8–31	0600–1430	1330–2200	17
June	0600–1430	1330–2200	17
July	0600–1430	1300–2130	17
August	0630–1500	1230–2100	16
September	0630–1500	1200–2030	15
October 1–15	0630–1500	1030–1900	14
Winter			
December 27–January 31	0700–1530	1100–1930	13
February	0700–1530	1100–1930	13
March 1–28	0700–1530	1100–1930	13

Table 3.–Coordinates (decimal degrees) for the Manistique lakes summer 2003 creel survey. See Figure 5 for general flight path and numbered locations.

Marker	Latitude	Longitude
1	46.29826ºN	85.72318ºW
2	46.27573ºN	85.75184ºW
3	46.26972ºN	85.72218ºW
4	46.24910ºN	85.73583ºW
5	46.22357ºN	85.73731ºW
6	46.22964ºN	85.76630ºW
7	46.22364ºN	85.75542ºW
8	46.24733ºN	85.75889ºW
9	46.25511ºN	85.78970ºW
10	46.23839ºN	85.78221ºW
11	46.21930ºN	85.77548ºW
12	46.21846ºN	85.79896ºW
13	46.24675ºN	85.81025ºW
14	46.26507ºN	85.81756ºW
15	46.26044ºN	85.83568ºW
16	46.21878ºN	85.82295ºW
17	46.16479ºN	85.80901ºW
18	46.16196ºN	85.77076ºW
19	46.17020ºN	85.76226ºW
20	46.18036ºN	85.78676ºW
21	46.18611ºN	85.77577ºW
22	46.18764ºN	85.75160ºW
23	46.20462ºN	85.74061ºW

Table 4.–Fish collected from North Manistique Lake using a total sampling effort of 28 trap-net lifts, and 50 fyke-net lifts from April 24 to May 6, 2003.

Species	Total catch[a]	Percent by number	Mean trap-net CPUE[a,b]	Mean fyke-net CPUE[a,b]	Length range (in)	Average length (in)[c]	Number measured[c]
White sucker	1,263	68.5	20.2	10.4	8.1–20.7	16.8	209
Walleye	447	24.2	6.7	4.2	9.2–28.5	20.4	404
Rock bass	88	4.8	0.4	1.4	2.1–12.5	4.8	87
Northern pike	17	0.9	0.6	0	16.3–40.0	29.7	17
Yellow perch	10	0.5	<0.1	0.2	4.3–5.8	4.8	10
Smallmouth bass	9	0.5	0	0.2	3.7–12.1	8.2	9
Redhorse spp.	8	0.4	0.2	<0.1	12.6–15.3	14.0	8
Spottail shiner	1	<0.1	0	<0.1	4.9	4.9	1
Bluegill	1	<0.1	<0.1	0	6.3	6.3	1

[a] Includes recaptures
[b] Number per trap-net or fyke-net night
[c] Does not include recaptures for walleyes, northern pike, or smallmouth bass.

Table 5.–Number of fish per inch group caught and measured in spring netting on North Manistique Lake, April 24 to May 6, 2003.

	Species								
Inch group	White sucker	Walleye	Rock bass	Northern pike	Yellow perch	Smallmouth bass	Redhorse spp.	Spottail shiner	Bluegill
2	–	–	6	–	–	–	–	–	–
3	–	–	30	–	–	1	–	–	–
4	–	–	26	–	7	–	–	1	–
5	–	–	9	–	3	3	–	–	–
6	–	–	5	–	–	–	–	–	1
7	–	–	2	–	–	–	–	–	–
8	3	–	3	–	–	2	–	–	–
9	2	1	2	–	–	–	–	–	–
10	–	–	–	–	–	–	–	–	–
11	10	–	3	–	–	–	–	–	–
12	5	–	1	–	–	3	2	–	–
13	6	–	–	–	–	–	2	–	–
14	8	–	–	–	–	–	2	–	–
15	7	–	–	–	–	–	2	–	–
16	30	4	–	1	–	–	–	–	–
17	67	16	–	–	–	–	–	–	–
18	44	59	–	–	–	–	–	–	–
19	24	102	–	–	–	–	–	–	–
20	3	68	–	–	–	–	–	–	–
21	–	74	–	–	–	–	–	–	–
22	–	50	–	1	–	–	–	–	–
23	–	19	–	–	–	–	–	–	–
24	–	9	–	–	–	–	–	–	–
25	–	1	–	1	–	–	–	–	–
26	–	–	–	–	–	–	–	–	–
27	–	–	–	4	–	–	–	–	–
28	–	1	–	2	–	–	–	–	–
29	–	–	–	1	–	–	–	–	–
30	–	–	–	–	–	–	–	–	–
31	–	–	–	1	–	–	–	–	–
32	–	–	–	1	–	–	–	–	–
33	–	–	–	2	–	–	–	–	–
34	–	–	–	–	–	–	–	–	–
35	–	–	–	1	–	–	–	–	–
36	–	–	–	–	–	–	–	–	–
37	–	–	–	–	–	–	–	–	–
38	–	–	–	1	–	–	–	–	–
39	–	–	–	–	–	–	–	–	–
40	–	–	–	1	–	–	–	–	–
Total	209	404	87	17	10	9	8	1	1

Table 6.–Estimates of abundance, angler exploitation, and annual mortality rates for North Manistique Lake walleyes and northern pike. Asymmetrical 95% confidence limits for estimates are given in parentheses, where applicable.

Parameter	Walleye	Northern pike
Number tagged	393	15
Total tag returns	29	2
Number of legal-size[a] fish		
Multiple-census estimate	1,827 (1,440–2,499)	No estimate[b]
Single-census estimate	1,576 (817–3,305)	No estimate[b]
Michigan model prediction[c]	2,601 (500–12,083)	NA
Number of adult[d] fish		
Multiple-census method	1,827 (1,440–2,499)	No estimate[b]
Single-census estimate	1,576 (817–3,305)	No estimate[b]
Michigan model prediction[e]	3,273 (785–13,641)	NA
Annual exploitation rates		
Based on reward tag returns	7.9%	14.0%
Based on harvest/abundance[f]	18.3% (1.2–35.5%)	No estimate
Based on harvest/abundance[g]	21.3% (0–44.1%)	No estimate
Annual mortality rates	36%	36%

[a]Walleyes ≥ 15 in and northern pike ≥ 24 in.
[b]Minimum number of recaptures not obtained.
[c]Michigan model prediction of legal-size walleye abundance based on lake area (N = 21 lakes).
[d]Fish of legal-size and sexually-mature fish of sublegal size on spawning grounds.
[e]Michigan model prediction of adult walleye abundance based on lake area (N = 35 lakes).
[f]Multiple-census estimate of legal-size walleye abundance.
[g]Single-census estimate of legal-size walleye abundance.

Table 7.–Weighted mean lengths and sample sizes by age and sex for walleyes collected from North Manistique Lake, April 24 to May 6, 2003. Standard deviation is in parentheses.

Age	Mean length						Number aged		
	Males		Females		All fish[a]		Males	Females	All fish[a]
2	–		–		9.0	(–)	–	–	1
3	16.6	(0.0)	–		16.6	(0.0)	3	–	3
4	18.2	(0.4)	19.2	(0.5)	18.9	(0.8)	14	17	31
5	18.9	(–)	–		18.9	(–)	1	–	1
6	19.7	(0.6)	21.4	(1.1)	20.4	(1.0)	3	5	8
7	19.5	(0.6)	19.0	(–)	19.3	(0.6)	4	1	5
8	20.8	(0.8)	22.2	(1.0)	21.4	(1.1)	16	17	33
9	20.9	(0.9)	22.5	(0.5)	21.7	(1.1)	8	6	14
10	21.9	(0.3)	22.8	(0.8)	22.5	(0.7)	3	3	6
11	22.8	(0.0)	22.7	(1.7)	22.6	(1.2)	1	2	3
12	–		24.0	(–)	24.0	(–)	–	1	1
13	23.4	(–)	28.5	(–)	25.1	(2.9)	1	1	2
14	–		24.2	(–)	24.2	(–)	–	1	1

[a] Mean length for 'All fish' includes males, females, and fish of unknown sex.

Table 8.–Mean lengths and sample sizes for northern pike (males and females combined) collected from North Manistique Lake, April 24 to May 6, 2003. Standard deviation is in parentheses.

Age	Mean length		Number aged
1	16.3	(–)	1
2	22.1	(–)	1
3	–		–
4	–		–
5	26.6	(1.1)	2
6	31.5	(3.1)	6
7	31.8	(5.1)	4
8	28.9	(1.3)	2
9	–		–
10	40.0	(–)	1

Table 9.–Catch-at-age estimates (apportioned by age-length key) by sex for walleyes, and for all northern pike from North Manistique Lake, April 24 to May 6, 2003.

	Year	Walleye			Northern pike
Age	class	Males	Females	All fish[a]	All fish[a]
1	2002	–	–	–	1
2	2001	–	–	1	1
3	2000	3	–	3	–
4	1999	53	56	132	–
5	1998	6	–	5	2
6	1997	26	11	37	6
7	1996	28	5	28	4
8	1995	80	53	119	2
9	1994	32	22	48	–
10	1993	8	9	17	1
11	1992	2	4	8	–
12	1991	–	2	2	–
13	1990	1	1	3	–
14	1989	–	2	2	–
Total		239	165	405	17

[a] Catch at age for ‘All fish’ includes males, females, and fish of unknown sex.

Table 10.–Creel survey estimates for summer 2003 from North Manistique Lake. Survey period was from May 15 through October 15, 2003. Two standard errors are given in parentheses.

Species	Catch per hour	Month: May	June	July	August	September	October	Season
		Number harvested						
Walleye	0.033 (0.032)	7 (14)	87 (80)	181 (288)	0 (0)	42 (41)	0 (0)	318 (302)
Yellow perch	0.563 (0.225)	12 (24)	609 (379)	1,669 (1,327)	2,229 (1,084)	836 (590)	0 (0)	5,355 (1,852)
Rock bass	0.001 (0.001)	0 (0)	0 (0)	0 (0)	0 (0)	3 (7)	0 (0)	3 (7)
Total harvest	0.597 (0.230)	19 (27)	697 (387)	1,850 (1,358)	2,229 (1,084)	882 (592)	0 (0)	5,677 (1,877)
		Number released						
Smallmouth bass	0.009 (0.009)	0 (0)	12 (24)	12 (24)	45 (71)	17 (34)	0 (0)	87 (86)
Rock bass	0.064 (0.064)	0 (0)	346 (365)	267 (474)	0 (0)	0 (0)	0 (0)	612 (598)
Yellow perch	2.635 (0.982)	26 (41)	2,361 (1,604)	6,272 (3,958)	11,589 (5,512)	3,092 (2,356)	1,736 (2,889)	25,075 (7,907)
Total released	2.709 (0.992)	26 (41)	2,719 (1,645)	6,550 (3,986)	11,634 (5,513)	3,109 (2,356)	1,736 (2,889)	25,774 (7,930)
Total catch	3.305 (1.079)	45 (49)	3,415 (1,690)	8,400 (4,211)	13,863 (5,618)	3,991 (2,430)	1,736 (2,889)	31,451 (8,149)
		Fishing effort						
Angler hours		798 (535)	2,102 (799)	2,987 (1,272)	2,355 (833)	940 (455)	334 (356)	9,515 (1,890)
Angler trips		282 (218)	935 (694)	1,584 (1,142)	1,266 (1,253)	399 (213)	191 (261)	4,656 (1,875)

Table 11.–Creel survey estimates for winter 2004 from North Manistique Lake. Survey period was from December 27, 2003 through March 28, 2004. Two standard errors are given in parentheses.

Species	Catch per hour	Month			Season
		December–January	February	March	
		Number harvested			
Walleye	0.015 (0.031)	17 (33)	0 (0)	0 (0)	17 (33)
Yellow perch	1.737 (1.339)	1,120 (852)	436 (417)	354 (707)	1,910 (1,183)
Total harvest	1.752 (1.344)	1,137 (852)	436 (417)	354 (707)	1,926 (1,183)
		Number released			
Yellow perch	0.522 (0.605)	541 (607)	32 (65)	0 (0)	574 (611)
Total released	0.522 (0.605)	541 (607)	32 (65)	0 (0)	574 (611)
Total catch	2.274 (1.599)	1,678 (1,047)	469 (422)	354 (707)	2,500 (1,332)
		Fishing effort			
Angler hours		642 (360)	416 (344)	42 (83)	1,099 (504)
Angler trips		228 (169)	110 (106)	22 (46)	361 (205)

Table 12.–Creel survey estimates for summer and winter 2003–04 from North Manistique Lake. Survey periods were May 15 through October 15, 2003 and December 27, 2003 through March 28, 2004. Two standard errors are given in parentheses.

		Month									
Species	Catch per hour	May	June	July	August	September	October	December–January	February	March	Season
		Number harvested									
Walleye	0.032 (0.029)	7 (14)	87 (80)	181 (288)	0 (0)	42 (41)	0 (0)	17 (33)	0 (0)	0 (0)	335 (304)
Yellow perch	0.684 (0.242)	12 (24)	609 (379)	1,669 (1,327)	2,229 (1,084)	836 (590)	0 (0)	1,120 (852)	436 (417)	354 (707)	7,265 (2,198)
Rock bass	<0.001 (0.001)	0 (0)	0 (0)	0 (0)	0 (0)	3 (7)	0 (0)	0 (0)	0 (0)	0 (0)	3 (7)
Total harvest	0.716 (0.247)	19 (27)	697 (387)	1,850 (1,358)	2,229 (1,084)	882 (592)	0 (0)	1,137 (852)	436 (417)	354 (707)	7,603 (2,219)
		Number released									
Smallmouth bass	0.008 (0.008)	0 (0)	12 (24)	12 (24)	45 (71)	17 (34)	0 (0)	0 (0)	0 (0)	0 (0)	87 (86)
Rock bass	0.058 (0.057)	0 (0)	346 (365)	267 (474)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	612 (598)
Yellow perch	2.417 (0.870)	26 (41)	2,361 (1,604)	6,272 (3,958)	11,589 (5,512)	3,092 (2,356)	1,736 (2,889)	541 (607)	32 (65)	0 (0)	25,649 (7,931)
Total released	2.482 (0.878)	26 (41)	2,719 (1,645)	6,550 (3,986)	11,634 (5,513)	3,109 (2,356)	1,736 (2,889)	541 (607)	32 (65)	0 (0)	26,348 (7,954)
Total catch	3.199 (0.976)	45 (49)	3,415 (1,690)	8,400 (4,211)	13,863 (5,618)	3,991 (2,430)	1,736 (2,889)	1,678 (1,047)	469 (422)	354 (707)	33,951 (8,258)
		Fishing effort									
Angler hours		798 (535)	2,102 (799)	2,987 (1,272)	2,355 (833)	940 (455)	334 (356)	642 (360)	416 (344)	42 (83)	10,614 (1,956)
Angler trips		282 (218)	935 (694)	1,584 (1,142)	1,266 (1,253)	399 (213)	191 (261)	218 (169)	105 (102)	18 (39)	4,997 (1,886)

Table 13.–Voluntary angler tag returns from walleyes and northern pike (reward and nonreward tags, harvested and released fish combined) by month for the year following tagging in North Manistique Lake. Percentage of total is in parentheses.

Month	Species			
	Walleye		Northern pike	
4	0	(0)	0	(0)
5	1	(3.4)	0	(0)
6	16	(55.2)	0	(0)
7	7	(24.1)	1	(50)
8	0	(0)	0	(0)
9	4	(13.8)	0	(0)
10	0	(0)	1	(50)
11	0	(0)	0	(0)
12	0	(0)	0	(0)
1	1	(3.4)	0	(0)
2	0	(0)	0	(0)
3	0	(0)	0	(0)
Total	29		2	

Table 14.–Mean lengths of walleyes from the 2003 survey of North Manistique Lake, compared to other surveys. Number aged is shown in parentheses.

		Lake / Sample year							
Age	State average[a]	North Manistique 2003[b]	North Manistique 2000[c]	Big Manistique 2003[b]	South Manistique 2003[b]	Michigamme Reservoir 2001[b]	Gogebic 1999[b]	Bond Falls 1999[c]	Lake Michigamme 2002[c]
2	10.4	9.0 (1)		12.6 (36)	11.4 (2)	8.3 (9)		8.5 (1)	8.3 (2)
3	13.9	16.6 (3)		15.3 (40)	13.5 (21)	12.5 (76)	11.4 (1)		10.4 (4)
4	15.8	18.9 (31)	19.5 (3)	18.2 (25)	15.9 (51)	14.0 (90)	13.0 (1)	14.5 (3)	11.9 (1)
5	17.6	18.9 (1)	19.1 (6)	19.2 (11)	17.1 (33)	14.8 (41)	13.8 (34)	15.7 (11)	12.7 (5)
6	19.2	20.4 (8)	18.6 (5)	19.7 (6)	19.7 (10)	15.5 (91)	16.4 (2)		15.1 (2)
7	20.6	19.3 (5)	20.4 (4)	20.1 (26)	19.4 (8)	16.2 (64)	16.7 (1)	18.7 (1)	14.5 (1)
8	21.6	21.4 (33)		19.8 (14)	19.8 (17)	16.8 (20)	17.1 (10)		16.7 (1)
9	22.4	21.7 (14)	17.9 (2)	20.9 (18)	19.9 (17)	18.7 (15)	17.0 (3)	22.0 (1)	
10	23.1	22.5 (6)		21.5 (6)	18.8 (2)	19.4 (15)	17.8 (7)		21.4 (1)
11		22.6 (3)	24.7 (1)	21.5 (12)	21.0 (19)	20.3 (12)	17.3 (2)		
12		24.0 (1)	24.9 (1)	22.3 (10)	22.1 (16)	18.7 (19)			18.4 (1)
13		25.1 (2)	25.2 (1)	23.2 (8)	23.6 (8)	19.9 (9)	20.1 (3)		
14		24.2 (1)		22.8 (7)	22.6 (4)	19.3 (11)			
15				26.0 (2)	26.0 (5)	20.2 (3)			
16				25.2 (1)		19.5 (3)			22.3 (1)
17						20.5 (1)			
Mean growth index[d]		+0.2	+0.5	+0.4	-0.8	-3.2	-3.3	-2.3	-5.3

[a] Jan–May averages from Schneider et al. (2000b), aged using scales.
[b] Fish collected in the spring and aged using spines.
[c] Fish collected in June and aged using spines.
[d] The mean deviation from the statewide quarterly average. Only age groups where N ≥ 5 were used.

Table 15.–Mean lengths of northern pike from the 2003 survey of North Manistique Lake compared to other surveys. Number aged is shown in parentheses.

		Lake / Sample year						
Age	State average[a]	North Manistique 2003[b]	Big Manistique 2003[b]	Big Manistique 1997[c]	South Manistique 2003[b]	Michigamme Reservoir 2001[b]	Bond Falls 1999[c]	Lake Michigamme 2002[c]
2	17.7	22.1 (1)	19.6 (61)	14.9 (3)	16.7 (41)	16.0 (94)	17.5 (5)	17.1 (8)
3	20.8		24.1 (27)	21.3 (3)	20.2 (46)	18.8 (118)	19.6 (7)	19.4 (17)
4	23.4		26.1 (12)	22.4 (11)	23.6 (26)	20.6 (64)	21.5 (9)	23.6 (6)
5	25.5	26.6 (2)	27.8 (28)	23.5 (14)	22.5 (5)	21.3 (51)	23.7 (4)	22.8 (5)
6	27.3	31.5 (6)	30.1 (13)	25.6 (4)	23.9 (6)	25.3 (35)	31.7 (1)	28.5 (10)
7	29.3	31.8 (4)	32.7 (6)	27.9 (3)	24.8 (4)	25.6 (21)		34.8 (8)
8	31.2	28.9 (2)	38.6 (7)	29.9 (1)		27.5 (3)		31.5 (1)
9			41.4 (5)		28.6 (1)	36.3 (4)		32.1 (1)
10		40.0 (1)	49.4 (1)		29.1 (1)			
11			44.3 (1)			34.0 (1)		
12			38.4 (2)					
Mean growth index[d]		+4.2	+3.4	-2.6	-1.6	-2.7	-2.1	-0.5

[a] Jan–May averages from Schneider et al. (2000b), aged using scales.
[b] Fish collected in the spring and aged using spines.
[c] Fish collected in the summer and aged using spines.
[d] The mean deviation from the statewide quarterly average. Only age groups where N ≥ 5 were used.

Table 16.–Comparison of recreational fishing effort and total harvest on North Manistique Lake to those of other selected Michigan lakes. Lakes are listed from highest to lowest total fishing effort. Lake size was from Laarman (1976).

Lake, County	Size (acres)	Survey period	Total fishing effort (hours)	Fish harvested (number)	Fish harvested per hour	Hours fished per acre	Fish harvested per acre
Houghton Roscommon	20,075	Apr 2001– Mar 2002	499,048	386,287	0.77	24.9	19.2
Erie[a] Wayne/Monroe	–	Apr– Oct, 2001	490,807	378,700	0.77	–	–
Superior[a] multiple	–	Apr– Oct, 2001	180,428	60,947	0.34	–	–
Cisco Chain Gogebic/Vilas	3,987	May 2002– Feb 2003	180,262	120,412	0.67	45.2	30.2
Muskegon Lake Muskegon	4,232	Apr 2002– Mar 2003	180,064	184,161	1.02	42.5	43.5
Fletcher Pond Alpena/Montmorency	8,970	May– Sep, 1997	171,521	118,101	0.69	19.1	13.2
Burt Cheboygan	17,120	Apr 2001- Mar 2002	134,205	68,473	0.51	7.8	4.0
South Manistique Mackinac	4,133	May 2003– Mar 2004	142,686	43,654	0.31	34.5	10.6
Gogebic Ontonagon/Gogebic	13,380	May 1998– Apr 1999	121,525	26,622	0.22	9.1	2.0
Lake Leelanau Leelanau	8,607	Apr 2002- Mar 2003	112,112	15,464	0.14	13.0	1.8
Big Manistique Luce/Mackinac	10,346	May 2003– Mar 2004	88,373	71,652	0.81	8.5	6.9
Mullett Cheboygan	16,630	May– Aug, 1998	87,520	18,727	0.21	5.3	1.1
Crooked and Pickerel Emmet	3,434	Apr 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
North Manistique[b] Luce	1,709	May 2003– Mar 2004	10,614	7,603	0.72	6.2	4.4

[a] Does not include charter boat harvest or effort.
[b] Current study.

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Appendix

Appendix–Fish species captured in North Manistique Lake from 1936 through 2003 using various gear types.

Common name	Scientific name
Species we collected in 2003 with fyke nets and trap nets	
Bluegill	*Lepomis macrochirus*
Northern pike	*Esox lucius*
Redhorse (nonspecific)	*Moxostoma spp.*
Rock bass	*Ambloplites rupestris*
Smallmouth bass	*Micropterus dolomieu*
Spottail shiner	*Notropis hudsonius*
Walleye	*Sander vitreus*
White sucker	*Catostomus commersonii*
Yellow perch	*Perca flavescens*
Additional species collected with electrofishing gear (1990-2000)	
Brook trout	*Salvelinus fontinalis*
Bluntnose minnow	*Pimephales notatus*
Lake herring	*Coregonus artedi*
Lake trout	*Salvelinus namaycush*
Largemouth bass	*Micropterus salmoides*
Logperch	*Percina caprodes*
Pumpkinseed	*Lepomis gibbosus*
Additional species collected with fyke nets (1981)	
Brown trout	*Salmo trutta*
Additional species collected with fyke nets (1964)	
Brown bullhead	*Ameiurus nebulosus*
Additional species collected with seines (1936-1960)	
Sand shiner	*Notropis stramineus*
Johnny darter	*Etheostoma nigrum*
Iowa darter	*Etheostoma exile*
Mimic shiner	*Notropis volucellus*
Mottled sculpin	*Cottus bairdi*