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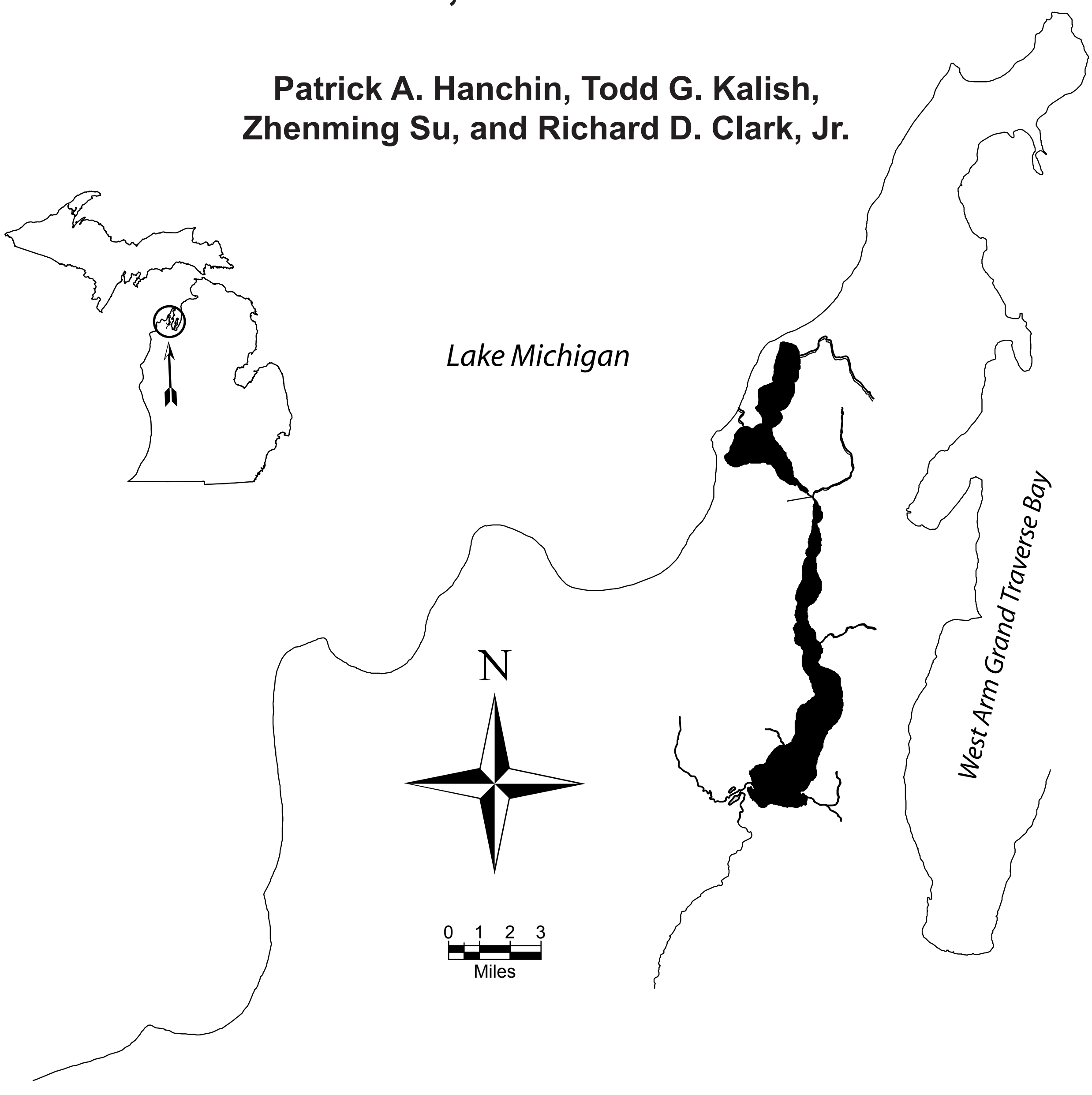
The Fish Community and Fishery of Lake Leelanau, Leelanau County, Michigan with Emphasis on Walleyes, Northern Pike, and Smallmouth Bass

Patrick A. Hanchin, Todd G. Kalish, Zhenming Su, and Richard D. Clark, Jr.



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Michigan Department of Natural Resources
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The Fish Community and Fishery of Lake Leelanau, Leelanau County, Michigan with Emphasis on Walleyes, Northern Pike and Smallmouth Bass

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Introduction

The Michigan Department of Natural Resources (MDNR), Fisheries Division surveyed fish populations and angler catch and effort on Lake Leelanau, Leelanau County, Michigan from April 2002 through March 2003. This work was part of a statewide program designed to improve assessment and monitoring of fish communities and fisheries in Michigan's largest inland lakes. Known as the Large Lakes Program, it is currently scheduled to survey about four lakes per year over the next ten years (Clark et al. 2004).

The Large Lakes Program has three primary objectives. First, we want to produce consistent indices of abundance and estimates of annual harvest and fishing effort for important fishes. Initially, important fishes are defined as species susceptible to trap or fyke nets and/or those readily harvested by anglers. Our hope is to produce statistics for important fishes to help detect major changes in their populations over time. Second, we want to produce abundance estimates and sufficient growth and mortality statistics to be able to evaluate effects of fishing on special-interest species which support valuable fisheries. This usually involves targeting special-interest species with nets or other gears to collect, sample, and mark sufficient numbers. We selected walleyes *Sander vitreus*, northern pike *Esox lucius*, and smallmouth bass *Micropterus dolomieu* as special-interest species in this survey of Lake Leelanau. Finally, we want to evaluate the suitability of various statistical estimators for use in large lakes. For example, we applied and compared three types of abundance and three types of exploitation rate estimators.

The Large Lakes Program will maintain consistent sampling methods over lakes and time. This will allow us to build a body of fish population and harvest statistics for direct evaluation of differences between lakes or changes within a lake over time. Lake Leelanau was the seventh lake sampled under the protocols of the program; thus, we were sometimes limited in our ability to make valid comparisons. Of course, as our program progresses we will eventually have a large body of netting data collected under the same conditions in the future.

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

Study Area

The Lake Leelanau watershed encompasses 140 square miles (Northwest Michigan Council of Governments 1996). According to the Michigan Digital Water Atlas (Breck 2004), Lake Leelanau is 8,607 surface acres with a maximum depth of 120 ft. Lake Leelanau has several major feeder tributaries, including the Cedar River, Cedar Run, and Houdek Creeks. The Carp River drains Lake Leelanau into Lake Michigan in the town of Leland, Michigan (Figure 1). The Leland Dam raises the natural water level seven feet and prevents migration of Lake Michigan aquatic species into Lake Leelanau. The elevation of Lake Leelanau is maintained at 589.21 feet from April 15–November 15, and lowered 12 inches from November 15–April 15. These elevations were established by a Leelanau County Circuit Court Order in 1978. Lake Leelanau has two basins (north and south) connected by a navigable channel called the "Narrows." These two basins are often considered separate lakes, North Lake Leelanau and South Lake Leelanau (Figure 1). In this report, we will refer to North Lake Leelanau and South Lake Leelanau as the north and south basins. Water chemistry is similar in the two basins (Laarman 1976), but there are some physical differences. The north basin is smaller at 2,914 acres and deeper with a maximum depth of 120 ft (Breck 2004). About 58% of its surface has depths greater than 20 feet (Figure 2) and 90% of its volume is in depths greater than 20 ft (Figure 3). The south basin is larger at 5,693 acres and shallower with a maximum depth of 62 feet. About 53% of its surface has depths greater than 20 feet (Figure 4) and 82% of its water volume is in depths greater than 20 ft (Figure 5).

Michigan Department of Environmental Quality (MDEQ) characterizes Lake Leelanau as oligotrophic based on low nutrient concentrations and water clarity. A thermocline typically develops at 30–40 ft. deep (Laarman 1976).

The topography of the Lake Leelanau watershed is gently sloping with soils that range from mucky to well-drained (Northwest Michigan Council of Governments 1996). Surrounding land use of the south basin was estimated at 60% undeveloped, 25% agriculture, and 15% urban in 1993. Shoreline composition was estimated at 80% upland and 20% wetland. Shoal soils were composed of 80% sand, 10% gravel, and 10% muck. The upland areas consisted of hemlock, red pine, maple, aspen, and orchard trees. Five-hundred and sixty-three houses, seven resorts, and two boat liveries were also tabulated along the shoreline of the south basin in 1996 (Northwest Michigan Council of Governments 1996).

Lake Leelanau has several public access sites with boat launches, including sites at the Narrows, two on the east shore on County Road 641, and three on the west shore on county roads 643, 204, and 22. There are also several public campgrounds and two marinas near or on Lake Leelanau.

The current fish community of Lake Leelanau is typical of oligotrophic lakes in the region. Coolwater fishes present include longnose gar, northern pike, minnows, suckers, sunfishes, yellow perch, and walleyes. However, it does not appear that walleyes were very abundant prior to the 1980s based on survey, harvest, and stocking records presented by Laarman (1976). It is likely that walleyes were native to the lake because it was connected to Lake Michigan prior to construction of Leland dam. Management efforts prior to the 1970s centered around coldwater species, primarily lake trout, rainbow trout, and brown trout (Laarman 1976). Coldwater fishes present include lake whitefish, lake herring, brown trout, rainbow trout, and lake trout. The lake was stocked with walleyes, bluegill, rainbow trout, lake trout, brown trout, splake, and lake whitefish between 1948 and 2005 (Table 1). In addition, smallmouth bass, largemouth bass, yellow perch, and warmouth were stocked prior to 1948 (Laarman (1976). Lake trout are the only species presently stocked in Lake Leelanau on a regular basis. Stocking of brown trout and walleyes was discontinued in 2000 and 2001 (Table 1). Brown trout were exhibiting poor survival and return to creel and walleyes were exhibiting sufficient natural reproduction. There have been 72 State of Michigan Master Angler awards taken from Lake Leelanau from 1994–2006, including 48 rock bass, nine smallmouth bass, six bluegill, three bowfin, two white suckers, one northern pike, one largemouth bass, one longnose gar, and one rainbow trout.

Methods

We used the same methods for Lake Leelanau as described by Clark et al. (2004) for Houghton Lake. We will give an overview of methods in this report, but will refer the reader to Clark et al. (2004) for details.

Briefly, we used nets and electrofishing gear to collect fish in April to coincide with spawning of primary targets – walleyes, northern pike, and smallmouth bass. We identified all fish to species and enumerated them. Fishing effort was recorded by individual net, but effort was not recorded for electrofishing. Electrofishing was used to increase the sample size of target species. Standard total lengths were measured for subsamples of each non-target species. All target species were measured and legal-sized fish were tagged with individually numbered jaw tags. Tagged fish were also fin clipped to evaluate tag loss. Angler catch and harvest surveys were conducted the year after tagging; one covered the summer fishery from April 27 through September 30, 2002 and one covered the winter fishery from January 1 through March 31, 2003. Tags on target species observed during angler surveys were tallied and the ratios of marked to unmarked fish were used to calculate abundance estimates. In addition, voluntary tag recoveries were requested. All tags contained a unique number and a mailing address for an MDNR field station. To encourage voluntary tag returns, about 50% of tags were identified as reward tags, and we paid $10 rewards to anglers returning them.

Our intention in this report was to present Lake Leelanau as a single system with north and south basins combined. Thus, we computed fish community and population statistics from pooled data from north and south basins. However, we presented some fishery statistics for each individual basin when it made biological sense and sample sizes were sufficient. In addition, for some fish population parameters we tested for statistical differences between basins.

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. We also collected more detailed data for walleyes, northern pike, and smallmouth bass as described below. We sampled fish populations in Lake Leelanau with trap nets, fyke nets, and electrofishing gear from April 8 to April 26, 2002. We used three boats daily to work nets, each with three-person crews, for 2 weeks. Each net-boat crew tended 10–15 nets, and electrofishing was used some nights to collect target species.

Fyke nets were 6 ft x 4 ft with 2-in stretch mesh and 90- to 98-ft leads. Trap nets were 8 ft by 6 ft by 3 ft with 2-in stretch mesh and 90- to 98-ft leads. Duration of net sets ranged from 1–14 nights, but most were 1–2 nights. We used a Smith-Root® boat equipped with boom-mounted electrodes (DC) for electrofishing. Latitude and longitude were recorded for all net locations and electrofishing runs using GPS.

We identified species and counted all fish captured. Total lengths of all walleyes, northern pike, and smallmouth bass were measured to the nearest 0.1 in. For other fish, we measured lengths to the nearest 0.1 in for sub-samples of up to 200 fish per work crew. Crews ensured that lengths were taken over the course of the survey to account for any temporal trends in the size structure of fish collected. Size structures were characterized as length frequencies indicating numbers collected per inch group (e.g., numbers of 10.0–10.9 in, 11.0–11.9 in, 12.0–12.9 in, etc.).

We used Microsoft Access to store and retrieve data collected during the tagging operation. Size-structure data only included fish on their initial capture occasion. We recorded mean catch per unit effort (CPUE) in trap nets and fyke nets indicators of relative abundance, utilizing 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).

Walleyes, Northern Pike, and Smallmouth Bass

Size structure.–We developed the size structures of walleyes, northern pike, and smallmouth bass as described above for Lake Leelanau as a whole and for north and south basins individually. We also computed the percent collected that were legal size. We assessed differences in length frequency data for the north and south basins by comparing the distribution of lengths between basins using the Kolmogorov-Smirnov asymptotic two-sample test. Additionally, differences in mean lengths were assessed using a two-sample t-test. Statistical significance was set at $\alpha = 0.05$.

Sex composition.–We recorded sex of walleyes and northern pike. Fish 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.

Abundance.–We estimated abundance of legal-sized walleyes, northern pike, and smallmouth bass using mark-and-recapture methods. Walleyes (≥15 in), northern pike (≥24 in), and smallmouth bass (≥14 in) were fitted with monel-metal jaw tags. In order to assess tag loss, we double-marked each tagged fish by clipping the left pelvic fin. We attempted to maintain approximately a 1:1 ratio of $10-reward : non-reward tags on fish tagged, but did not attempt to make the ratio exact. 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 we tagged. Large tags (size 16) that were used on large northern pike (≥36 in) were all non-reward.

Initial tag loss was assessed during the marking period as the proportion of recaptured fish of legal size without tags. This tag loss was largely caused by entanglement with nets, and thus was not used to adjust estimates of abundance or exploitation. Newman and Hoff (1998) reported similar concern for netting-induced tag loss. All fish that lost tags during netting recapture were re-tagged, and so were accounted for in the total number of marked fish at large.

We compared two different abundance estimates from mark-and-recapture data, one derived from marked-unmarked ratios during the spring survey (multiple census) and the other derived from marked-unmarked ratios from the angler survey (single census).

For the multiple-census estimate, we used the Schumacher-Eschmeyer formula from daily recaptures during the tagging operation (Ricker 1975). The minimum number of recaptures necessary for an unbiased estimate was set a priori at four. For the single-census estimate, we used numbers of marked and unmarked fish seen by creel clerks in the companion angler survey as the “recapture-run” sample. The Chapman modification of the Petersen method (Ricker 1975) was used to generate population estimates, and the minimum number of recaptures necessary for an unbiased estimate was set a priori at three (Ricker 1975). For more details on methods for abundance estimates, see Clark et al. (2004).

No prior abundance estimates existed for walleyes, northern pike, or smallmouth bass in Lake Leelanau to help us gauge how many fish to mark. For walleyes, we used a regression equation developed for Wisconsin lakes (Hansen 1989) to provide an a priori estimate of abundance. This regression predicts adult walleye abundance in lakes with stocking as the recruitment source based on lake size. Parameters for this equation are re-calculated every year by Wisconsin Department of

Natural Resources (WDNR). We used the same parameters used by WDNR in 2001 (D. Beard, WDNR, personal communication):

$$\ln(N) = 1.1982 + 0.8678 \times \ln(A),$$

where *N* is the estimated number of walleyes and *A* is the surface area of the lake in acres. This equation was derived from abundance estimates on 102 lakes in northern Wisconsin. The equation gives an estimate of 8,614 walleyes, with a 95% confidence interval of 1,864 to 39,801 for Lake Leelanau. The 'confidence interval' here is, more precisely, a prediction interval with 95% confidence (Zar 1999).

We also used two regression equations developed for Michigan lakes to provide additional estimates of walleye 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. The following equation for adult walleyes was based on 35 abundance estimates:

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

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

where *N* is the estimated number of adult walleyes and *A* is the surface area of the lake in acres. For Lake Leelanau, the equation gives an estimate of 18,539 adult walleyes, with a 95% prediction interval (Zar 1999) of 4,296 to 80,014.

The equation for legal walleyes was based on 21 estimates:

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

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

where *N* is the estimated number of legal walleyes and *A* is the surface area of the lake in acres. For both regressions we calculate prediction intervals with 95% confidence (Zar 1999). The equation gives an estimate of 13,353 legal walleyes, with a 95% prediction interval (Zar 1999) of 2,755 to 64,729 for Lake Leelanau.

We determined our tagging goal by evaluating the effect of increasing the proportion tagged on the precision of the estimate (Clark et al. 2004). Based on this analysis, it was our judgment that marking 10% of the population achieved a good compromise between marking effort and precision, assuming the fraction marked was a function of marking effort. Thus, we set our tagging goal at 10% of the population or approximately 1,000 adult walleyes. Because those estimates were made for adult walleyes, the goal was optimistic for walleyes of legal size. We set no specific tagging goal for northern pike or smallmouth bass. We simply tagged as many as possible until the walleye goal was achieved.

It is important to recognize the difference between walleye abundance estimates from the Wisconsin regression equation and walleye abundance estimates we made. The Wisconsin equation predicts abundance of adult walleyes on the spawning grounds, while our primary, single-census estimate was for walleyes 15 in and larger. WDNR defined adult walleyes as legal sized, or sub-legal sized of identifiable sex, many of which would be smaller than 15 in. Because we clipped fins and recorded recaptures of all walleyes, we were also able to make a direct multiple-census estimate of adult walleyes for comparison using the Schumacher-Eschmeyer formula and including the sub-legal and mature fish that were marked and recaptured.

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

Similar to walleyes, we defined adult northern pike as those ≥ 24 in or <24 in, but of identifiable sex. We estimated adult northern pike using the multiple-census and adjusted single-census methods as was done for walleyes. For smallmouth bass, we could not identify the sex or sexual maturity of enough fish to make separate estimates for adult fish.

We accounted for fish that recruited to legal size over the course of the angler survey by removing a portion of the unmarked fish observed by the creel clerk. The number of unmarked fish removed was based on a weighted average monthly growth for fish of slightly sub-legal size (i.e., 14.0–14.9-in walleyes). For a detailed explanation of our methods to adjust for in-season recruitment, see Clark et al. (2004) and Ricker (1975). This adjusted ratio was used to make the primary (single census) population estimate. We calculated the coefficient of variation (CV) for each abundance estimate and considered anything 0.40 or less indicative of a reliable estimate (Hansen et al. 2000).

Mean lengths at age.–We used dorsal spines to age walleyes and smallmouth bass, 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. Clark et al. (2004) described advantages and disadvantages of various body structures for aging walleyes and northern pike.

Sample sizes for age analysis were based on historical length at age data from Lake Leelanau and methods given in Lockwood and Hayes (2000). We attempted to collect 15 male and 15 female fish per inch group, from each lake, and for each species.

Samples were sectioned using a table-mounted Dremel® rotary cutting tool. Sections approximately 0.5-mm thick were cut as close to the proximal end of the spine or ray as possible. Sections were examined at 40x–80x with transmitted light and were photographed with a digital camera. The digital image was archived for multiple reads. Two technicians independently aged samples. Ages were considered correct when results of both technicians agreed. Samples in dispute were aged by a third technician. Disputed ages were considered correct when the third technician agreed with one of the first two. Samples were discarded if three technicians disagreed on age, though occasionally an average age was used when those assigned to older fish (≥ age 10) were within 10% of each other.

After a final age was identified for all samples, we calculated weighted mean lengths at age and age-length keys for all fish (males, females, and fish of unknown sex) for walleyes, northern pike, and smallmouth bass (Devries and Frie 1996) for Lake Leelanau as a whole, and for north and south basins individually. We then tested for differences in mean lengths at age between north and south basins using a two-way analysis of variance, controlling for age as a covariate. Statistical significance was set at $\alpha = 0.05$. We then proceeded to compute weighted mean lengths at age for male and female walleyes and northern pike. For smallmouth bass a significant proportion of our samples were of unknown sex so we did not make separate computations by sex.

We compared our mean lengths at age to those from previous surveys of Lake Leelanau and to other large lakes. Also, we computed a mean growth index to compare our data to Michigan state averages as described by Schneider et al. (2000). The mean growth index is the average of deviations between the observed mean lengths and statewide seasonal average lengths.

Mortality.–As was done for mean lengths at age, we calculated catch at age for all fish (males, females, and unknown sex) for Lake Leelanau as a whole and for north and south basins individually. We assessed differences in the catch-curve regressions between the north and south basins using an analysis of covariance, with statistical significance set at $\alpha = 0.05$.

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

We estimated angler exploitation rates using three methods: 1) the percent of reward tags returned by anglers; 2) the estimated harvest divided by the multiple-census estimate of abundance; and 3) the estimated harvest divided by the single-census estimate of abundance. We compared these three estimates of exploitation and converted them to instantaneous fishing mortality rates.

In the first method, exploitation rate was estimated as the fraction of reward tags returned by anglers adjusted for tag loss. We did not assess tagging mortality or incomplete reporting of reward tags. We made the assumption that mortality was negligible and that near 100% of reward tags on fish caught by anglers would be returned. Although we did not truly assess non-reporting, we did compare the actual number of tag returns to the number we expected (*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, and H = Total expanded harvest of species.

Additionally, we checked individual tags observed by the creel clerk to see if they were subsequently reported by the anglers. This last step is also not a true estimate of non-reporting 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.

Voluntary tag returns were encouraged with a monetary reward ($10) denoted on approximately ½ 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. Return rates were calculated separately for reward and non-reward tags.

In the second method, we calculated exploitation as the estimated annual harvest from the angler survey divided by the various 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 (Clark et al. 2004).

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

We obtained population data only one year, so we could not rigorously evaluate year-class strength as did the investigators cited in the previous paragraph. However, we suggest that valuable 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.

As Maceina (2003), we assumed residuals of our catch-curve regressions were indices of year-class strength. We related year-class strength to various environmental variables by using correlation, simple linear, and multiple regression analyses. Historic weather data were obtained from the National Weather Service observation station in Maple City, Michigan. We did not have any historic water-quality data specific to the lake itself. 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.

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

Angler Survey

Fishing harvest seasons for walleyes and northern pike during this survey were April 27, 2001–March 15, 2002. Minimum size limits were 15 in for walleyes and 24 in for northern pike. Daily bag limit was five fish of any combination of walleyes, northern pike, smallmouth bass, or largemouth bass.

Fishing harvest seasons for smallmouth bass and largemouth bass were May 25, 2002 through Dec 31, 2002. Minimum size limit was 14 in for both smallmouth bass and largemouth bass.

Harvest was permitted all year for all other species present. In North Lake Leelanau, the minimum size limit for brook trout, brown trout, rainbow trout, lake trout, and splake was 15 in, with a daily possession limit of three. In South Lake Leelanau, the minimum size limit for the aforementioned species was 8 in, with a daily possession limit of five, no more than three of which could be 15 in or greater. No minimum size limits were imposed for other species. Possession limit for lake whitefish was 12. Possession limit for yellow perch was 50 per day. Possession limit for sunfishes including black crappie, bluegill, pumpkinseed, and rock bass was 25 per day in any combination.

Direct contact angler creel surveys were conducted during one spring-summer period – April 27 to September 30, 2002, and one winter period – January 1, 2003 through March 31, 2003. For sampling purposes, Lake Leelanau was split into two sections, representing the north and south basins (Figure 1). All count and interview data were collected and recorded by section. Similarly, effort and catch estimates were made by section and summed for lake-wide estimates. Scanner-ready interview and count forms were used.

Both summer and winter surveys were designed to collect roving interviews. Minimum fishing time prior to interview (incomplete-trip interview) was 1 h (Lockwood 2004). When anglers reported fishing in more than one section, the clerk recorded the section number where they spent most of that trip fishing. Global positioning system (GPS) coordinates were used to determine grid boundaries and associated waypoints (Figure 6 and Table 2). All roving interview data were collected by individual angler to avoid party size bias (Lockwood 1997).

While both summer and winter surveys were designed to collect roving interviews, 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 from a completed trip. Similar to roving interviews, all access interview data were collected by individual angler.

Count information collected included date, grid, fishing mode (fishing boat, open ice, or occupied shanty), count time, and number of fishing boats counted. Interview information collected included date, section, fishing mode (fishing boat open ice, or shanty), start time of fishing trip, interview time, species targeted, bait used, number of fish harvested by species, number of fish caught and released by species, length of harvested walleyes and northern pike, and applicable tag number. Catch and release of smallmouth bass, largemouth bass, walleyes, northern pike, and muskellunge were recorded. Number of anglers in each party was recorded on one interview form for each party.

Summer.–We used an aerial-roving design for the summer survey (Lockwood 2000a). Fishing boats were counted by aircraft and one clerk working from a boat collected angler interview data. Survey period was from April 27 through October 31, 2002. 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 this period were Memorial Day (May 27, 2002), Fourth of July, and Labor Day (September 2, 2002). 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.

One of two shifts was selected each sample day for interviewing (Table 3). Interview starting location and order were randomized daily. On days when the clerk interviewed in all sections prior to completion to the shift, they continued interviewing at the beginning of the specified order and proceeded to the appropriate scheduled sections. In this situation, interview forms were updated for any anglers encountered for a second time (i.e., anglers that had been interviewed earlier during the day). If the clerk knew that a party had been interviewed earlier that day but could not identify their interview form, the party was not re-interviewed. That is, no angling party had a second set of interview forms filled out for them on the same day.

Aerial counts progressed from marker 1 to marker 9 or from marker 9 to marker 1 (Figure 6; Table 2). This sequence was randomized. The pilot flew one of the two randomly selected predetermined routes using GPS coordinates. Each flight was made at 500–700 ft elevation and took approximately 12 min to complete with air speed of about 100 mph. Counting was done by the contracted pilot and only fishing boats were counted (i.e., watercraft involved in alternate activities, such as water skiing, were not counted). Time of count was randomized to cover daylight times within the sample period.

Winter.–We used a progressive-roving design for winter surveys (Lockwood 2000a). One clerk working from a snowmobile collected count and interview data. Survey period was from December 15, 2002 through March 31, 2003. No interview or count data were collected on holidays. Holidays during the period were New Years Eve (December 31, 2002), New Years Day (January 1, 2003), Martin Luther King Day (January 13, 2003), and President's Day (February 17, 2003). Both weekend days and three randomly selected weekdays were selected for sampling during each week of the survey season. The clerk followed a randomized count and interview schedule. One of two shifts was selected each sample day (Table 3). Starting location (waypoint) and direction of travel were randomized for both counting and interviewing (Figure 6; Table 2).

Progressive (instantaneous) counts of open-ice anglers and occupied shanties were made once per day. No anglers were interviewed while counting (Wade et al. 1991).

Estimation methods.–Catch and effort estimates were made by section using a multiple-day method (Lockwood et al. 1999). Expansion values ("F" in Lockwood et al. 1999) are given in Table 3. These values are the total number of hours in which fishing occurs within sample days. Effort is the product of mean counts by grid for a given period day type, days within the period, and the expansion value for that period. Thus, the angling effort and catch reported here are for those periods sampled, no expansions were made to include periods not sampled (e.g., 0100 to 0400 hours).

Lake-wide estimates were the sum of section estimates for each given time period and day type. While both summer and winter surveys were designed to collect roving interviews, the clerk was instructed to also collect access interviews from any angling parties observed completing their trip. Similar to roving interviews, all anglers within a party were interviewed. When 80% or more of interviews (80:20 ratio) within a time period (weekday or weekend day within a multiple-day period) were of an interview type, the appropriate catch-rate estimator for that interview type was used on all interviews. When less than 80% 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 interviews and $\overline{R}$ is the mean-of-ratios estimator for n_2 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 $\overline{R}$. (See Lockwood et al. 1999 for appropriate catch rate and variance equations.)

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: Chapter 6). Angler trips differ from angler days because multiple trips can be made within a day. Historically, Michigan angler creel data average 1.2 trips per angler day (MDNR Fisheries Division – unpublished data).

All estimates are given with 2 SE. Error bounds (2 SE), provided statistical significance, assuming normal distribution shape and $N \geq 10$, of 75% to 95% (Dixon and Massey 1957). All count samples exceeded minimum sample size (10) 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 from normality of catch rates.

As a routine part of interviewing, the creel clerk recorded presence or absence of jaw tags and fin clips, tag numbers, and lengths of walleyes and northern pike. These data were used to estimate tag loss and to determine the ratio of marked-unmarked fish for Petersen population estimates.

Results

We provide confidence limits for all estimates in relevant tables but not in the text.

Fish Community

We collected 20 species of fish in Lake Leelanau (Table 4), 17 in the north basin (Table 5) and 18 in the south basin (Table 6). Total sampling effort was 197 trap-net lifts (48 in north basin and 149 in south basin), 88 fyke-net lifts (76 in north basin and 12 in south basin), and eight electrofishing runs

(3 on north basin and 5 on south basin). We captured 3,680 walleyes (161 in north basin and 3,519 in south basin), 992 northern pike (86 in north basin and 906 in south basin), and 318 smallmouth bass (25 in north basin and 293 in south basin). Other species that we collected are listed in order of abundance in tables 4, 5, and 6.

White suckers were the most abundant fish in our catch in Lake Leelanau. They comprised 37.8% of the catch by number in the lake as a whole, and were especially abundant in the north basin where they comprised 81.6% of the catch by number. Walleyes were the next most abundant fish. They comprised 32.3% of the catch by number in the lake as a whole and were most abundant in the south basin, where they comprised 44.1% of the total catch. Northern pike and smallmouth bass were 8.7% and 2.8% of the catch by number in the lake as a whole, respectively. We collected one exceptionally large lake herring worthy of note. It was 16.6 inches, but the mean length of all lake herring collected was 9.9 inches.

Of the species we collected, we classified walleyes, northern pike, smallmouth bass, largemouth bass, bowfin, burbot, longnose gar, and brown trout as piscivores; rock bass, bluegill, pumpkinseed, yellow perch, rainbow smelt, brook trout, and lake herring as pelagic planktivores-insectivores; and suckers, bullheads, and central mudminnows as benthivores. This classification gave an overall fish community composition in Lake Leelanau of 48% piscivores, 13% pelagic planktivores-insectivores, and 38% benthivores (Table 4). The overall fish community composition in the north basin was 9% piscivores, 9% pelagic planktivores-insectivores, and 82% benthivores (Table 5). The overall fish community composition in the south basin was 65% piscivores, 15% pelagic planktivores-insectivores, and 20% benthivores (Table 6).

Walleyes, Northern Pike, Smallmouth Bass

Size structure.–We computed size structure of walleyes, northern pike, and smallmouth bass for Lake Leelanau as a whole and for north and south basins individually. Size structures of target species are presented in tables 7, 8, and 9. The percentage of walleyes in Lake Leelanau that were legal size was 69: 70% in the north basin and 69% in the south basin.

Mean lengths of walleyes in net samples did not differ between the north and south basins (t = 0.206, P = 0.837); the mean difference was only 0.08 in. However, walleye length frequency distributions differed significantly (Kolmogorov-Smirnov asymptotic test statistic = 2.496; P = 0.0001) between the north and south basins, and the shape of the distributions differed (Kolmogorov-Smirnov asymptotic test statistic = 2.496; P = 0.0001) when the distributions were centered for length. There were more mid-sized walleyes in the south basin where the population was dominated by 14- to 18-in walleyes, with proportionally few walleyes over 24 in.

The percentage of northern pike in Lake Leelanau that were legal size was 13: 21% in the north basin and 12% in the south basin. Most northern pike were from 17 to 23 in and few fish were of legal size. Mean lengths of northern pike in net samples did not differ between the north and south basins (t = 1.137, P = 0.258); the mean difference was only 0.6 in. However, length frequency distributions differed significantly (Kolmogorov-Smirnov asymptotic test statistic = 1.744; P = 0.005), though the shape of the distributions did not differ (Kolmogorov-Smirnov asymptotic test statistic = 1.151; P = 0.141) when the distributions were centered for length.

The percentage of smallmouth bass in Lake Leelanau that were legal size was 81: 83% in the north basin and 81% in the south basin. Mean lengths of smallmouth bass in net samples did not differ significantly between the north and south basins (t = 1.070, P = 0.286); the mean difference was only 0.5 in. Additionally, length frequency distributions did not differ significantly (Kolmogorov-Smirnov asymptotic test statistic = 0.864; P = 0.445) between north and south basins, and the shape of the distributions did not differ (Kolmogorov-Smirnov asymptotic test statistic = 0.540; P = 0.933) when the distributions were centered for length.

Sex composition.–We computed sex composition of walleyes and northern pike for Lake Leelanau as a whole and for north and south basins individually. Male walleyes outnumbered females in our samples from Lake Leelanau. Of all walleyes captured, 81% were male, 14% were female, and 5% were unknown sex. In the north basin, 46% were male, 23% were female, and 31% were unknown sex. In the south basin, 83% were male, 13% were female, and 4% were unknown sex. This corresponds to a sex ratio (M:F) of 5.9:1.0 overall, 2.0:1.0 in the north basin and 6.2:1.0 in the south basin. Of legal-sized walleyes captured, 79% were male (55% in the north basin and 80% in the south basin), 18% were female (32% in the north basin and 17% in the south basin), and 3% were unknown sex (14% in the north basin and 3% in the south basin. These sex ratios are typical for walleyes (Carlander 1997).

Of all northern pike captured in Lake Leelanau, 31% were male (48% in the north basin and 29% in the south basin), 40% were female (30% in the north basin and 41% in the south basin), and 29% were unknown sex (22% in the north basin and 10% in the south basin). The corresponding sex ratio was 0.8:1.0 for the lake as a whole (1.6:1.0 in the north basin and 0.7:1.0 in the south basin). Of legal-sized northern pike captured, 5% were male (12% in the north basin and 4% in the south basin), 87% were female (88% in the north basin and 86% in the south basin), and 8% were unknown sex (0% in the north basin and 10% in the south basin).

Abundance.–We tagged 2,375 legal-sized walleyes (1,174 reward and 1,201 non-reward tags) and clipped fins of 1,091 sublegal walleyes. One recaptured walleye lost its tag during the spring netting/electrofishing survey, and six fish were found dead, so the effective number tagged was 2,368. We did not obtain the minimum number of recaptures to make separate multiple-census estimates for each basin. The estimated number of legal-sized and adult walleyes in Lake Leelanau was 22,351 and 42,679, respectively using the multiple-census method (Table 10). The coefficient of variation (CV = standard deviation/estimate) was 0.18 for the two multiple-census estimates, which means precision was reasonable.

We did not get sufficient recaptures of walleyes in the angler survey to compute direct, single-census estimates. The angler survey clerk observed 487 walleyes on Lake Leelanau, and only two were tagged. However, we did calculate indirect, single-census estimates from regression equations based on existing (N = 9) multiple- and single-census estimates from other populations. These regressions describe the average biases between multiple- and single-census estimates. We refer to these as “indirect” estimates because they were not calculated directly from mark-and-recapture data. We will further explain the logic for these indirect estimates in the **Discussion** section.

We estimated the indirect, single-census estimate of legal-sized walleyes (SC_L) as:

$$SC_L = 1475.956 + 1.5425 \times MC_L,$$

$$R^2 = 0.94, \qquad P = 0.0001,$$

where MC_L is the direct, multiple-census estimate of the number of legal-sized walleyes. For Lake Leelanau, the equation gives an estimate of 35,952 legal walleyes (Table 10), with a 95% prediction interval (Zar 1999) of 24,085 to 47,819.

We estimated indirect, single-census estimate of adult walleyes (SC_A) as:

$$SC_A = 2525.4407 + 1.2217 \times MC_A,$$

$$R^2 = 0.89, \qquad P = 0.0001,$$

where MC_A is the direct, multiple-census estimate of the number of adult walleyes. For Lake Leelanau, the equation gives an estimate of 54,665 adult walleyes (Table 10), with a 95% prediction interval (Zar 1999) of 33,761 to 75,569.

We tagged 117 northern pike (61 reward and 56 non-reward tags) in Lake Leelanau. One recaptured fish lost its tag during the spring netting/electrofishing survey, so the effective number tagged was 116. We also clipped fins of 786 sub-legal northern pike. We did not obtain the minimum number of recaptures to make separate multiple-census estimates for each basin. The estimated number of legal-sized and adult northern pike was 282 (CV = 0.16) and 6,349 (CV = 0.20) using the multiple-census method (Table 10).

We did not get any recaptures of northern pike in the angler survey, so we could not compute direct, single-census estimates. The creel clerk observed only seven northern pike, and none were tagged. We attempted to calculate regressions for northern pike to estimate indirect, single-census estimates, but our sample size of lakes with both types of estimates for northern pike was only six, and the estimates had large variances. Thus, the regressions for northern pike were not significant at $P \leq 0.05$.

We tagged 247 legal-sized smallmouth bass in Lake Leelanau (131 reward and 116 non-reward tags). One recaptured fish lost its tag during the spring netting/electrofishing survey, so the effective number tagged was 246. We also clipped fins of 58 sub-legal smallmouth bass in Lake Leelanau. We did not obtain the minimum number of recaptures to make separate multiple-census estimates for each basin. The estimated number of legal-sized smallmouth bass in Lake Leelanau was 2,543 (CV = 0.17) using the multiple-census method (Table 10).

We did not get any recaptures of smallmouth bass in the angler survey, so we could not compute direct, single-census estimates. The creel clerk observed 28 smallmouth bass, of which none were tagged, and we reduced the number of unmarked smallmouth bass in the single-census calculation by four fish to adjust for sub-legal fish that grew over the minimum size limit during the fishing season. There was no tag loss for smallmouth bass observed by the creel clerk. We did not have enough information for smallmouth bass to describe the relationship between multiple- and single-census abundance estimates, so we could not compute indirect, single-census estimates.

Mean lengths at age.–For walleyes, there was 57% agreement between the first two aging technicians. For fish that were aged by a third reader, agreement was with first reader 67% of the time and with second reader 33% of the time; thus, there appeared to be bias among readers. This bias was apparently due to identification of the first annulus. At least two readers agreed 92% of the time, and 5% of samples were discarded due to poor agreement. For the remaining 3% of samples we used an average age from the three readers.

Walleyes in Lake Leelanau ranged in age from two to thirteen (Table 11) and had a mean growth index of -2.6. Females generally had higher mean lengths at age than males.

The analysis of variance indicated a significant difference in walleye mean length at age between the north and south basins ($F = 28.426$, $P = 0.0001$). There was no significant basin-age interaction ($F = 2.399$, $P = 0.137$).

Walleyes collected in the north basin had longer mean lengths at age than those collected in the south basin (tables 12 and 13). We calculated mean growth indices for walleyes of -1.0 and -2.8 for the north and south basins, respectively.

Female walleyes had higher mean lengths at age than males in both the north and south basins when samples were sufficient for comparison (tables 12 and 13). This is typical for walleye populations in general (Colby et al. 1979; Carlander 1997; Kocovsky and Carline 2000).

Mean length at age data for male, female, and all walleyes were fit to a von Bertalanffy growth curve. In Lake Leelanau, male, female, and all walleyes had L_∞ values of 21.3, 26.7, and 21.6 in, respectively. In the north basin, male, female, and all walleyes had L_∞ values of 22.8, 29.5, and 24.6 in, respectively. In the south basin, male, female, and all walleyes had L_∞ values of 21.0, 25.6, and 21.2 in, respectively.

For northern pike, there was 67% agreement between the first two aging technicians. For fish that were aged by a third reader, agreement was with first reader 55% of the time and with second reader 45% of the time; thus, there appeared to be little bias among readers. At least two readers agreed 95% of the time, and 5% of samples were discarded due to poor agreement. We did not use an average age for any samples.

Female northern pike generally had higher mean lengths at age than males (Table 14). As with walleyes, this is typical for northern pike populations in general (Carlander 1969; Craig 1996). We obtained sufficient sample sizes for comparison through age 5, and females were three inches longer than males at age 5 (Table 14). Our analysis of variance indicated no significant difference in northern pike mean length at age between the north and south basins (F = 0.001, P = 0.976). Additionally, there was no significant basin-age interaction (F = 0.753, P = 0.435).

We calculated a mean growth index for northern pike of +0.1 for Lake Leelanau, though this was largely due to mean length at age 6; removing age 6 resulted in a mean growth index of -0.7.

Mean length at age data for male, female, and all northern pike were fit to a von Bertalanffy growth curve. Male, female, and all northern pike had L_∞ values of 25.0, 39.4, and 37.5 in, respectively.

For smallmouth bass we had multiple readers for the 18 samples from the north basin, but only had a single reader for samples from the south basin. However, for the north basin samples at least two readers agreed 94% of the time and no samples were discarded due to poor agreement. We did not have enough samples from the north basin to statistically compare mean lengths at age between basins.

Mean lengths at age for smallmouth bass in Lake Leelanau were above average for Michigan (Table 15). We calculated a mean growth index for smallmouth bass of +1.0, thus mean lengths at age were higher than the state average, even with the potential biases between aging methods. State average mean lengths were estimated by scale aging, and though we found no literature comparing smallmouth bass aging structures, it is likely that biases exist similar to those mentioned for walleyes and northern pike.

Mean length at age data for smallmouth bass were fit to a von Bertalanffy growth curve, and the resulting L_∞ value was 19.5 in.

Mortality.–We estimated catch at age for 2,836 males, 478 females, and 3,473 total walleyes (including unknown-sex fish) in Lake Leelanau (Figure 7, Table 16). We used ages 6 and older in the catch-curve analysis to represent the legal-sized population (Figure 7). We chose age 6 as the youngest age because 1) average length of walleyes at age 6 was 15.5 in for males and 17.1 in for females (Table 11), so a high proportion of age-6 fish were of legal size at the beginning of fishing season; and 2) relative abundance of fish younger than age 6 do not appear to be represented in proportion to their true abundance (Figure 7), suggesting that fish (males and females) are not fully mature at age 5. We did not include age 13 in the catch-curve regressions where it appeared to be an outlier.

The catch-curve regressions for male, female and all walleyes were significant (P < 0.050), and produced total instantaneous mortality rates for legal-sized fish of 0.4366 for males, 0.4682 for females, and 0.4734 for all fish combined (Figure 7). These instantaneous rates corresponded to annual percent mortality rates of 35% for males, 37% for females, and 38% for all walleyes combined.

For walleyes in the north basin, we estimated catch at age for 69 males, 33 females, and 133 total walleyes (including unknown-sex fish), (Table 16). We used ages 4 and older in the catch-curve analysis to represent the legal-sized population (Figure 8). We chose age 4 as the youngest age because 1) average length of walleyes at age 4 was 15.5 in for males and 18.1 in for females (Table 12), so a high proportion of age-4 fish were of legal size at the beginning of fishing season; and 2) relative abundance of fish younger than age 4 do not appear to be represented in proportion to their true abundance (Figure 8), suggesting that fish (males and females) are not fully mature at age 3.

The catch-curve regressions for female and all walleyes were significant ($P < 0.050$), though that for male walleyes was not. Regressions produced total instantaneous mortality rates for legal-sized fish of 0.2005 for males, 0.2355 for females, and 0.2737 for all fish combined (Figure 8). These instantaneous rates corresponded to annual percent mortality rates of 18% for males, 21% for females, and 24% for all walleyes combined.

For walleyes in the south basin, we estimated catch at age for 2,760 males, 441 females, and 3,339 total walleyes (including unknown-sex fish). We used ages 6 through 12 in the catch-curve analysis to represent the legal-sized population (Table 16; Figure 9). We chose age 6 as the youngest age because 1) average length of walleyes at age 6 was 15.3 in for males and 17.1 in for females (Table 13), so a high proportion of age-6 fish were of legal size at the beginning of fishing season; and 2) relative abundance of fish younger than age 6 do not appear to be represented in proportion to their true abundance (Figure 9), suggesting that fish (males and females) are not fully mature at age 5. We did not include age-13 fish because the mortality estimates appear more indicative of the general trend in declining catch with age when it is not included.

The catch-curve regressions for male, female and all walleyes were significant ($P < 0.050$), and produced total instantaneous mortality rates for legal-sized fish of 0.4434 for males, 0.4169 for females, and 0.4858 for all fish combined (Figure 9). These instantaneous rates corresponded to annual percent mortality rates of 36% for males, 34% for females, and 39% for all walleyes combined.

The catch-curve regressions for walleyes differed between the north and south basins (F = 47.806, P = 0.0001), and the basin-age interaction term was also significant (F = 6.720, P = 0.024). Not only does the catch by age differ between the lakes, but the differences in catch between the lakes changes across different ages.

Anglers returned 331 walleye tags (178 reward and 153 non-reward tags) in the year following tagging from Lake Leelanau (Table 17). As mentioned previously, the creel clerk did not observe any tag loss, but we used an average rate of 5% from data collected on seven lakes to date. One tagged fish was observed in the possession of an angler that was not subsequently reported to the central office by the angler. In Lake Leelanau, the estimated exploitation rate for walleyes was 16.0% based on return of reward tags. The return rate was slightly higher in South Leelanau (15.3% versus 13.9%). Lake wide, anglers reported reward tags at a slightly higher rate than non-reward tags (15.2% versus 12.9%), but they likely did not fully report either one. The estimated exploitation rate for walleyes was 21.2% based on dividing harvest by the indirect, single-census abundance estimate (Table 10). The harvest estimate used here was first adjusted for non-surveyed months (using tag returns), and second for the proportion of harvested fish that were not of legal size at the time of tagging.

For northern pike, we estimated catch at age for 279 males, 361 females, and 887 total northern pike (including unknown-sex fish; Table 18). We did not have enough samples to do separate age-length keys by basin. The only age group of males where the mean length was greater than legal size (>24 in) was age 8, thus we calculated a catch curve for sub-legal fish. We used ages 2 through 8 in the catch-curve regression to represent the sub-legal male northern pike population (Figure 10). We included age 8 because it did not seem deviant from the trend of the previous age groups, and because likely some of the age-8 northern pike were of sub-legal size. For female northern pike, we used ages 5–9 in the catch-curve analysis. We chose age 5 as the youngest age because mean length at age 5 was 25.7 in (Table 14), so a high proportion of age-5 fish were legal-sized at the beginning of fishing season. For all northern pike, we used ages 6–9 in the catch-curve analysis. We chose age 6 as the youngest age because mean length at age 6 was the first age for which the mean length was greater than legal size (Table 14), so a high proportion of age-6 fish were legal-sized at the beginning of fishing season.

The catch-curve regression of sub-legal male northern pike was significant ($P < 0.050$), and it resulted in a total instantaneous mortality rate of 0.8541 (Figure 10). The regressions for legal female and all northern pike were also significant ($P < 0.050$), with total instantaneous mortality rates of 0.9423 and 0.8100, respectively. These instantaneous rates corresponded to total annual mortality rates of 57% for sub-legal males, 61% for legal-sized females, and 56% for legal-sized fish of all sexes combined. A comparison of mortality between males and females is not appropriate because the estimate for males did not include fishing mortality.

Anglers returned 20 northern pike tags (15 reward and 5 non-reward tags) in the year following tagging from Lake Leelanau (Table 17). The creel clerk did not observed any tagged fish in the possession of anglers that were not subsequently reported to the central office by the anglers, but we used the average rate of 5% tag loss due to the small sample observed in the creel. The estimated exploitation rate for northern pike was 25.9% based on return of reward tags (Table 10). The return rate was slightly higher in South Leelanau (27.4% versus 19.1%). Lake wide, anglers reported reward tags at a higher rate than non-reward tags (24.6% versus 9.1%), but they likely did not fully report either one. The estimated exploitation rate for northern pike was 57.4% based on dividing harvest by the multiple-census abundance estimate (Table 10). The harvest estimate used here was first adjusted for non-surveyed months (using tag returns), and second for the proportion of harvested fish that were not of legal size at the time of tagging.

For smallmouth bass, we estimated catch at age without identifying sex for 308 fish (Table 18). We used ages 5–13 in the catch-curve analysis. We chose age 5 as the youngest age because mean length at age 5 was 16.1 in (Table 15), so a high proportion of age-5 fish were legal-sized at the beginning of fishing season. The catch-curve regression for smallmouth bass was significant ($P < 0.050$), and resulted in a total instantaneous mortality rate of 0.4963 (Figure 11), and corresponding total annual mortality rate of 39%.

Anglers returned 32 smallmouth bass tags (14 reward and 18 non-reward tags) in the year following tagging from Lake Leelanau (Table 17). We used the average rate of 5% tag loss due to the small sample observed in the creel. The estimated exploitation rate for smallmouth bass was 13.7% based on return of reward and non-reward tags (Table 10). The return rate was higher in the north basin (22.2% versus 12.3%); though the north basin estimate was based on only nine tags at large. Lake wide, anglers actually reported non-reward tags at a higher rate than reward tags (15.7% versus 10.7%), but they likely did not fully report either one. The estimated exploitation rate for smallmouth bass was 14.2% based on dividing harvest by the multiple-census abundance estimate (Table 10). The harvest estimate used here was first adjusted for non-surveyed months (using tag returns), and second for the proportion of harvested fish that were not of legal size at the time of tagging.

Recruitment.–For walleyes in Lake Leelanau, variability in year-class strength was relatively low, which can be seen in the statistics of the catch-curve regression. Residual values were small (see scatter of observed values around the regression line for all walleyes in Figure 7) and the amount of variation explained by the age variable was high (R^2 = 0.9408). For walleyes in the north basin, variability in year-class strength was relatively high. Residual values were large (Figure 8) and the amount of variation explained by the age variable was low (R^2 = 0.6778). For walleyes in the south basin, variability in year-class strength was lower, and indicative of rather stable recruitment for a walleye population. Residual values were for the most part small (Figure 9) and the amount of variation explained by the age variable was high (R^2 = 0.96).

We found a few weak relationships between climatological variables and walleye year-class strength in the basins of Lake Leelanau. In the north basin, residuals from the walleye catch curve were positively correlated with average minimum ($r = 0.839$, $P = 0.009$, $df = 7$), average maximum ($r = 0.872$, $P = 0.005$, $df = 7$), and average ($r = 0.892$, $P = 0.003$, $df = 7$) June air temperature ($r = 0.728$, $P = 0.032$, $df = 6$). There was also a positive correlation with average maximum April air temperature ($r = 0.719$, $P = 0.045$, $df = 7$). In the south basin, residuals from the walleye catch curve were positively correlated with the maximum March air temperature ($r = 0.728$, $P = 0.032$, $df = 6$), the average minimum June air temperature ($r = 0.734$, $P = 0.030$, $df = 6$), and the total precipitation from January through March ($r = 0.677$, $P = 0.048$, $df = 6$). Although these relationships are weak, and do not imply causation, they are at least in agreement with the findings of other studies on recruitment relationships which we detail in the **Discussion** section. In Lake Leelanau as a whole, residuals from the walleye catch curve were not significantly correlated with any of the climatological variables.

Variability in northern pike year-class strength was low in Lake Leelanau, which can be seen in the statistics of the catch-curve regression. Residual values were relatively small (see scatter of observed values around the regression line for all northern pike in Figure 10), and the amount of variation explained by the age variable was high ($R^2 = 0.93$). Our catch curve for northern pike was based on legal size fish, and thus was only comprised of four year classes. For evaluating recruitment, it is not necessary for the fish to be legal size, only that they are recruited to the sampling gear. Thus, we made a second regression for northern pike utilizing the natural log of catch for ages 3 through 9. With the addition of these ages the amount of variation explained by the age variable improved ($R^2 = 0.97$). In four other Michigan northern pike populations surveyed as part of the Large Lakes Program to date, the R^2 has ranged from 0.80 to 1.00, with an average of 0.91. In at least one of these populations, the catch-curve regression was only done for fish of sub-legal size.

We found no significant climatological variables that were related to northern pike year-class strength. We tested the same environmental variables for northern pike as we did for walleyes.

It is difficult to assess the variability in smallmouth bass year-class strength in Lake Leelanau, since we have no other Michigan lakes for comparison. However, the amount of variation explained by the age variable was rather high ($R^2 = 0.91$), suggesting year-class strength was relatively consistent.

We found no significant climatological variables that were related to smallmouth bass year-class strength. We tested the same environmental variables as we did for walleyes and northern pike.

Movement.–Based on voluntary tag returns, there was considerable movement of walleyes, northern pike, and smallmouth bass between the north and south basins of Lake Leelanau (Table 19). While the percentages of walleyes moving from north to south basins and vice versa were similar, the net movement after the spawn, based on spawning population size, is much larger from the south to the north basin. One walleye tag return came from a carcass retrieved by a bird hunter’s dog in the Leland area, possibly the remains of a fish eaten by a bald eagle.

Although northern pike tag returns showed some movement in both directions, it appears that the majority of those tagged in the south basin remained there throughout the year. We tagged few northern pike in the north basin, so not much could be learned from the tag return data, but we did document movement between the basins.

Similar to what we found for walleye, smallmouth bass movement between basins was comparable in percentage of total returns, but the net movement appears larger from south to north following the spring.

Angler Survey

Summer.–Our clerk interviewed 2,208 boating anglers during the summer 2002 survey. Most interviews (96%) were roving (incomplete-fishing trip). Anglers fished an estimated 93,135 angler hours and made 31,372 trips (Table 20).

The total harvest was 12,916 fish, which consisted of ten different species (Table 20). Walleyes were most numerous with an estimated harvest of 8,910. Yellow perch were second at 2,556. Anglers harvested 408 smallmouth bass and very few largemouth bass (20). Anglers reported releasing 23,170 walleyes (72% of total catch) and 5,384 smallmouth bass (93% of total catch). Anglers harvested 144 northern pike and reported releasing 2,218 (94% of total catch). We do not know what proportion of the released fish was legal size. In future surveys, we recommend distinguishing between sub-legal- and legal-size fish released.

Winter.–Our clerk interviewed 161 open ice anglers and 225 shanty anglers. Most open ice (90%) and shanty (88%) interviews were roving type. Open ice and shanty anglers fished 18,977 angler hours and made 6,423 trips on Lake Leelanau (Table 21).

A total of 2,548 fish were harvested. Yellow perch were most numerous with an estimated harvest of 1,749. Walleyes were second at 496. Only 19 northern pike were harvested. Anglers harvested 206 lake trout and 78 lake herring. No smallmouth bass or largemouth bass were harvested during winter months.

Anglers reported releasing 404 walleyes (46% of total catch) and 51 northern pike and released 34 (73% of total catch).

Annual totals for summer and winter.–In the annual period from April 27 through September 30, 2002 and January 1 through March 31, 2003, anglers fished 112,112 hours and made 37,795 trips to Lake Leelanau (Table 22). Of the total annual fishing effort, 83% occurred in the open-water summer period and 17% occurred during ice-cover winter period. Anglers made 27,846 trips and fished 84,561 hours on the south basin, compared to 9,949 trips and 27,552 hours on the north basin.

The total annual harvest was 15,464 fish. The estimated total annual harvest of walleyes was 9,406, with 7,883 coming from the south basin and 1,523 from the north basin. Walleyes made up 61% of the total harvest. Yellow perch were the second most harvested species at 4,305, making up 28% of the total harvest. Harvest of northern pike was low, with an estimated 108 from the south basin and 54 from the north basin. Harvest of smallmouth bass was also low, with 269 from the south basin and 139 from the north basin.

Walleyes were the predominant species caught (harvested + released) at 32,980. Resulting catch rate (catch per h) for walleyes was 0.2942. Total catch of walleyes peaked in July, but walleyes were readily caught from June through September. Anglers released 71% of all walleyes caught. Estimated total annual catch of northern pike was 2,431, with a resulting catch rate of 0.0216. Anglers released 93% of northern pike caught. Estimated total annual catch of smallmouth bass was 5,792, with a resulting catch rate of 0.0516. Smallmouth bass catch peaked in June and again in September, with none reported caught during winter months even incidentally (harvest of smallmouth and largemouth bass would have been illegal January–March).

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.

Although we did not differentiate between sub-legal and legal released fish, we assume that a large proportion of the released walleyes and northern pike were sub-legal. At least for northern pike, the assumption that the high release rate was due to catching many sub-legal fish is corroborated by the size structure of this species, which contained high proportions of sub-legal-sized fish (Table 7).

We did not survey from October through December, because we thought that relatively little fishing occurred during that time of year. Twenty-seven walleye tag returns were reported from October through December, prior to the start of the winter creel survey (Table 17). Thus, the total annual walleye harvest was actually about 8% higher than our direct survey estimate, or 10,173 walleyes. No northern pike tag returns were reported as caught during the non-surveyed months (Table 17). April was not surveyed because both walleye and northern pike seasons are closed at that time.

Ten species that we captured during spring netting operations did not appear in the angler harvest—black bullhead, brown bullhead, brown trout, burbot, central mudminnow, longnose gar, lake herring, pumpkinseed, rainbow smelt, and yellow bullhead.

Separate estimates of angler harvest and effort for the north and south basins are presented in Appendices B and C, respectively.

Discussion

Fish Community

The current survey of Lake Leelanau differed from past surveys of the lake in both the season, and amount and type of fishing effort used. This survey was the most comprehensive fisheries survey of Lake Leelanau (collected more fish than any previous survey). Because of the seasonal bias, we likely caught more large, mature fish of several species than would normally be caught in surveys that have historically been conducted later in spring or summer. This would include spring spawners such as walleyes, northern pike, white sucker, yellow perch, 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 would not be represented in our sample in proportion to their true abundance in the lake. This would include juveniles of all species as well as entire populations of smaller fishes known to exist in Lake Leelanau such as various species of shiners, darters, or minnows. For example, seven species of fish have been collected or observed in Lake Leelanau in previous surveys (Table 23) that were not collected in 2002 (see Appendix A).

The relative proportion of feeding guilds in the north basin was similar to that of Burt Lake, which was surveyed as part of the Large Lakes Program in 2001. Burt Lake had 26% piscivores, 20% pelagic planktivores-insectivores, and 54% benthivores. The fish community of the south basin however, was more similar to that of Houghton Lake, which had 61% piscivores, 30% pelagic planktivores-insectivores, and 9% benthivores. The differences in fish community composition between the north and south basins are in part a result of differences in lake morphologies and habitats. For example, maximum depth in the north basin is 122 ft, whereas the maximum depth of the south basin is only 62 ft (Figures 2–5).

Lake Leelanau has a long and diverse survey history that describes the fish community since 1949 (Table 23). The most recent surveys of the south basin occurred in 1992, 1993, and 1994; and of the north basin in 2000. Most surveys were basin- and species-specific (trout or walleye stock evaluations); thus differences between this survey and historical surveys are not well suited for comparisons of relative abundance. However, we can make simple comparisons about the presence and absence of some species. Of particular importance is the presence of walleyes in historic surveys. No walleyes were collected in the 1949 or 1967 surveys of Lake Leelanau. Additionally, based on the general creel survey data, walleyes and other species never made up more than 0.6% of the total catch during the years 1928–39, 1940–50, and 1951–63 (Laarman 1976). More recently, in 1978, 1988, 1992, 1993, and 1994, walleyes were collected in every survey. Although these surveys are not suited for a comparison using catch per unit effort data since they did not occur at the same time of year, we will explain in the *Mean Lengths at Age* section how the growth and age structure data for walleyes is consistent with a population that increase its population density between 1978 and 2002.

Walleyes, Northern Pike and Smallmouth Bass

Size structure.–The size structure of walleyes from our spring survey of Lake Leelanau was about average when compared to other large lakes. In six Large Lakes Program surveys to date, the average percentage of walleyes over legal size was 69, which was the same percentage we found for Lake Leelanau. In general, walleyes in Lake Leelanau are unlikely to attain lengths much greater than 24 in, though there is the potential to reach 30 in. The difference we found in length distributions between the two basins was likely due to the larger number of walleyes collected in the south basin, and a more representative distribution of lengths. However, it is possible that the higher proportion of large (>20 in) walleyes in the north basin could be a result of higher mobility in large walleyes that end up migrating to the north basin, or because density is lower and growth rates are higher in the north.

The size structure of northern pike in Lake Leelanau is about average. In six Large Lakes Program surveys to date, the average percentage of northern pike over legal size was 18. We calculated 13% for Lake Leelanau. Similar to walleye, the differences we found in length distributions between the two basins was likely due to the larger number of pike collected in the south basin, and the more representative distribution of lengths. However, as stated about walleyes, there are other possible explanations for the differences. Northern pike in Lake Leelanau are unlikely to attain lengths much greater than 30 in, though there is the potential to reach 40 in. Historic length frequency evaluations of northern pike similarly indicate that the population is dominated by sub-legal fish. In 1994, under the same size limit, 65% of northern pike collected were sub-legal.

The size structure of smallmouth bass in Lake Leelanau appeared to be very good. In six large lakes surveys to date, there have been on average 77% legal smallmouth bass. We calculated 81% for Lake Leelanau. We did not collect enough bass in North Leelanau to make comparisons between the two basins. Smallmouth bass in Lake Leelanau are likely to attain lengths of 18 in, and have good potential to reach 20 in. The current survey of Lake Leelanau is comparable to historic surveys with respect to the good size structure of smallmouth bass.

Sex composition.–Male walleyes outnumbered females in our survey both when all sizes and fish of legal size were considered. We were unable to find any previous information concerning sex composition from Lake Leelanau for comparison. Sex of walleyes is readily determined during the spawning season by extruding gametes, but at other times of the year, sex determination would require dissection of the fish, which is not part of past sampling protocols.

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).

Male northern pike outnumbered females in Lake Leelanau when all sizes were considered. However, females greatly outnumbered males when only legal size fish were considered. This disparity between sex composition of all sizes and fish of legal size is likely due to faster growth in females. Higher mortality of males as reported by Craig (1996) would also contribute to this disparity, though our estimates of mortality for northern pike were similar between sexes. In other large lakes, we have found the found the same disparity in sex ratio of all northern pike versus northern pike of legal size (Clark et al. 2004; Hanchin et al. 2005a).

For northern pike from other lakes, males dominate sex composition in spawning-season samples, but not at other times of the year (Priegel and Krohn 1975; Bregazzi and Kennedy 1980). Bregazzi and Kennedy (1980) sampled northern pike with gill nets set throughout the year in Slapton Ley, a eutrophic lake in southern England. Sex ratios during the February and March spawning period ranged from 6:1 to 8:1 (male to female), but the overall sex ratio for an entire year of sampling was not significantly different from 1:1.

Abundance.–To our knowledge, no one has attempted to estimate walleye abundance before in Lake Leelanau. We were successful in obtaining reasonable multiple-census estimates for both legal-sized and adult walleyes, but we probably underestimated true abundances in both cases. Pierce (1997) found that multiple-census methods underestimated abundance when applied to northern pike. He compared multiple-census estimates made with a single gear type (trap nets) to single-census estimates made with two gear types (marking with trap nets and recapturing several weeks later with experimental gill nets). He found that multiple-census estimates averaged 39% lower than single-census estimates. Pierce concluded that gear size selectivity and unequal vulnerability of fish to near shore netting make multiple-census estimates consistently low. Collecting recaptures later with a second gear type (single-census estimate) allowed for better mixing of marked and unmarked fish, so the estimate was theoretically less biased. While Pierce worked with northern pike, our previous work supports the hypothesis that such biases are similar for walleyes. Multiple-census estimates for walleyes were lower than single-census estimates in eight of nine other lakes we have surveyed (Clark et al. 2004; Hanchin et al. 2005a, 2005b, 2005c). They averaged 34% lower for legal-sized walleyes and 21% lower for adult walleyes.

For the single-census estimates of walleyes, we had sufficient numbers of fish marked, but we failed to obtain enough recaptures in our angler survey to produce reliable estimates. We discovered later that the cause of this problem was a miscommunication with the angler survey clerk, who did not record marked fish properly. Thus, our failure to obtain direct, single-census estimates was more an operational problem than an experimental design problem. Based on the regression equations given in the **Results** section, we estimated indirect, single-census estimates from our direct, multiple census estimates. For walleyes, the indirect, single-census estimates were 56,665 adult fish and 35,952 legal-sized fish (Table 10). These adjusted estimates fit well with other independently derived statistics, such as the number harvested, and we think they are closer to the true abundances than the multiple-census estimates. We consider these our best estimates of walleye abundances in Lake Leelanau.

Whether we use the direct, multiple-census estimate of 42,679 or the indirect, single-census estimate of 54,665, it seems obvious that the population density of adult walleyes in Lake Leelanau is well above average. Both the Wisconsin and Michigan regression models predict much lower adult walleye abundance for Lake Leelanau than we found, and the regressions were based on abundance estimates from dozens of lakes. Our a priori Wisconsin regression prediction was only 9,121 fish for Lake Leelanau, but this Wisconsin model was meant to be used for lakes with stocking as the primary recruitment source, which was in hindsight the wrong model to use for Lake Leelanau. However, even if we had used the Wisconsin model for natural reproduction we would have predicted only 25,866 adult walleyes. Similarly, our Michigan regression model predicts only 18,539 adult walleyes for Lake Leelanau.

The population density of adult walleyes in Lake Leelanau was also well above average when compared directly to estimates in other lakes – 6.4 per acre based on our best abundance estimate of 55,665. Few lakes have higher adult walleye densities. Adult walleye abundance has averaged 2.8 per acre in seven large lakes surveyed thus far in Michigan. Nate et al. (2000) reported an average density of 2.2 adult walleyes per acre for 131 Wisconsin lakes having natural reproduction. Lake Gogebic is one of the few lakes with a population density of adult walleyes as high as Lake Leelanau. Miller (2001) estimated 62,497 male spawning walleyes (approximately 13 in and greater) there, or 4.8 adult males per acre. Norcross (1986) similarly estimated 63,000 male walleyes in Lake Gogebic, though after adjusting for under-sampled females he arrived at an estimate of around 125,000 legal (≥13 in) walleyes, or 9.5 per acre, which is higher than the population density in Lake Leelanau as a whole.

However, the south basin of Lake Leelanau had a much higher walleye density than the north basin. We collected approximately 95% of our walleyes in the south basin in our spring netting operation. If considered alone, then, the south basin would have about 51,930 adult walleyes or a density of 9.1 adult fish per acre, which is similar to the Norcross estimate for Lake Gogebic.

The population density of legal-sized walleyes in Lake Leelanau was also well above average when compared directly to other lakes in Michigan and elsewhere. Our best estimate of 35,952 for 15-in-and-larger walleyes in Lake Leelanau converts to a population density of 4.2 per acre. Density of legal-size walleyes estimated recently for seven large lakes in Michigan has averaged 2.2, and has ranged from 0.8 to 2.9 per acre (Clark et al. 2004; Hanchin et al. 2005a, 2005b, 2005c). Furthermore, if considered alone, the south basin of Lake Leelanau would have one of the highest population densities of legal-sized walleyes ever reported. During the spring spawning season, the south basin contained approximately 95% of the walleyes in the lake, or 34,154 fish, so the density during spring would have been 6.0 legal walleyes per acre. Thus, legal walleye density, at least during the spawning season, is relatively high in Lake Leelanau as a whole and is extremely high in the south basin.

We had mixed success in obtaining abundance estimates for northern pike (Table 10). We collected the minimum number of recaptures for multiple-census estimates, but we did not collect any recaptures for single-census estimates, and thus, could not make direct single-census estimates. Nor could we calculate indirect, single-census estimates. Therefore, the multiple-census estimate is the best estimate we can make for northern pike with our data. However, we suspect the true abundance is somewhat higher, because the multiple-census estimate is usually biased low.

Compared to other large lakes we have sampled in Michigan, population density for adult northern pike in Lake Leelanau is somewhat below average. Our best estimate of 6,349 adult northern pike for Lake Leelanau converts to a density of 0.7 adult northern pike per acre for the lake as a whole. Adult northern pike abundance has averaged 1.3 per acre (range 0.1–2.0) in four large lakes surveyed thus far in Michigan (Clark et al. 2004; Hanchin et al. 2005a, 2005b, 2005c). As with walleyes, population densities of northern pike differed in the north and south basins. Given that approximately 90% of the adult northern pike were captured in the south basin, densities in the north and south basins would be 0.2 and 1.0 per acre, respectively.

Compared to other lakes worldwide, the population density of northern pike in Lake Leelanau is low. 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 done for 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. Their estimates of density ranged from 4.5 to 22.3 per acre for fish age 2 and older. Our estimate of adult northern pike in Lake Leelanau also would essentially be for fish age 2 and older.

Based on our best estimate of 282 fish, the population density of legal-sized northern pike in Lake Leelanau is 0.03 per acre, which is below average relative to other lakes in Michigan. Because about 85% of the legal northern pike tagged in Lake Leelanau were tagged in the south basin, springtime densities would be 0.01 and 0.04 legal-sized northern pike per acre in the north and south basins, respectively. Density of legal-size northern pike estimated recently for seven large lakes in Michigan has averaged 0.2, and has ranged from 0.01 to 0.53 per acre (Clark et al. 2004; Hanchin et al. 2005a, 2005b, 2005c).

We had mixed success in obtaining abundance estimates for smallmouth bass (Table 10). We collected the minimum number of recaptures for multiple-census estimates, but we did not collect any recaptures for a single-census estimate. Thus, we could not make a single-census estimate for smallmouth bass. Furthermore, few other lakes have had concurrent multiple- and single-census estimates conducted for smallmouth bass, so we could not develop a predictive regression equation as we did for walleyes and could not make indirect, single-census estimates. However, our multiple-census estimate for smallmouth bass did appear reasonable when judged in relation to the independently derived harvest estimate. Our harvest estimate for legal-sized smallmouth bass of 408 becomes 361 when adjusted for non-surveyed months and fish that were sub-legal at tagging. This produced an exploitation rate of 14.2% when divided by the multiple-census abundance estimate, which is close to the exploitation rate estimate based on tag returns of 13.0%.

Our multiple-census abundance estimate for Lake Leelanau converts to a population density of 0.3 legal-sized smallmouth bass per acre. Because about 93% of the legal smallmouth bass tagged in Lake Leelanau were tagged in the south basin, the estimated densities of legal-sized smallmouth bass for the north and south basins would be 0.1 and 0.4, respectively.

A thorough comparison of smallmouth bass density in Lake Leelanau to other lakes in Michigan and elsewhere is difficult due to the paucity of abundance estimates for smallmouth bass in lakes and the variety of gears and methods used to make the ones that do exist. Lake Leelanau was the first lake in our Large Lakes Program where abundance estimates were made for smallmouth bass. However, estimates were made previously in several other Michigan lakes for other reasons, and if we compare our estimates to those, it appears that Lake Leelanau has a relatively low density of smallmouth bass. Bryant and Smith (1988) reported an abundance estimate for adult smallmouth bass in the Lake St. Clair - Detroit River System that corresponds with a lake-wide density of about 3.5 per acre. Clady (1975) estimated adult smallmouth bass density was 3.6, 13.4, and 25.1 per acre in three small (25–75 acre) western Upper Peninsula lakes. Adult fish in these Michigan populations would be fish of approximately 12 inches and larger. We collected about 15% more 12- to 14-inch smallmouth bass, based on our length frequencies, but if we increase our abundance estimates by 15%, we get at most 0.5 adult smallmouth bass per acre in the south basin of Lake Leelanau. Elsewhere, Marinac-Sanders and Coble (1981) reported a density of 3.5 per acre for smallmouth bass >225 mm (~ 9 in) in 845-acre Clear Lake, Wisconsin. Engel et al. (1999) reported an average density of 16.2 per acre for smallmouth bass ages 3–8 (> ~8 in) in Nebish Lake, Wisconsin. Finally, Newman and Hoff (2000) reported a density in Palette Lake, Wisconsin more similar to ours of 0.3 smallmouth bass (>16.0 in) per acre.

We believe it would be possible to improve abundance estimates for Lake Leelanau or other lakes of comparable size. Obtaining more precise estimates would require 1) marking more fish, 2) observing more fish for the marked : unmarked ratio, or 3) both. We collected and marked 2,368 walleyes with three 10–15 net, 3-person work crews in Lake Leelanau. Based on our experience from making abundance estimates on other lakes (Clark et al. 2004; Hanchin et al. 2005a, 2005b, 2005c), this should have been enough marked fish to get a reasonable single-census population estimate. Our primary problem was not obtaining a sufficient number of recaptures through the angler survey. For Lake Leelanau, this was due largely to our failure to communicate to the angler survey clerk the proper procedures for recording recapture ratios.

Mean lengths at age.–Our reader agreement (first two reads) for walleye spines was similar to other studies. Isermann et al. (2003) achieved 55% reader agreement and Kocovsky and Carline (2000) achieved 62%. Reader agreement (first two reads) in five Michigan large lakes surveyed to date has ranged from 41% to 68% with an average of 56%. Similar to us, Miller (2001) found that at least two of three readers agreed 94% of the time.

Walleye mean lengths at age for Lake Leelanau were considerably lower than the state average, indicating poor growth. Walleye mean lengths at age for the north basin appeared to be only slightly lower than the state average, while those for the south basin were substantially lower. However, these deviations from the state average were likely due, at least in part, to biases between aging methods. State average mean lengths were estimated by scale aging, and past studies comparing spine aging to scale aging suggest that biases of these techniques generally lead to estimated mean lengths at age of scale-aged fish to be larger than spine-aged fish (Kocovsky and Carline 2000; Miller 2001; Clark et al. 2004). Eventually, the Large Lakes Program will obtain enough data to recalculate new state averages based on spines, which will improve future comparisons.

Walleye growth was assessed in the south basin of Lake Leelanau by DNR Fisheries Division in 1978, 1988, 1992, 1993, 1994, and 2002 (Table 23). Walleye growth rates have steadily declined in both the north and south basins since the 1978 survey (tables 24 and 25). In the 1978 survey, 32 walleyes were collected that ranged in age from 3 to 8, and had a mean growth index of +2.5. In the 1988 survey, 25 walleyes ranged in age from 2 to 8, and had a mean growth index of +3.1. In the 1992 survey, 33 walleyes were collected up to age 6, and the mean growth index had decreased to +0.3. The following year (1993), 34 walleyes were collected up to age 7, and the mean growth index decreased further to -0.3. In 1994, 36 walleyes were collected up to age 7, and the growth index was -0.4. Finally, in our 2002 survey of the south basin, we collected walleyes up to age 13, and the mean growth index was -2.8. Assuming growth is inversely related to population density, the continuous decline in mean lengths at age is consistent with a hypothesis that walleye abundance increased from 1978 to 2002.

The values we calculated for L_∞ provide us some insight into the growth potential of individuals in a population. The growth potential appears much higher in the north basin with an L_∞ of 26.7 in than the south basin with an L_∞ of 21.6 in, which could be due to the lower population density in the north basin.

Our reader agreement for northern pike was similar to other studies. Reader agreement (first two reads) in four Michigan large lakes surveyed to date has ranged from 59% to 81% with an average of 68%.

The mean lengths at age for our fin ray-aged northern pike were probably average compared to other lakes in Michigan. They were within 1.0 in of the scale-aged state average mean lengths. However, there could be biases between fin ray and scale aging methods. Northern pike have historically exhibited acceptable growth indices (at or above state averages) in previous surveys of Lake Leelanau in which fish were aged with scales. The only surveys where a mean growth index could be calculated occurred in 1993 and 1994 when the indices were 0.0 and +0.8, respectively. As with walleyes, the Large Lakes Program will eventually age enough northern pike with fin rays to recalculate state averages for future comparisons.

Length infinity (L_∞) values of male (25.0 in) and female (39.4 in) northern pike suggest that growth potential is average, or above average in Lake Leelanau. Female pike typically attain legal size (24 in) at age 4, while males attain this size near the end of their life (ages 7 – 8).

For smallmouth bass, mean lengths at age were higher than the state average, even with the potential biases between aging methods. Our mean growth index was +1.0 in as compared to state averages. State average mean lengths were estimated by scale aging, and though we found no literature comparing smallmouth bass aging structures, it is likely that biases exist similar to those mentioned for walleyes and northern pike.

Smallmouth bass have historically exhibited adequate growth rates in Lake Leelanau. The mean growth index of smallmouth bass from the south basin was estimated to be +0.2 in 1994. In past surveys, the mean growth index of smallmouth bass from the south basin was -1.0 in 1988, +0.2 in 1994, and was -0.4 in the north basin in 2000.

Mortality.–To our knowledge, this was the first attempt to estimate total mortality of walleyes from Lake Leelanau. Total mortality of walleyes was rather low at 38% for the lake as a whole, 24% for the north basin, and 39% for the south basin. For such a low total mortality rate, our sample of walleyes seems to have too few older-aged fish. Only 12 year classes (age 2–13) were represented. We found more older-aged walleyes in other lakes with similar total mortality rates. In Burt Lake the total mortality rate for walleyes was 38%, and we found fish up to age 20 (Hanchin et al. 2005c). In Michigamme Reservoir with a total mortality rate of 37%, we found fish up to age 17 (Hanchin et al. 2005a). The lack of older walleyes in Lake Leelanau could be an indication that the 1989 year class was the first in a series of big year classes in an expanding population. In other words, there might not have been any walleyes of age 14 or older in the lake, or so few were present that the likelihood of catching them was low.

The differences we observed in walleye mortality (and growth) between the two portions of the lake are likely due, at least in part, to the differing habitats and population densities between basins. In addition, the very low total mortality rate of 24% for the north basin could be the net result of mortality and in-migration. That is, we found a general pattern of movement of walleyes from south to north (see *Movement* section), and that movement could somewhat offset losses from mortality.

In seven walleye populations surveyed previously as part of the Large Lakes Program, mortality has ranged from 29% to 51% with an average of 39%. Schneider (1978) summarized available estimates of total annual mortality for adult walleyes in Michigan. They ranged from 20% in Lake Gogebic to 65% in the bays de Noc, Lake Michigan. Schneider also presented estimates from lakes throughout Midwestern North America, other than Michigan. They ranged from 31% in Escanaba Lake, Wisconsin to 70% in Red Lakes, Minnesota. Colby et al. (1979) summarized total mortality rates for walleyes from a number of lakes across North America. They ranged from 13% to 84% for fish age 2 and older, with the majority of lakes between 35% and 65%.

We think 21.2% is our best estimate of the annual exploitation rate for walleyes in Lake Leelanau. Considering the biases for the two methods we used, the true rate is probably in the 20–25% range. Our two estimates for walleyes were 21.2% from dividing harvest by the indirect, single-census abundance estimate and 16.0% from tag returns. We consider the tag return estimate to be an underestimate because we did not adjust for tagging mortality or non-reporting, and if these problems occurred to any degree, we would have underestimated exploitation (Miranda et al. 2002). We did not estimate tagging mortality, and we used an average tag loss rate of 5%. We did not make a true estimate of non-reporting, but one of two tags observed by the creel clerk was not subsequently reported by anglers. This indicates that non-reporting may have occurred to some degree, but the small number of tagged fish observed by the creel clerk was not a large enough sample from which to draw conclusions. Also, non-reporting appeared to be low because the number of tags voluntarily returned by anglers exceeded the predicted number of returns based on the ratio described previously in the **Methods** section.

We attempted to get some measure of non-reporting of tags by offering a $10 reward on about half of the tags and comparing return rates of reward to non-reward tags. We found that reporting rate for reward tags (15.2%) was slightly higher than for non-reward tags (12.9%), which might be expected given that our reward amount was relatively low compared to those used by other authors (Miranda et al. 2002). Clark et al. (2004) used the same tags and reward amount in Houghton Lake and did not observe much difference in return rates of reward and non-reward tags. However, in Michigamme Reservoir, there was a large difference in reporting rates, and the authors believed that anglers must have returned nearly 100% of reward tags (Hanchin et al. 2005a).

Compared to exploitation rates for walleyes from other lakes in Michigan and elsewhere, our estimate for Lake Leelanau is about average. The average exploitation rate for walleyes from seven large lakes surveyed to date was 15.9% with a range of 3.5% to 31.8%. Comparable to our estimate, Serns and Kempinger (1981) reported average exploitation rates of 24.6% and 27.3% for male and female walleyes respectively in Escanaba Lake, Wisconsin during 1958–79. 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 water body; in western Lake Erie estimates ranged from 7.5% to 38.8% from 1989 through 1998 (Thomas and Haas 2000).

This was the first attempt to estimate total mortality of northern pike in Lake Leelanau. Our estimate of 56% was slightly above average compared to estimates from other lakes. Pierce et al. (1995) estimated total mortality for northern pike in seven small (<300 acres) 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 and they ranged from a low of 19% (Mosindy et al. 1987) to a high of 91% (Kempinger and Carline 1978), with the majority of lakes between 35% and 65%. Clark et al. (2004) estimated total annual mortality for northern pike in Houghton Lake, Michigan to be 51%. Diana (1983) estimated total annual mortality for two other lakes in Michigan, Murray Lake at 24.4% and Lac Vieux Desert at 36.2%.

We think the true annual exploitation rate for northern pike in Lake Leelanau is in the 30% to 50% range. Our two estimates for northern pike were 57.4% from dividing harvest by the multiple-census abundance estimate and 25.9% from tag returns. Considering the biases of these methods, we think use of tag returns underestimated and use of multiple-census abundance estimates overestimated the true exploitation rate.

Compared to exploitation rates for northern pike from other lakes in Michigan and elsewhere, our estimate of 30% to 50% for Lake Leelanau appears to be slightly above average. Latta (1972) reported northern pike exploitation in two Michigan lakes, Grebe Lake at 12–23% and Fletcher Pond at 38%. Pierce et al. (1995) reported rates of 8% to 46% for fish over 20 in for seven lakes in Minnesota. Carlander (1969) gave a range of 14% to 41% for a sample of lakes throughout North America. Finally, Clark et al. (2004) reported rates of exploitation from 18.2% to 44.7% for northern pike in Houghton Lake, Michigan.

This was the first attempt to estimate total mortality of smallmouth bass in Lake Leelanau. Our estimate of 39% for legal-size fish appears to be within the range for lakes reported in the literature, though it may be near the lower end of the range. Forney (1961) reported estimates of 52%, 58%, and 18% total mortality for smallmouth bass in Oneida Lake, New York, while Paragamian and Coble (1975) reported 55% for the Red Cedar River, Wisconsin. Clady (1975) reported total mortality estimates of 32.5% for smallmouth bass in a Michigan lake with no fishing, and 40.5–65.0% in a lake subject to simulated exploitation of 13.2–15.8%. Bryant and Smith (1988) reported 58% total mortality of adult smallmouth bass from Anchor Bay of Lake St. Clair.

We think the true annual exploitation rate of smallmouth bass in Lake Leelanau is in the 10–15% range. Our two estimates were very similar; 13.7% from tag returns, 14.2% using harvest divided by the multiple-census abundance estimate. As discussed before, tag returns probably underestimated the true rate and, because the multiple-census abundance estimate is probably biased low, harvest divided by multiple-census abundance probably overestimated the true rate.

Compared to exploitation rates for smallmouth bass from other lakes in Michigan and elsewhere, our estimate for Lake Leelanau appears to be slightly below average. Latta (1975) reported a range of 9% to 33% exploitation with an average of 19.2% for a sample of smallmouth bass populations throughout the Great Lakes region and the northeastern United States. In Oneida Lake, Forney (1972) reported 20% exploitation of adult smallmouth bass, while in the Red Cedar River of Wisconsin Paragamian and Coble (1975) reported 29% exploitation. In Michigan, Latta (1963) reported 22% exploitation of smallmouth bass near Waugoshance Point in Lake Michigan, and Bryant and Smith (1988) reported a rate of 13% for smallmouth bass in Lake St. Clair.

Recruitment.–Walleyes in Lake Leelanau were represented by 12 year classes (ages 2 through 13) in our samples. Variability in year-class strength was rather consistent for the lake as a whole (R^2 = 0.94 in Figure 7). In five other Michigan walleye populations surveyed as part of the Large Lakes Program to date, the R^2 has ranged from 0.67 to 0.94, with an average of 0.85. Variability in year-class strength was greater in the north basin (R^2 = 0.68, Figure 8) than the south basin (R^2 = 0.96, Figure 9). The difference could be that the south basin has more walleyes, better walleye habitat, and has had walleyes stocked.

Considering the consistency of year-class strength and the lack of consistency in annual stocking rates, natural reproduction of walleyes must be excellent in Lake Leelanau. Walleye fry were stocked in only four years, 1989, 1992, 1995, and 1998, that corresponded with year classes we collected (tables 1 and 16). Therefore, substantial natural reproduction must have occurred in at least 1990, 1991, 1993, 1994, and 1996. Substantial natural reproduction also probably occurred from 1997 to 2000, though these fish were not fully recruited to our sampling gear and survey timing.

Natural reproduction of walleyes appears to have increased in Lake Leelanau in the last 10 to 15 years. As mentioned earlier, our sample of walleyes seems to have too few older-aged fish (none over age 13) for a population with total mortality rate of only 38%. This lack of older walleyes could be an indication that the 1989 year class was the first in a series of big year classes in an expanding population. In fact, analyses from the 1992, 1993, and 1994 surveys all indicated that the 1989 year class dominated the age composition. Existing records suggest that walleye abundance was very low in the lake prior to the 1980s. No walleyes were reported captured in MDNR netting surveys done in 1949 and 1967, 32 were collected in 1978, 25 were collected in 1988, and only trace numbers were reported caught by anglers in general creel surveys done from 1928 to 1963 (Laarman 1976).

We find it interesting to note that the 1992 and 1993 year classes corresponded with negative residuals (Figure 7). Many lakes in the Midwest had poor walleye year classes in 1992 and 1993 due to the eruption of Mount Pinatubo and subsequent cooling (Shupp 2002). Additionally, the relationships we found between walleye year-class strength and June temperatures are consistent with the findings of Shupp (2002) for Minnesota lakes.

Northern pike in Lake Leelanau were represented by 8 year classes (ages 2 through 9) in our samples. Variability in year-class strength was relatively low (R^2 = 0.93 in Figure 10), though we only included four ages in the catch-curve regression. In five other Michigan northern pike populations surveyed as part of the Large Lakes Program to date, the R^2 has ranged from 0.80 to 1.00, with an average of 0.92.

As previously stated, we were unable to compare the variability in smallmouth bass year-class strength in Lake Leelanau to other lakes, though recruitment appears to be rather consistent with an R^2 of 0.91 on the catch-curve regression (Figure 11). In the future, we will have more estimates of smallmouth bass recruitment variability for comparison.

Movement.–We documented considerable movement of walleye, northern pike, and smallmouth bass between the north and south basins of Lake Leelanau. Although we do not necessarily know the timing of individual fish movements, a large portion of the fish likely move from early spring through early summer. It would be interesting to know the seasonal movement patterns of fish within Lake Leelanau, but movements associated with spawning are the most important. Currently, we do not know if walleyes and northern pike in Lake Leelanau demonstrate site fidelity in spawning. Knowledge of site fidelity should be considered in future research because it would have potential implications in the allocation of walleye harvest. Future efforts could involve extensive collection of spawning walleyes in the years after marking.

Angler Survey

The fishery of Lake Leelanau is dominated by walleyes, yellow perch, and smallmouth bass, which together comprised 91% of the total annual harvest, and 87% of the released fish. Walleye harvest peaked in July and August, corresponding with the highest catch rates. Catch rate for walleyes was highest in August (0.485/hour), followed by July (0.426/hour), and September (0.332/hour). Yellow perch harvest was highest in September and March, though they were caught throughout the year. Black bass (smallmouth bass and largemouth bass) were not frequently harvested, though they are often caught and released. The catch (harvest + release) rate for black bass over the entire survey was 0.05 per hour.

A variety of other species provides angling opportunity throughout the year. Lake trout and lake herring were harvested only in the north basin. Relatively few northern pike were harvested; these have a high release rate, which is most likely a result of catch and release of sublegal fish.

Historical comparisons.–Previous harvest and effort estimates for Lake Leelanau were reported by Laarman (1976). A general creel census from 1928–63 included Lake Leelanau, but this "census" was designed only to measure success of anglers who were actually interviewed and was not expanded to estimate total catch of all anglers. These general census estimates would not be directly comparable to our estimates. However, considering the general census alone, yellow perch, rock bass, and bluegill were the predominant species in the fishery from 1928–39, 1940–50, and 1951–63, with smallmouth bass also making up a certain portion of the total catch. Walleyes were rarely found in the catch, contrary to the present survey.

In 1970 and 1973, annual fishing effort on Lake Leelanau was estimated as 29,420 and 29,790 angler days, respectively, from mail surveys. Using current knowledge of the average number of trips per day (1.2 trip/day), and the average length of a trip (2.88 h/trip) from the 2002 creel survey, the 1970 and 1973 estimate equates to 102,854 and 109,990 hours of fishing effort, respectively. These two numbers are comparable to our results: the 2002-03 annual estimate of 112,112 total angler hours. It appears that effort has not changed much from what it was in 1970 and 1973.

Comparison to other large lakes.–In general, surveys conducted in Michigan in the past 10 years used the same methods we used on Lake Leelanau, 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, we used recent angler 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).

We estimated 112,112 angler hours occurred on Lake Leelanau during the year from April 27 through September 30, 2002 and January 1 through March 31, 2003. This corresponds to 13.0 hours per acre, which is about average compared to other large lakes in Michigan (Table 26). The harvest per acre for Lake Leelanau was 1.8 per acre, which is low relative to other large lakes (Table 26), though Leelanau does not have a popular panfish fishery to boost the total harvest like some of the other lakes. Also, the release rate of game fish was relatively high in Lake Leelanau. For example, the percentages of the total walleyes and northern pike catches that were released were 75 and 95, respectively, while the averages for five previously surveyed large lake populations were 41% and 71%, respectively.

For walleyes, our estimated annual harvest from Lake Leelanau was 1.09 fish per acre, and more specifically, it was 1.47 per acre in the south basin. This harvest is above average relative to other waters in Michigan. In fact, it is the highest we have observed thus far in the Large Lakes Program and is exceeded only by Chicagon Lake, Iron County, which had an estimated harvest of 1.68 walleyes per acre in 1993-94 (Lockwood 2000b). The average harvest of seven large Michigan lakes surveyed thus far in the Large Lake Program was 0.73 walleyes per acre, ranging from 0.49 for Michigamme Reservoir to 1.47 for the south basin of Lake Leelanau. The average harvest of six other large Michigan Lakes (>1,000 acres) reported by Lockwood (2000b) was 0.63 walleyes per acre, ranging from 0.09 for Brevoort Lake to 1.68 for Chicagon Lake. These Michigan lakes all were subject to similar gears and fishing regulations, including a 15-in-minimum size limit.

For northern pike, our estimated annual harvest from Lake Leelanau was 0.019 fish per acre. This harvest was below average compared to other waters in Michigan and elsewhere. The average harvest in four other lakes we have sampled in the Large Lakes Program was 0.135 northern pike per acre, ranging from 0.004 in Crooked-Pickerel lakes (Hanchin et al. 2005b) to 0.460 in Houghton Lake (Clark et al. 2004). The average harvest of seven other large Michigan lakes (>1,000 acres) reported by Lockwood (2000b) was 0.151 northern pike per acre, ranging from 0.002 per acre in Bond Falls

Flowage, Gogebic County to 0.654 per acre in Fletcher Pond, Alpena County. These Michigan lakes all were subject to similar gears and fishing regulations, including a 24-in 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.

For smallmouth bass, the total catch (harvest + release) in Lake Leelanau was 5,792. This exceeded the total annual catch of smallmouth bass in Houghton Lake (3,049; Clark et al. 2004), Crooked and Pickerel lakes (1,300; Hanchin et al. 2005b), and Burt Lake (796; Hanchin et al. 2005c). The annual harvest of smallmouth bass in Lake Leelanau was 0.047 per acre, which is slightly below average compared to other waters in Michigan. The average harvest in four other lakes we have sampled in the Large Lakes Program was 0.053 smallmouth bass per acre, ranging from 0.007 in Burt Lake (Hanchin et al. 2005c) to 0.094 in Houghton Lake (Clark et al. 2004). The average harvest of seven other large Michigan lakes (>1,000 acres) reported by Lockwood (2000b) was 0.088 smallmouth bass per acre, ranging from 0.026 per acre in Brevoort Lake, Mackinac County to 0.146 per acre in Elk Lake, Antrim, and Grand Traverse counties.

Management Implications

The walleye fishery in Lake Leelanau is one of the best in Michigan. In 2002-03, the lake contained an estimated 6.4 adult walleyes per acre and anglers harvested 1.09 per acre at a rate of 0.084 per hour fished. These are among the highest values found in Michigan or elsewhere. It remains to be seen if the fishery is sustainable at this high level. Available data strongly suggests that this good walleye fishery is a relatively recent phenomenon, probably beginning in about 1989. We know that walleye abundance was very low prior to the 1980s. No walleyes were reported captured in MDNR netting surveys of 1949 and 1967, and only trace numbers were reported caught by anglers in creel surveys conducted from 1928 to 1963 (Laarman 1976). No walleyes over age 13 (the 1989 year class) were present in our collections in 2002, despite finding a low total mortality rate that should have produced at least some fish older than age 15. Apparently, strong natural reproduction did not occur prior to 1989. In addition, MDNR surveys showed that walleye growth has declined between 1978 and 2002, which could be a result of increasing walleye density.

It is impossible to know with certainty if favorable natural events, fisheries management activities, or both generated the big increase in walleye abundance in Lake Leelanau. We know walleyes were present at low levels in the lake as early as 1928–39 (Laarman 1976), so it is conceivable that favorable natural events during the 1980s caused a walleye population explosion. However, walleye stocking and regulation changes did occur with the correct timing for them to be responsible. The first known walleye stocking occurred in 1975, with yearlings, followed by fingerlings in 1986, although stocking rates were relatively low. Also, Muskegon-River-strain fry were stocked beginning in 1989 (Table 1). Changes in fishing regulations for walleyes could have been a factor also. The minimum size limit became more restrictive during the period, increasing from 13 to 15 inches in 1976 (Schneider et al. 2006). At the least, given this increase in walleye abundance in recent years, we must assume that current fishing regulations are adequately protecting the walleye stock.

The north and south basins of Lake Leelanau could be treated as separate lakes for walleye management purposes. Walleyes in the two basins had different population characteristics, in spite of the high degree of movement between basins. Walleyes had a low-density population with near average growth in the north basin, but a high-density population with below average growth in the south basin. The abundance of legal-size and adult walleyes respectively was 10.0 and 10.9 times higher in south than in north. The high walleye density in the south basin likely has a density-dependent effect on growth. Most walleyes in the north basin were legal size by age 4, but they were not legal size in the south basin until age 6. Yet, size structure was good for fishing in the south basin, with 69% of the spring spawning stock above the 15-in-minimum size limit. This is similar to Houghton Lake, in which 73% of the spring spawning stock was above 15 in (Clark et al. 2004).

Our estimates of legal and adult walleye abundance were higher than the estimates made a priori using the Wisconsin and Michigan regression equations. However, in the short term, it would be reasonable to apply the regression to estimate legal walleye abundance in Michigan lakes when abundance estimates are needed for management purposes. In the long term, the MDNR should continue to work towards developing an improved regression by conducting abundance estimates in other Michigan lakes.

The northern pike fishery in Lake Leelanau is below average. Only 0.019 northern pike per acre were harvested at a rate of 0.001 per hour. Both these figures are low compared to those in other lakes. Population density is also low compared to other lakes. Yet, natural mortality and growth rates are in acceptable ranges and natural reproduction is consistent from year to year. Thus, we must assume that while reproduction is consistent, the total number of recruits produced is consistently low.

We lacked sufficient sample sizes to calculate separate abundance, growth, and mortality estimates for northern pike in the north and south basins, although the abundance of spawning northern pike was clearly greater in the south basin.

The smallmouth bass fishery in Lake Leelanau is about average. Anglers harvested 0.047 smallmouth bass per acre at a rate of 0.004 per hour, which is similar to other large lakes in Michigan. However, there were numerous smallmouth bass caught and released, and the total catch per acre (0.714) was high relative to the average (0.224) for four other lakes surveyed under the Large Lakes Program. Population density of smallmouth bass is similar to other large, inland lakes, though there are few populations for comparison. Natural mortality and growth rates are in acceptable ranges and natural reproduction is consistent from year to year. We lacked sufficient sample sizes to calculate separate abundance, growth, and mortality estimates for smallmouth bass in the north and south basins, although the abundance of smallmouth bass was clearly greater in the south basin.

In Lake Leelanau, the number of fish harvested per acre was below average for other large lakes in Michigan, but this is a result of fishing effort directed at large predators, rather than panfish. The north and south basins have differences, which should be considered when managing their fisheries. The south basin is primarily a walleye and perch fishery, with an average smallmouth bass fishery and a less-than-average northern pike fishery. The perch fishery is not very productive (harvest = 0.652 per acre) relative to the average (1.825) for four other large lakes surveyed recently, which could be a result of a high-density walleye population. The north basin is primarily a coldwater fishery with some opportunity for walleye, perch, and smallmouth bass.

Acknowledgements

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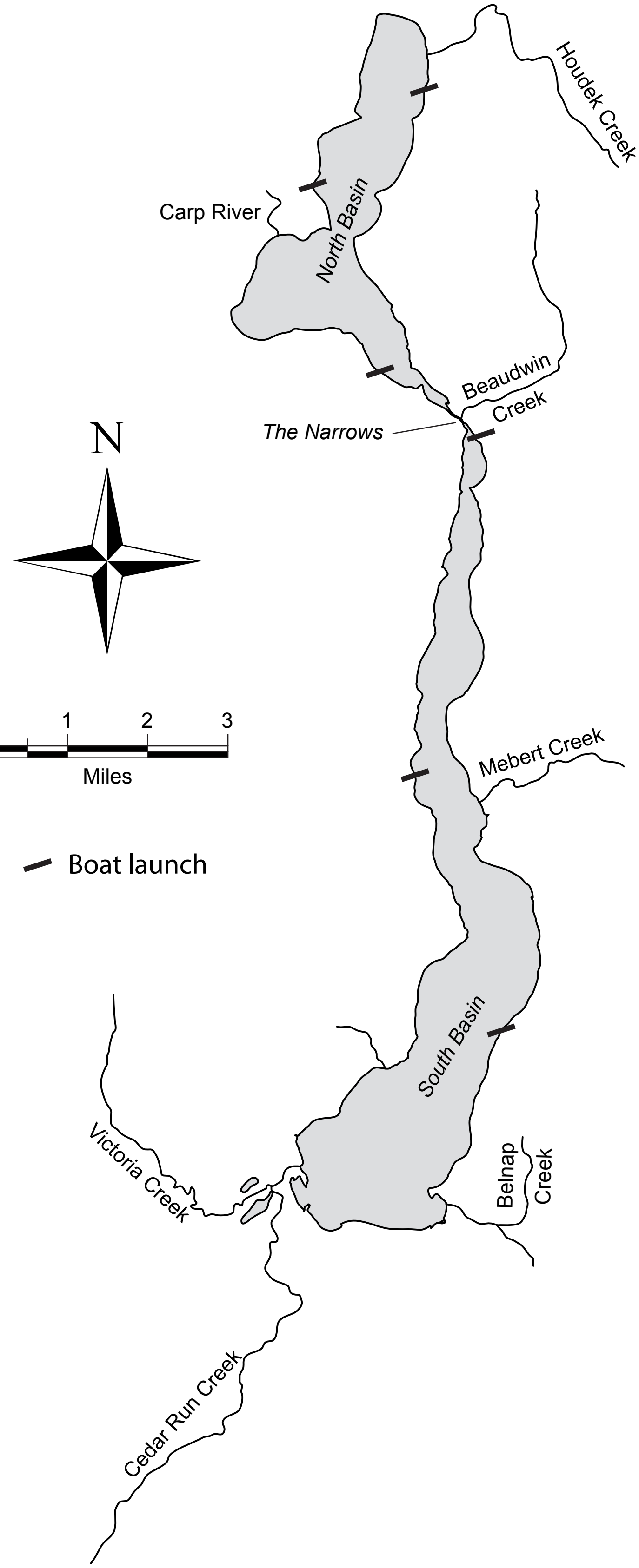

Figure 1.–Map of Lake Leelanau, Leelanau County, Michigan.

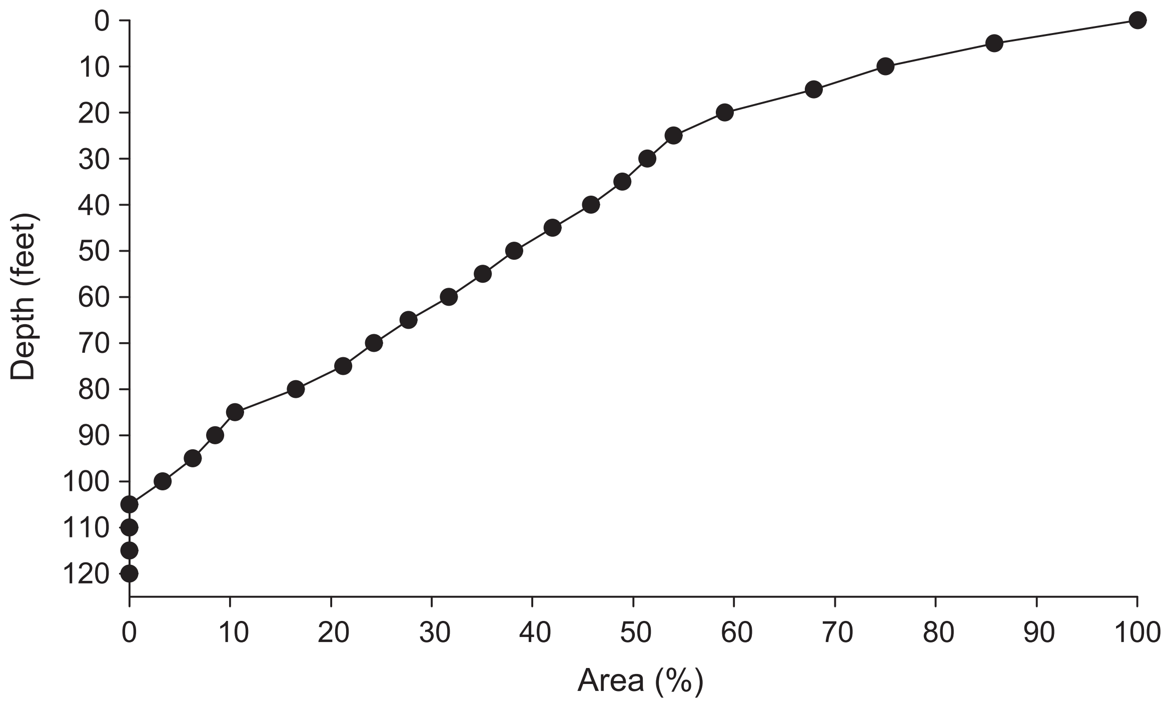

Figure 2.–Percent of area equal to or greater than a given depth for the north basin of Lake Leelanau. Data taken from MDNR Digital Water Atlas (Breck 2004).

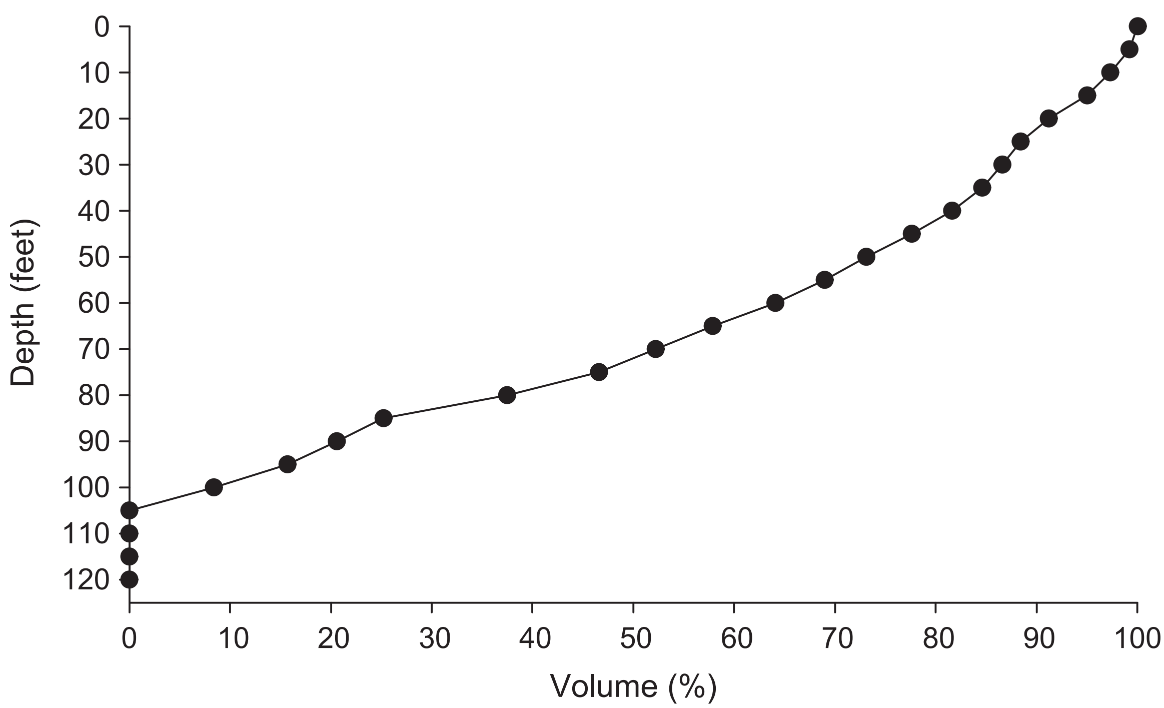

Figure 3.–Percent of volume equal to or greater than a given depth for the north basin of Lake Leelanau. Data taken from MDNR Digital Water Atlas (Breck 2004).

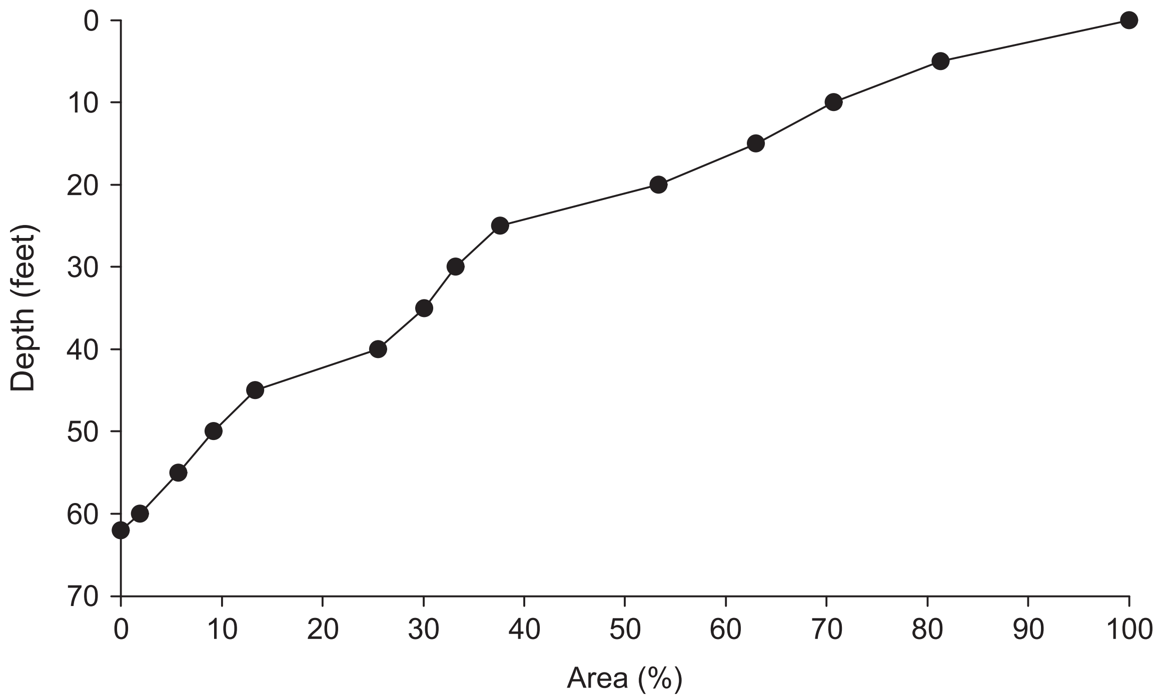

Figure 4.–Percent of area equal to or greater than a given depth for the south basin of Lake Leelanau. Data taken from MDNR Digital Water Atlas (Breck 2004).

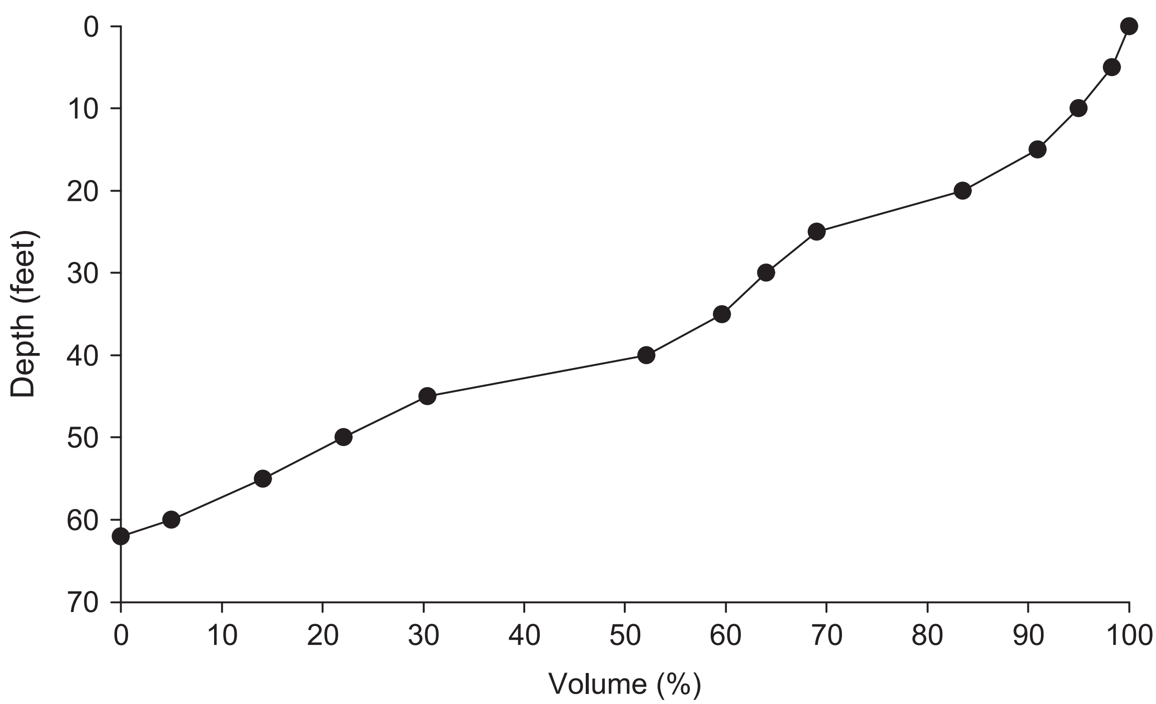

Figure 5.–Percent of volume equal to or greater than a given depth for the south basin of Lake Leelanau. Data taken from MDNR Digital Water Atlas (Breck 2004).

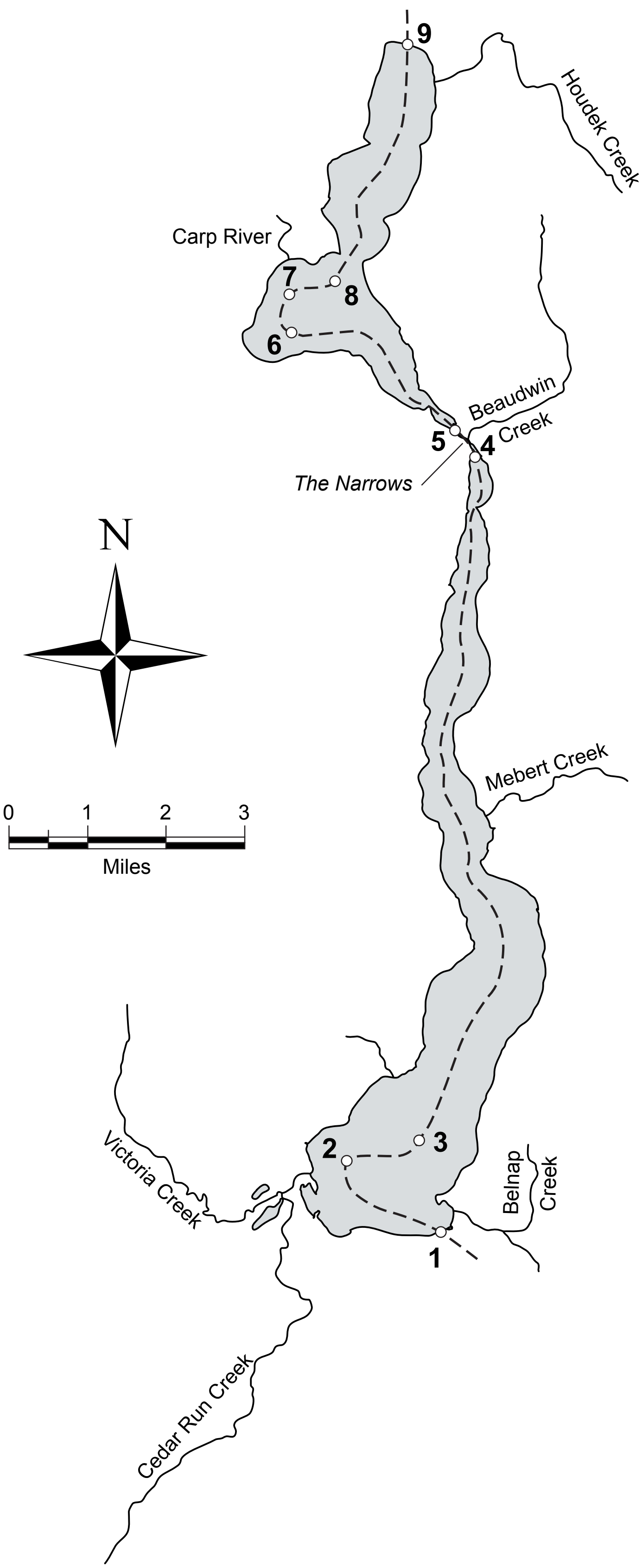

Figure 6.–Counting path and associated way points for Lake Leelanau angler survey. Latitude and longitude for points 1-9 are given in Table 2.

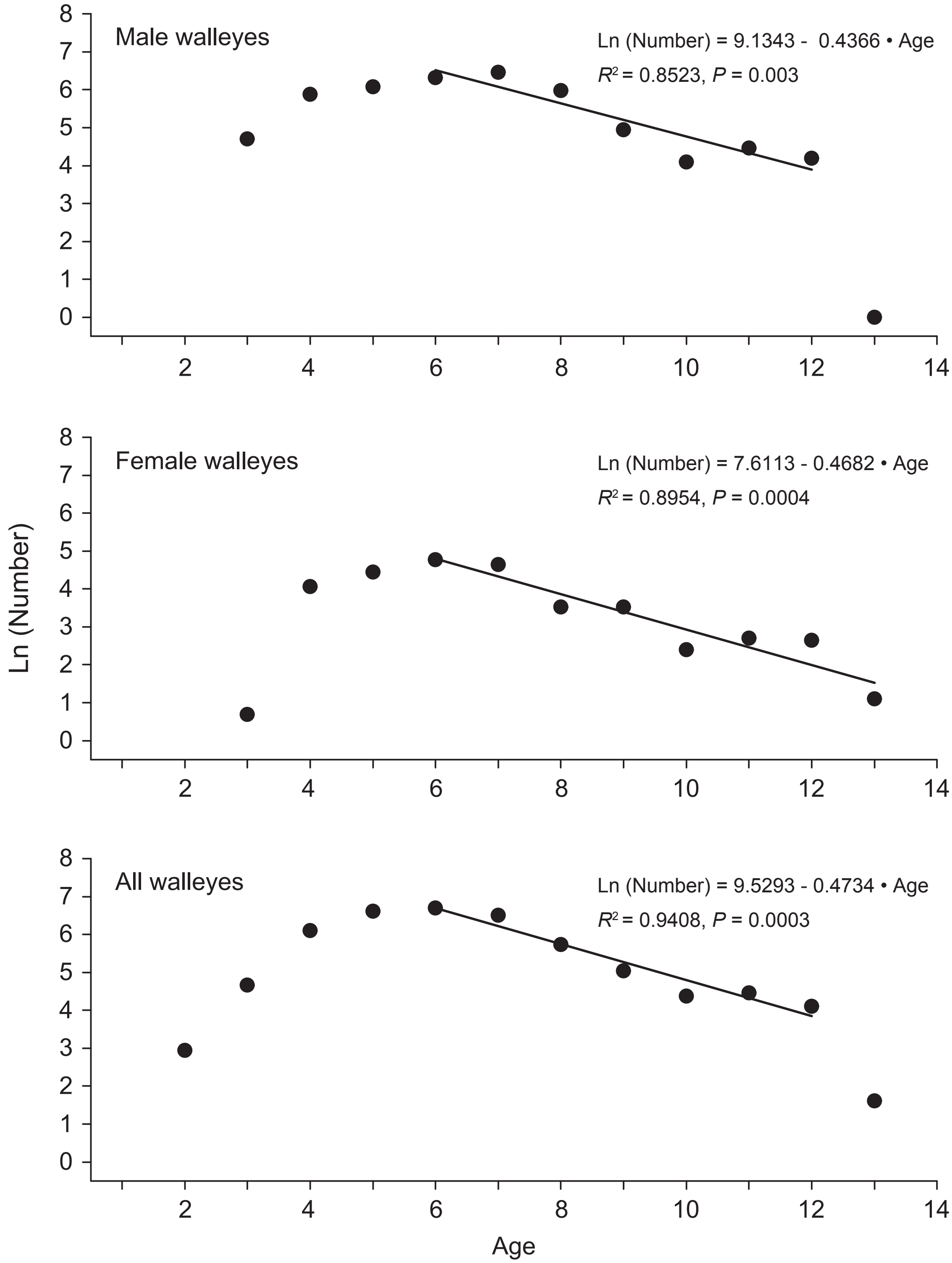

Figure 7.–Plots of observed ln(number) versus age for male, female, and all (including males, females, and unknown sex) walleyes in Lake Leelanau. Lines are plots of regression equations given with each graph.

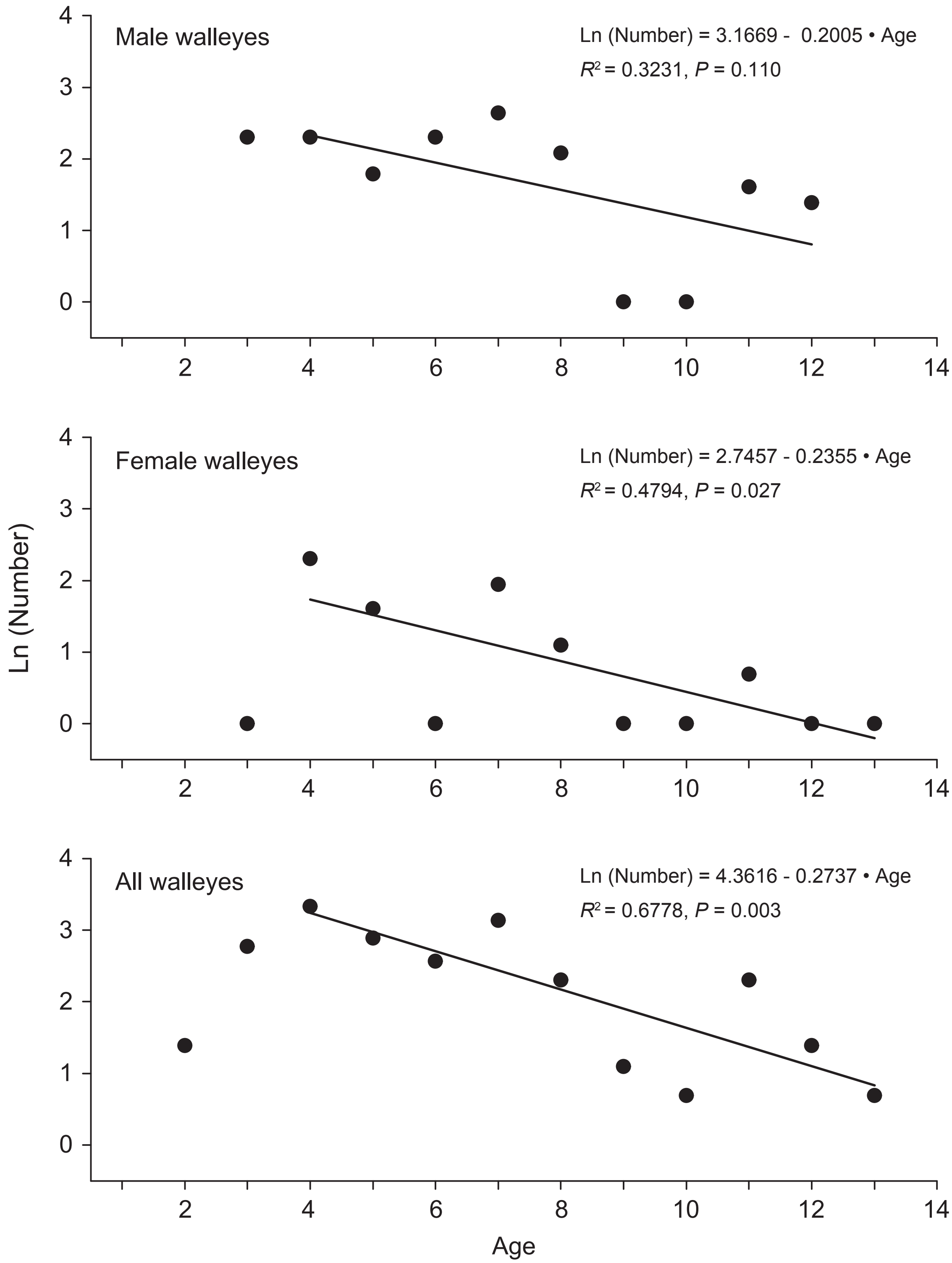

Figure 8.–Plots of observed ln(number) versus age for male, female, and all (including males, females, and unknown sex) walleyes in north basin of Lake Leelanau. Lines are plots of regression equations given with each graph.

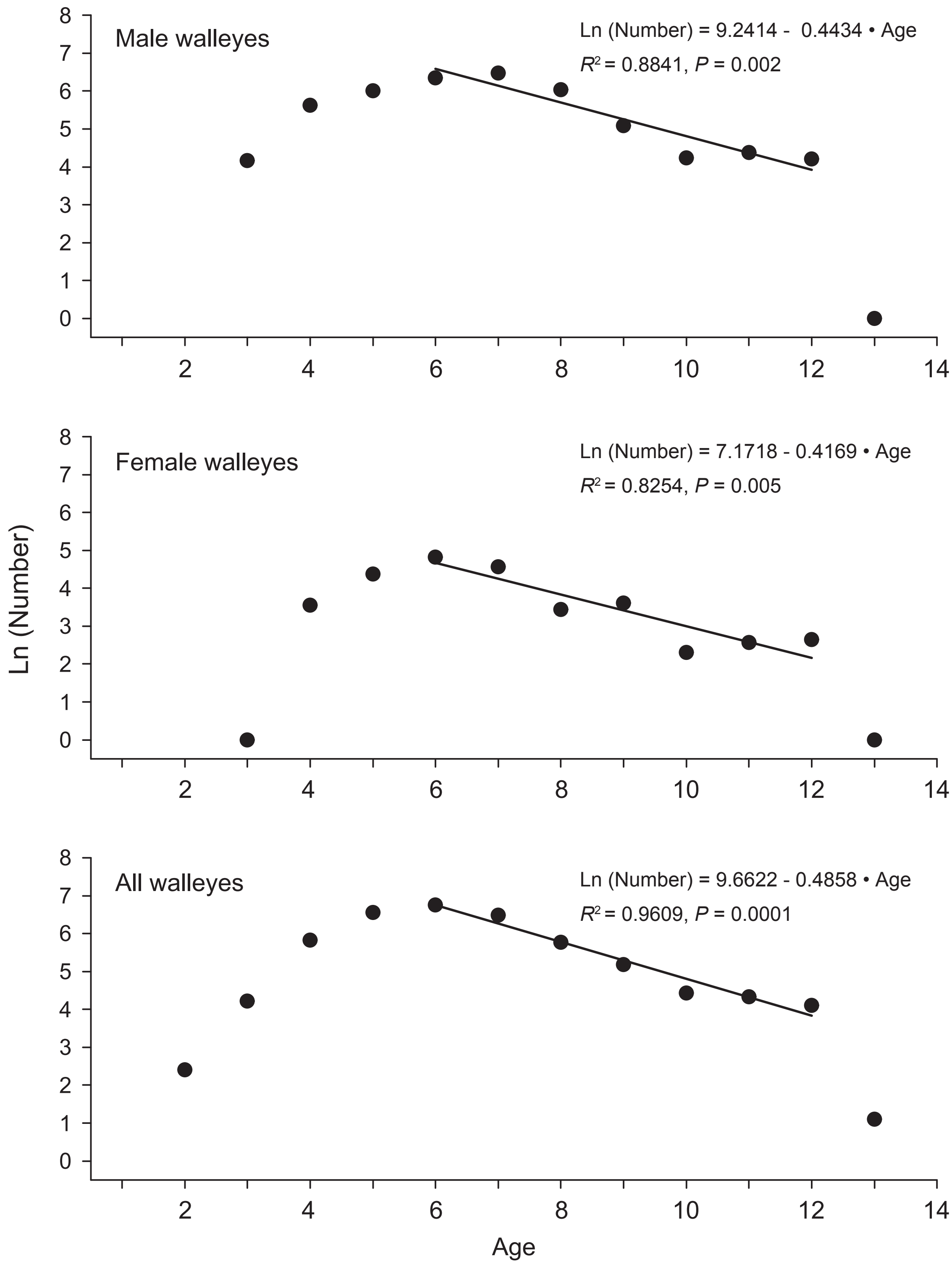

Figure 9.–Plots of observed ln(number) versus age for male, female, and all (including males, females, and unknown sex) walleyes in south basin of Lake Leelanau. Lines are plots of regression equations given with each graph.

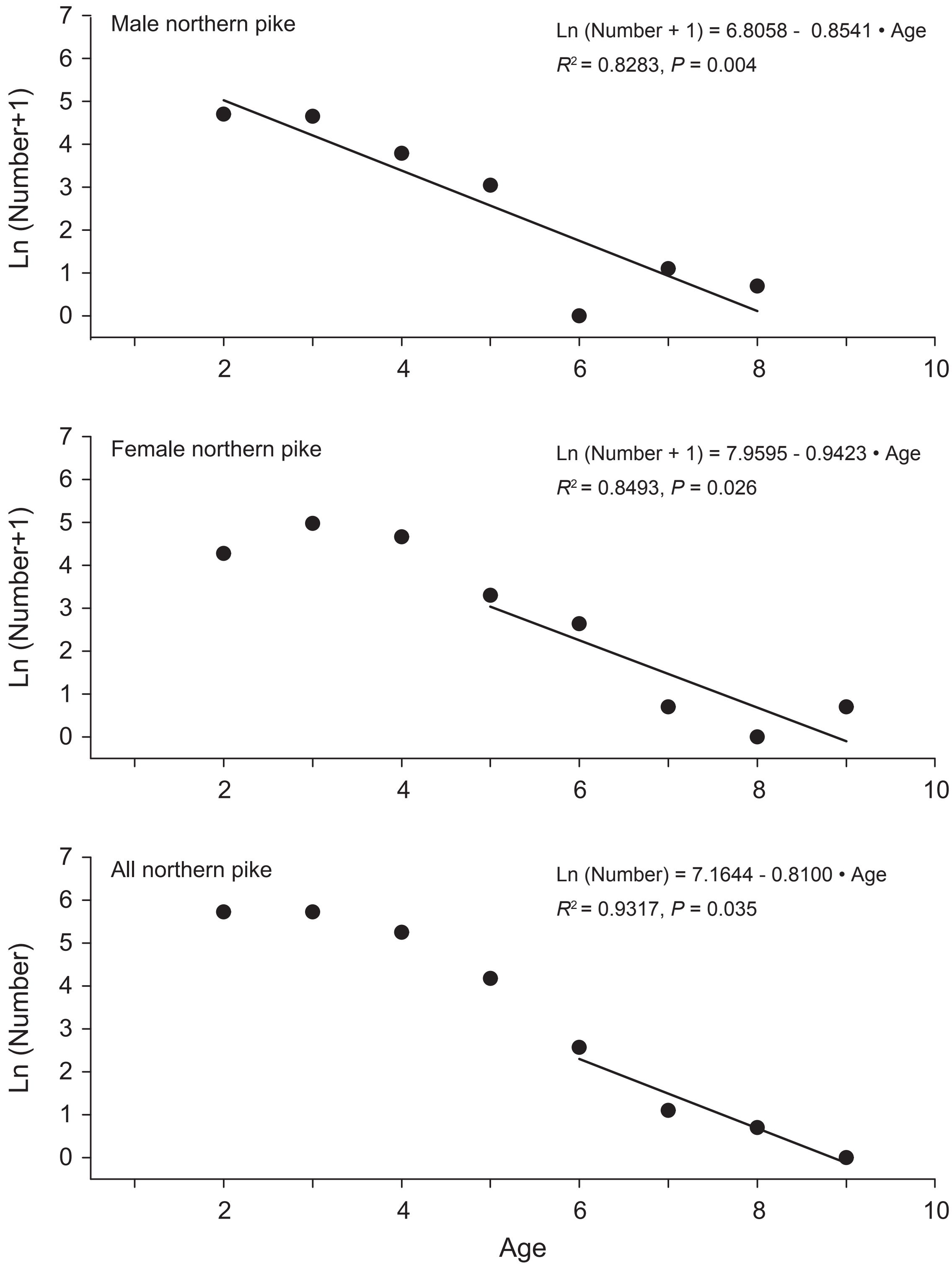

Figure 10.–Plots of observed ln(number) versus age for male, female, and all (including males, females, and unknown sex) northern pike in Lake Leelanau. Lines are plots of regression equations given with each graph.

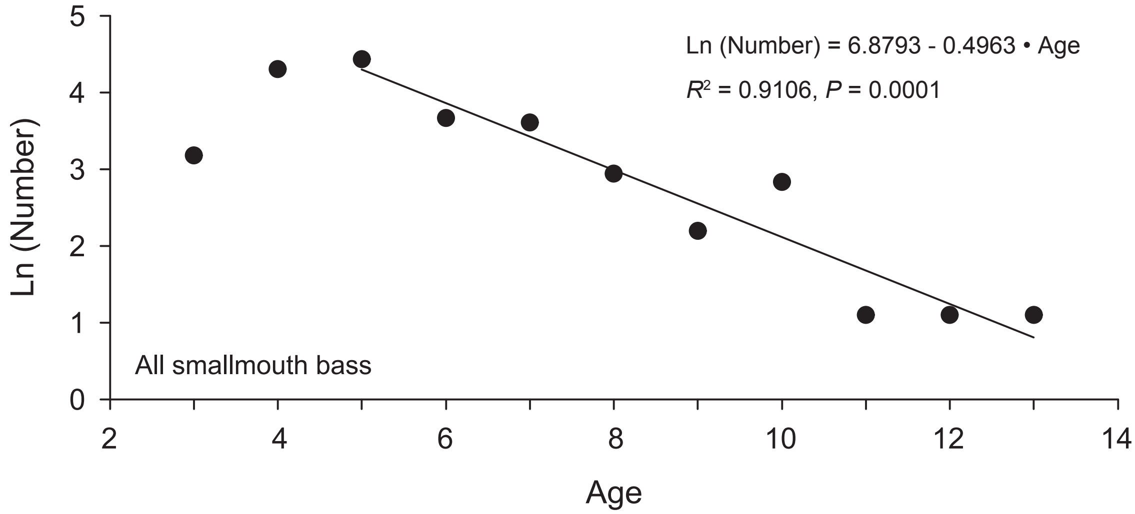

Figure 11.–Plots of observed ln(number) versus age for smallmouth bass in Lake Leelanau. Line is plot of regression equation given with graph.

Table 1.–Fish stocked in Lake Leelanau from 1948 through 2005.

Species Strain	Date	Number	Size
	North basin		
Brown trout			
Wild Rose	1958–65	2,000/year	adults
Seeforellen, Wild Rose, and Plymouth Rock	1974–2000	5,000–40,0000/year	yearlings
Lake trout			
unknown	1948–57	1,000–9,000/year	adults
unknown	1964 and 1965	unknown	adults
primarily Marquette	1970–current	15,000–30,000 (annually when available)	yearlings
Splake			
unknown	1985, 1987, and 1988	13,000–30,000	yearlings
Rainbow trout			
unknown	1949–73 and 1991 (intermittently)	5,000–20,000	yearlings
Lake whitefish			
Lake Michigan	1995	27,000	fingerlings
	South basin		
Brown trout			
unknown	1955–64	2,000–5,000	adults
Seeforellen, Plymouth Rock, and Soda Lake	1968–91	7,000–20,000	yearlings
Lake trout			
unknown	1947	1,000	adults
Rainbow trout			
unknown	1950 and 1951	2,500 and 5,000	yearlings
unknown	1965	25,000	fingerlings
unknown	1970	355	adults
Bluegill			
unknown	1996, 1999, 2001, and 2005	3,800–5,600	yearlings and adults
Walleye			
unknown	1903–13	1,420,000	fry
unknown	1933–42	3,240,000	fry
unknown	1975	8,400	yearlings
Bay de Noc	1986	50	fingerlings
Muskegon	1989	6,113,550	fry
Muskegon	1992	6,500,000	fry
Muskegon	1995	6,500,000	fry
Muskegon	1998	5,000,000	fry
Muskegon	2001	5,500,000	fry

Table 2.–GPS coordinates for Lake Leelanau angler survey. See Figure 6 for general flight path and numbered locations.

Location	Latitude	Longitude
(SE end of Lake Leelanau) 1	44°50.20′	85°43.13′
2	44°51.03′	85°44.67′
3	44°51.08′	85°43.84′
4	44°58.77′	85°42.64′
5	44°59.03′	85°42.93′
6	45°00.12′	85°45.53′
7	45°00.52′	85°45.54′
8	45°00.60′	85°44.84′
(N end of Lake Leelanau) 9	45°03.30′	85°43.66′

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

Survey period	Sample shifts (h)		F
May 15–31	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	0630–1500	1200–1900	14
December 15–31	0700–1530	1100–1930	14
January	0700–1530	1100–1930	14
February	0700–1530	1100–1930	14
March	0700–1530	1100–1930	14

Table 4.–Fish collected from Lake Leelanau using a total sampling effort of 197 trap-net lifts, 88 fyke-net lifts, and 8 electrofishing runs from April 8 to 26, 2002.

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	4,308	37.8	11.4	19.0	7.7–23.0	18.8	365
Walleye	3,680	32.3	11.6	4.1	6.1–29.2	16.2	3,500
Northern pike	992	8.7	3.1	0.5	9.6–42.0	20.2	906
Rock bass	726	6.4	2.7	0.7	3.3–12.0	8.3	647
Yellow perch	643	5.6	1.5	0.4	4.5–13.2	7.2	477
Bowfin	370	3.3	1.0	0.1	14.1–28.5	22.5	196
Smallmouth bass	318	2.8	1.4	0.1	9.9–20.1	15.9	308
Lake Herring	86	0.8	0.3	0.2	8.6–16.6	9.9	78
Largemouth bass	52	0.5	0.1	<0.1	11.4–19.7	15.4	52
Brown bullhead	49	0.4	0.2	<0.1	10.4–14.5	12.9	49
Bluegill	36	0.3	0.1	<0.1	4.0–9.6	6.6	36
Brown trout	34	0.3	<0.1	0	5.4–22.3	10.1	34
Pumpkinseed	33	0.3	0.1	<0.1	4.2–8.8	6.3	33
Black bullhead	20	0.2	<0.1	<0.1	9.0–14.7	12.5	20
Burbot	14	0.1	<0.1	<0.1	19.8–27.4	23.7	14
Central mudminnow	8	<0.1	<0.1	0	–	–	0
Gar	5	<0.1	<0.1	<0.1	26.1–31.6	29.7	4
Yellow bullhead	3	<0.1	<0.1	<0.1	9.0–12.0	10.0	3
Rainbow smelt	3	<0.1	0	0	2.4–4.8	3.9	3
Brook trout	2	<0.1	<0.1	0	12.7–13.4	13.0	2

[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.–Fish collected from north basin of Lake Leelanau using a total sampling effort of 48 trap-net lifts, 76 fyke-net lifts, and 3 electrofishing runs from April 8 to 26, 2002.

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	2,778	81.6	20.9	21.4	10.9–23.0	18.9	351
Walleyes	161	4.7	0.7	0.4	6.1–28.4	16.3	156
Yellow perch	128	3.8	1.5	0.4	4.6–12.1	6.8	126
Northern pike	86	2.5	1.3	0.2	11.5–42.0	20.7	81
Lake herring	86	2.5	1.4	0.2	8.6–16.6	9.9	78
Rock bass	78	2.3	0.9	0.4	3.3–11.3	7.1	78
Smallmouth bass	25	0.7	0.4	0	10.4–19.8	16.4	23
Pumpkinseed	16	0.5	0.2	0.1	4.8–8.8	6.5	16
Largemouth bass	14	0.4	0.2	<0.1	12.1–17.9	15.3	14
Bluegill	12	0.4	0.1	0.1	4.0–8.1	7.0	12
Brown bullhead	7	0.2	0.1	0	12.0–14.2	13.2	7
Bowfin	4	0.1	0.1	0	19.5–28.5	23.1	4
Black bullhead	3	0.1	<0.1	<0.1	9.0–14.7	12.6	3
Rainbow smelt	3	0.1	0	0	2.4–4.8	3.9	3
Central mudminnow	3	0.1	0.1	0	–	–	0
Burbot	1	<0.1	<0.1	0	27.4	27.4	1
Brown trout	1	<0.1	0	0	11.9	11.9	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 6.–Fish collected from south basin of Lake Leelanau using a total sampling effort of 149 trap-net lifts, 12 fyke-net lifts, and 5 electrofishing runs from April 8 to 26, 2002.

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]
Walleye	3,519	44.1	15.1	27.9	6.7–29.2	16.2	3,344
White sucker	1,530	19.2	8.4	3.7	7.7–22.0	18.2	14
Northern pike	906	11.4	3.7	2.0	9.6–40.0	20.1	825
Rock bass	648	8.1	3.3	2.9	3.9–12.0	8.5	569
Yellow perch	515	6.5	1.5	0.6	4.5–13.2	7.4	351
Bowfin	366	4.6	1.4	0.9	14.1–28.3	22.5	192
Smallmouth bass	293	3.7	1.7	0.6	9.9–20.1	15.9	285
Brown bullhead	42	0.5	0.2	0.1	10.4–14.5	12.9	42
Largemouth bass	38	0.5	0.1	0	11.4–19.7	15.4	38
Brown trout	33	0.4	0.1	0	5.4–22.3	10.1	33
Bluegill	24	0.3	0.1	0	4.8–9.6	6.4	24
Pumpkinseed	17	0.2	0.1	0	4.2–8.2	6.1	17
Black bullhead	17	0.2	<0.1	0	10.7–14.1	12.4	17
Burbot	13	0.2	<0.1	0.1	19.8–24.8	23.4	13
Central mudminnow	5	0.1	<0.1	0	–	–	0
Gar	5	0.1	<0.1	0.1	26.1–31.6	29.7	4
Yellow bullhead	3	<0.1	<0.1	0.1	9.0–12.0	10.0	3
Brook trout	2	<0.1	<0.1	0	12.7–13.4	13.0	2

[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 7.–Number of fish per inch group caught and measured in spring netting and electrofishing operations on Lake Leelanau, April 8 to 26, 2002.

Inch group	Species																		
	Walleyes	Northern pike	Rock bass	Yellow perch	White sucker	Bowfin	Smallmouth bass	Lake herring	Largemouth bass	Brown bullhead	Bluegill	Brown trout	Pumpkinseed	Black bullhead	Burbot	Gar	Yellow bullhead	Rainbow smelt	Brook trout
2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–
3	–	–	4	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
4	–	–	20	10	–	–	–	–	–	–	2	–	5	–	–	–	–	2	–
5	–	–	52	55	–	–	–	–	–	–	11	1	9	–	–	–	–	–	–
6	14	–	97	146	–	–	–	–	–	–	8	4	11	–	–	–	–	–	–
7	8	–	121	143	1	–	–	–	–	–	13	4	3	–	–	–	–	–	–
8	3	–	56	81	–	–	–	3	–	–	1	5	5	–	–	–	–	–	–
9	6	1	117	32	–	–	1	55	–	–	1	6	–	1	–	–	2	–	–
10	10	2	131	7	1	–	5	8	–	2	–	5	–	2	–	–	–	–	–
11	15	15	48	1	1	–	15	8	3	7	–	3	–	5	–	–	–	–	–
12	78	12	1	1	–	–	14	3	2	10	–	2	–	2	–	–	1	–	1
13	291	9	–	1	–	–	23	–	2	22	–	1	–	7	–	–	–	–	1
14	666	10	–	–	1	1	32	–	10	8	–	–	–	3	–	–	–	–	–
15	759	23	–	–	2	1	41	–	15	–	–	1	–	–	–	–	–	–	–
16	597	55	–	–	26	2	47	1	12	–	–	–	–	–	–	–	–	–	–
17	401	106	–	–	59	–	82	–	6	–	–	–	–	–	–	–	–	–	–
18	233	131	–	–	103	10	35	–	–	–	–	–	–	–	–	–	–	–	–
19	148	106	–	–	79	15	11	–	2	–	–	–	–	–	1	–	–	–	–
20	93	96	–	–	56	26	2	–	–	–	–	1	–	–	–	–	–	–	–
21	62	98	–	–	29	29	–	–	–	–	–	–	–	–	–	–	–	–	–
22	38	65	–	–	6	38	–	–	–	–	–	1	–	–	1	–	–	–	–
23	35	57	–	–	1	20	–	–	–	–	–	–	–	–	7	–	–	–	–
24	12	44	–	–	–	14	–	–	–	–	–	–	–	–	4	–	–	–	–
25	8	28	–	–	–	9	–	–	–	–	–	–	–	–	–	–	–	–	–
26	7	12	–	–	–	15	–	–	–	–	–	–	–	–	–	1	–	–	–
27	9	8	–	–	–	10	–	–	–	–	–	–	–	–	1	–	–	–	–
28	6	5	–	–	–	6	–	–	–	–	–	–	–	–	–	–	–	–	–
29	1	4	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
30	–	6	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–
31	–	3	–	–	–	–	–	–	–	–	–	–	–	–	–	2	–	–	–
32	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
33	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
34	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
35	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
36	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
37	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
38	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
39	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
40	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
41	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
42	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Total	3,500	906	647	477	365	196	308	78	52	49	36	34	33	20	14	4	3	3	2

Table 8.–Number of fish per inch group caught and measured in spring netting and electrofishing operations on the north basin of Lake Leelanau, April 8 to 26, 2002.

	Species															
Inch group	White sucker	Walleyes	Yellow perch	Northern pike	Lake herring	Rock bass	Smallmouth bass	Pumpkinseed	Largemouth bass	Bluegill	Brown bullhead	Bowfin	Black bullhead	Smelt	Burbot	Brown trout
2	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–
3	–	–	–	–	–	3	–	–	–	–	–	–	–	–	–	–
4	–	–	1	–	–	10	–	1	–	1	–	–	–	2	–	–
5	–	–	17	–	–	18	–	5	–	1	–	–	–	–	–	–
6	–	13	62	–	–	12	–	6	–	2	–	–	–	–	–	–
7	–	7	33	–	–	9	–	–	–	7	–	–	–	–	–	–
8	–	2	8	–	3	4	–	4	–	1	–	–	–	–	–	–
9	–	–	4	–	55	5	–	–	–	–	–	–	1	–	–	–
10	1	3	–	–	8	14	1	–	–	–	–	–	–	–	–	–
11	1	1	–	4	8	3	1	–	–	–	–	–	–	–	–	1
12	–	3	1	3	3	–	1	–	1	–	2	–	–	–	–	–
13	–	10	–	3	–	–	1	–	2	–	4	–	–	–	–	–
14	1	8	–	1	–	–	1	–	4	–	1	–	2	–	–	–
15	1	20	–	–	–	–	2	–	2	–	–	–	–	–	–	–
16	26	18	–	1	1	–	4	–	1	–	–	–	–	–	–	–
17	59	13	–	5	–	–	6	–	4	–	–	–	–	–	–	–
18	97	12	–	5	–	–	3	–	–	–	–	–	–	–	–	–
19	77	13	–	7	–	–	3	–	–	–	–	1	–	–	–	–
20	53	9	–	11	–	–	–	–	–	–	–	–	–	–	–	–
21	29	6	–	10	–	–	–	–	–	–	–	1	–	–	–	–
22	5	4	–	5	–	–	–	–	–	–	–	–	–	–	–	–
23	1	7	–	9	–	–	–	–	–	–	–	1	–	–	–	–
24	–	1	–	10	–	–	–	–	–	–	–	–	–	–	–	–
25	–	1	–	3	–	–	–	–	–	–	–	–	–	–	–	–
26	–	2	–	2	–	–	–	–	–	–	–	–	–	–	–	–
27	–	2	–	–	–	–	–	–	–	–	–	–	–	–	1	–
28	–	1	–	1	–	–	–	–	–	–	–	1	–	–	–	–
29	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
30	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
31	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
32	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
33	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
34	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
35	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
36	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
37	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
38	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
39	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
40	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
41	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
42	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–
Total	351	156	126	81	78	78	23	16	14	12	7	4	3	3	1	1

Table 9.–Number of fish per inch group caught and measured in spring netting and electrofishing operations on the south basin of Lake Leelanau, April 8 to 26, 2002.

	Species																
Inch group	Walleyes	Northern pike	Rock bass	Yellow perch	Bowfin	Smallmouth bass	Brown bullhead	Largemouth bass	Brown trout	Bluegill	Pumpkinseed	Black bullhead	White sucker	Burbot	Gar	Yellow bullhead	Brook trout
2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
3	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–
4	–	–	10	9	–	–	–	–	–	1	4	–	–	–	–	–	–
5	–	–	34	38	–	–	–	–	1	10	4	–	–	–	–	–	–
6	1	–	85	84	–	–	–	–	4	6	5	–	–	–	–	–	–
7	1	–	112	110	–	–	–	–	4	6	3	–	1	–	–	–	–
8	1	–	52	73	–	–	–	–	5	–	1	–	–	–	–	–	–
9	6	1	112	28	–	1	–	–	6	1	–	–	–	–	–	2	–
10	7	2	117	7	–	4	2	–	5	–	–	2	–	–	–	–	–
11	14	11	45	1	–	14	7	3	2	–	–	5	–	–	–	–	–
12	75	9	1	–	–	13	8	1	2	–	–	2	–	–	–	1	1
13	281	6	–	1	–	22	18	–	1	–	–	7	–	–	–	–	1
14	658	9	–	–	1	31	7	6	–	–	–	1	–	–	–	–	–
15	739	23	–	–	1	39	–	13	1	–	–	–	1	–	–	–	–
16	579	54	–	–	2	43	–	11	–	–	–	–	–	–	–	–	–
17	388	101	–	–	–	76	–	2	–	–	–	–	–	–	–	–	–
18	221	126	–	–	10	32	–	–	–	–	–	–	6	–	–	–	–
19	135	99	–	–	14	8	–	2	–	–	–	–	2	1	–	–	–
20	84	85	–	–	26	2	–	–	1	–	–	–	3	–	–	–	–
21	56	88	–	–	28	–	–	–	–	–	–	–	–	–	–	–	–
22	34	60	–	–	38	–	–	–	1	–	–	–	1	1	–	–	–
23	28	48	–	–	19	–	–	–	–	–	–	–	–	7	–	–	–
24	11	34	–	–	14	–	–	–	–	–	–	–	–	4	–	–	–
25	7	25	–	–	9	–	–	–	–	–	–	–	–	–	–	–	–
26	5	10	–	–	15	–	–	–	–	–	–	–	–	–	1	–	–
27	7	8	–	–	10	–	–	–	–	–	–	–	–	–	–	–	–
28	5	4	–	–	5	–	–	–	–	–	–	–	–	–	–	–	–
29	1	4	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
30	–	6	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–
31	–	3	–	–	–	–	–	–	–	–	–	–	–	–	2	–	–
32	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
33	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
34	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
35	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
36	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
37	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
38	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
39	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
40	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Total	3,344	825	569	351	192	285	42	38	33	24	17	17	14	13	4	3	2

Table 10.–Estimates of abundance, angler exploitation rates, and instantaneous fishing mortality rates for Lake Leelanau walleye, northern pike, and smallmouth bass using the different methods described in text. Symmetrical 95% confidence intervals for estimates are given in parentheses, where applicable.

Parameter	Walleyes	Northern pike	Smallmouth bass
Number tagged	2,368	116	246
Total tag returns	332	20	32
Number of legal-size[a] fish			
Multiple-census estimate	22,351 (13,724–30,978)	282 (184–380)	2,543 (1,558–3,528)
Indirect, single-census estimate[b]	35,952 (24,085–47,819)	–	–
Michigan model prediction[c]	13,353 (2,755–64,729)	–	–
Number of adult[d] fish			
Multiple-census method	42,679 (26,603–58,755)	6,349 (3,624–9,074)	–
Indirect, single-census estimate[b]	54,665 (33,761–75,569)	–	–
Michigan model prediction[e]	18,539 (4,296–80,014)	–	–
Annual exploitation rates			
Based on reward tag returns	16.0%	25.9%	13.7%
Based on harvest/abundance[f]	21.2% (14.5 − 27.9%)	57.4% (11.9–100%)	14.2% (5.4–23.0%)
Instantaneous fishing rates (F)			
Based on reward tag returns	0.2007	0.3778	0.1738
Based on harvest/abundance[e]	0.4284	0.8384	0.1800

[a] Walleyes ≥15 in, northern pike ≥24 in, smallmouth bass ≥14 in.
[b] Predicted single-census estimate based on regression equation of multiple-census and single-census estimates from other populations. See **Discussion** section for explanation.
[c] Michigan model prediction of legal walleye abundance based on lake area, $N = 21$.
[d] Fish of legal-size and sexually mature fish of sub-legal size on spawning grounds.
[e] Michigan model prediction of adult walleye abundance based on lake area, $N = 35$.
[f] Indirect, single-census estimates of legal-size fish abundance for walleyes and northern pike and multiple-census estimate for northern pike and smallmouth bass.

Table 11.–Weighted mean lengths and sample sizes (number aged) by age and sex for walleyes collected from Lake Leelanau, April 8 to 26, 2002. Standard deviation is in parentheses.

Age	Mean length						Number aged		
	Males		Females		All fish [a]		Males	Females	All fish [a]
2	–		–		10.8	(1.2)	–	–	11
3	14.4	(1.9)	13.1	(0.7)	13.6	(1.8)	18	2	27
4	14.7	(1.4)	17.4	(1.8)	15.3	(1.9)	22	19	43
5	14.5	(1.2)	16.4	(1.7)	15.1	(1.4)	20	28	53
6	15.5	(1.5)	17.1	(2.0)	15.9	(1.7)	22	40	65
7	16.3	(1.3)	18.4	(2.0)	16.9	(1.6)	34	37	73
8	16.8	(1.6)	19.8	(2.8)	17.4	(2.1)	29	15	45
9	17.8	(1.8)	20.4	(2.7)	18.5	(2.4)	17	17	37
10	18.6	(2.5)	22.1	(4.5)	18.1	(3.4)	13	7	20
11	19.5	(2.0)	25.8	(2.4)	21.2	(3.1)	23	12	41
12	19.8	(2.2)	26.7	(1.8)	21.5	(3.5)	19	11	30
13	24.4	(–)	23.4	(2.7)	23.6	(2.0)	1	2	4

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

Table 12.–Weighted mean lengths and sample sizes (number aged) by age and sex for walleyes collected from north basin of Lake Leelanau, April 8 to 26, 2002. Standard deviation is in parentheses.

Age	Mean length						Number aged		
	Males		Females		All fish [a]		Males	Females	All fish [a]
2	–		–		11.5	(1.0)	–	–	4
3	13.7	(1.3)	13.6	(–)	13.4	(1.3)	3	1	6
4	15.5	(1.8)	18.1	(0.9)	16.6	(1.9)	3	7	11
5	16.0	(0.8)	18.0	(2.1)	16.8	(1.5)	2	4	8
6	17.8	(1.2)	17.5	(–)	18.5	(1.3)	5	1	8
7	17.6	(2.5)	19.3	(2.9)	18.0	(2.4)	6	6	14
8	17.4	(2.3)	23.3	(2.4)	19.2	(3.6)	4	3	7
9	19.9	(–)	23.6	(–)	21.1	(2.1)	1	1	2
10	23.7	(–)	23.4	(–)	23.6	(0)	1	1	2
11	21.1	(1.3)	27.0	(0.7)	22.3	(2.7)	5	2	9
12	22.5	(1.1)	27.6	(–)	23.8	(2.8)	3	1	4
13	–		26.5	(–)	25.0	(2.2)	–	1	2

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

Table 13.–Weighted mean lengths and sample sizes (number aged) by age and sex for walleyes collected from south basin of Lake Leelanau, April 8 to 26, 2002. Standard deviation is in parentheses.

Age	Mean length						Number aged		
	Males		Females		All fish [a]		Males	Females	All fish [a]
2	–		–		9.9	(0.5)	–	–	7
3	14.2	(2.3)	12.6	(–)	13.3	(2.1)	15	1	21
4	14.6	(1.4)	16.9	(2.1)	14.9	(1.8)	19	12	32
5	14.3	(1.1)	16.3	(1.7)	15.0	(1.4)	18	24	45
6	15.3	(1.3)	17.1	(2.0)	15.8	(1.6)	17	39	57
7	16.3	(1.3)	18.2	(1.8)	16.9	(1.6)	28	31	59
8	16.7	(1.6)	19.0	(2.5)	17.3	(1.9)	25	12	38
9	17.6	(1.7)	20.3	(2.6)	18.3	(2.3)	16	16	35
10	18.3	(2.3)	21.6	(4.7)	17.9	(3.3)	12	6	18
11	19.1	(2.0)	25.6	(2.5)	20.8	(3.2)	18	10	32
12	19.4	(2.0)	26.2	(1.9)	21.1	(3.4)	16	10	26
13	24.4	(–)	21.8	(–)	22.7	(1.5)	1	1	2

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

Table 14.–Weighted mean lengths and sample sizes (number aged) by age and sex for northern pike collected from Lake Leelanau, April 8 to April 26, 2002. Standard deviation is in parentheses.

Age	Mean length						Number aged		
	Males		Females		All fish [a]		Males	Females	All fish [a]
2	17.4	(1.3)	18.3	(1.1)	17.5	(1.7)	52	31	113
3	19.1	(1.4)	21.5	(1.9)	20.1	(2.3)	46	59	113
4	21.6	(1.5)	24.0	(2.4)	23.1	(2.3)	26	60	100
5	22.7	(1.0)	25.7	(3.1)	23.8	(2.7)	13	18	36
6	–		30.9	(2.6)	30.9	(2.6)	–	12	12
7	23.8	(–)	35.0	(–)	27.5	(6.5)	1	1	2
8	25.8	(–)	–		32.9	(10)	1	–	2
9	–		35.2	(–)	35.2	(–)	–	1	1

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

Table 15.–Weighted mean lengths and sample sizes (number aged) by age and sex for smallmouth bass collected from Lake Leelanau, April 8 to April 26, 2002. Standard deviation is in parentheses.

Age	Mean length		Number aged
3	12.6	(1.0)	21
4	13.8	(1.8)	62
5	16.1	(1.0)	58
6	16.7	(1.0)	25
7	17.5	(0.5)	21
8	17.7	(0.8)	14
9	18.4	(0.3)	7
10	18.6	(1.0)	12
11	18.7	(0.4)	2
12	19.9	(0.1)	2
13	19.3	(0.8)	2

Table 16.–Catch at age estimates (apportioned by age-length key) by sex for walleyes from Lake Leelanau, April 8 to 26, 2002.

Age	Year class	Lake Leelanau			North basin			South basin		
		Males	Females	All fish [a]	Males	Females	All fish [a]	Males	Females	All fish [a]
2	2000	–	–	19	–	–	4	–	–	11
3	1999	110	2	106	10	1	16	64	1	68
4	1998	356	58	445	10	10	28	276	35	337
5	1997	435	85	737	6	5	18	405	79	697
6	1996	550	118	808	10	1	13	571	124	855
7	1995	638	104	666	14	7	23	650	96	652
8	1994	393	34	308	8	3	10	416	31	319
9	1993	140	34	154	1	1	3	161	37	177
10	1992	60	11	79	1	1	2	69	10	84
11	1991	87	15	86	5	2	10	80	13	76
12	1990	66	14	60	4	1	4	67	14	60
13	1989	1	3	5	–	1	2	1	1	3
Total		2,836	478	3,473	69	33	133	2,760	441	3,339

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

Table 17.–Angler tag returns from walleyes, northern pike, and smallmouth bass (reward and non-reward) by month from Lake Leelanau for the year following tagging. Percentage of total returns is in parentheses.

Month	Number of tag returns		
	Walleye	Northern pike	Smallmouth bass
4	5 (1.5)	1 (5.0)	0 (0)
5	20 (6.0)	6 (30.0)	5 (15.6)
6	53 (16.0)	3 (15.0)	10 (31.3)
7	80 (24.2)	5 (25.0)	7 (21.9)
8	55 (16.6)	3 (15.0)	3 (9.4)
9	36 (10.9)	2 (10.0)	6 (18.8)
10	20 (6.0)	0 (0)	1 (3.1)
11	4 (1.2)	0 (0)	0 (0)
12	3 (0.9)	0 (0)	0 (0)
1	34 (10.3)	0 (0)	0 (0)
2	16 (4.8)	0 (0)	0 (0)
3	5 (1.5)	0 (0)	0 (0)
Total	331	20	32

Table 18.–Catch at age estimates (apportioned by age-length key) by sex for northern pike, and for smallmouth bass (undetermined sex) from Lake Leelanau. Fish were collected from April 8 to 26, 2002.

Age	Year class	Northern pike			Smallmouth bass
		Males	Females	All fish [a]	
2	2000	109	71	307	–
3	1999	104	144	306	24
4	1998	43	105	190	74
5	1997	20	26	65	84
6	1996	–	13	13	39
7	1995	2	1	3	37
8	1994	1	–	2	19
9	1993	–	1	1	9
10	1992	–	–	–	16
11	1991	–	–	–	2
12	1990	–	–	–	2
13	1989	–	–	–	2
Total		279	361	887	308

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

Table 19.–Fish movement depicted from tag returns (reward and non-reward) from walleye, northern pike and smallmouth bass tagged from (April 8 to 26, 2002) in Lake Leelanau for the year following tagging. Percent of total first-year tag returns is in parentheses.

Species	Tagging location	Recapture location	
		North basin	South basin
Walleye	North basin	10 (66.7)	5 (33.3)
	South basin	97 (30.7)	219 (69.3)
Northern pike	North basin	1 (50.0)	1 (50.0)
	South basin	2 (11.1)	16 (88.9)
Smallmouth bass	North basin	3 (75.0)	1 (25.0)
	South basin	5 (17.2)	24 (82.8)

Table 20.–Angler survey estimates for summer 2002 from Lake Leelanau. Survey period was from April 27 through September 30, 2002. Two standard errors are given in parentheses.

Species	Catch/hour	April–May	June	July	August	September	Season
		Number harvested					
Brook trout	0.0003 (0.0005)	24 (49)	0 (0)	0 (0)	0 (0)	0 (0)	24 (49)
Lake trout	0.0024 (0.0023)	52 (64)	26 (52)	143 (193)	0 (0)	0 (0)	221 (210)
Smallmouth bass	0.0044 (0.0023)	106 (105)	93 (87)	0 (0)	64 (76)	146 (133)	408 (205)
Walleye	0.0957 (0.0231)	124 (74)	1,799 (766)	2,804 (974)	2,860 (1,053)	1,323 (685)	8,910 (1,766)
Yellow perch	0.0274 (0.0147)	0 (0)	53 (70)	132 (153)	453 (403)	1,918 (1,244)	2,556 (1,319)
Northern pike	0.0015 (0.0012)	30 (44)	51 (73)	63 (73)	0 (0)	0 (0)	144 (113)
Bluegill	0.0008 (0.0010)	0 (0)	17 (35)	0 (0)	0 (0)	60 (87)	77 (94)
Largemouth bass	0.0002 (0.0004)	0 (0)	20 (40)	0 (0)	0 (0)	0 (0)	20 (40)
Rock bass	0.0057 (0.0037)	5 (11)	9 (17)	129 (148)	41 (54)	349 (299)	533 (339)
White sucker	0.0002 (0.0005)	0 (0)	22 (44)	0 (0)	0 (0)	0 (0)	22 (44)
Total harvested	0.1387 (0.0309)	341 (158)	2,090 (782)	3,270 (1,018)	3,418 (1,132)	3,796 (1,460)	12,916 (2,255)
		Number caught and released					
Lake trout	0.0024 (0.0035)	0 (0)	71 (143)	148 (295)	0 (0)	0 (0)	219 (328)
Smallmouth bass	0.0578 (0.0161)	735 (363)	2,287 (972)	706 (393)	489 (278)	1,167 (612)	5,384 (1,297)
Largemouth bass	0.0013 (0.0011)	20 (24)	13 (26)	44 (87)	20 (41)	19 (23)	116 (105)
Walleye	0.2488 (0.0609)	168 (101)	4,227 (2,027)	9,324 (3,079)	5,385 (2,018)	4,065 (2,033)	23,170 (4,669)
Northern pike	0.0238 (0.0082)	246 (145)	444 (279)	550 (351)	270 (176)	708 (490)	2,218 (702)
White sucker	0.0015 (0.0014)	0 (0)	90 (109)	40 (57)	14 (27)	0 (0)	144 (126)
Rock bass	0.0159 (0.0064)	15 (22)	305 (220)	526 (387)	285 (200)	348 (277)	1,479 (562)
Bowfin	0.0023 (0.0019)	0 (0)	182 (170)	0 (0)	0 (0)	28 (35)	210 (173)
Bluegill	0.0009 (0.0010)	0 (0)	0 (0)	0 (0)	67 (85)	19 (37)	86 (93)
Yellow perch	0.0175 (0.0077)	25 (27)	30 (59)	725 (462)	200 (152)	654 (466)	1,634 (676)
Total release	0.3722 (0.0744)	1,209 (406)	7,650 (2,290)	12,063 (3,197)	6,731 (2,062)	7,008 (2,246)	34,661 (4,992)
Total (harvested + released)	0.5108 (0.0921)	1,550 (436)	9,740 (2,420)	15,333 (3,355)	10,149 (2,352)	10,805 (2,679)	47,577 (5,478)
		Fishing effort					
Angler hours		8,595 (2,913)	22,838 (7,135)	28,453 (6,133)	17,008 (4,750)	16,241 (6,863)	93,135 (12,910)
Angler trips		2,774 (1,319)	6,962 (2,515)	11,744 (7,073)	4,723 (1,744)	5,169 (2,873)	31,372 (8,330)

Table 21.–Angler survey estimates for winter 2003 from Lake Leelanau. Survey period was from January 1, 2002 through March 30, 2003. Two standard errors are given in parentheses.

Species	Catch/hour	January	February	March	Season
		Number harvested			
Lake trout	0.0109 (0.0110)	0 (0)	120 (104)	87 (173)	206 (202)
Lake herring	0.0041 (0.0082)	0 (0)	78 (155)	0 (0)	78 (155)
Walleye	0.0262 (0.0157)	28 (54)	245 (186)	224 (189)	496 (270)
Yellow perch	0.0922 (0.0721)	453 (549)	189 (172)	1,107 (1,160)	1,749 (1,295)
Northern pike	0.0010 (0.0016)	0 (0)	14 (29)	4 (8)	19 (30)
Total harvested	0.1343 (0.0786)	481 (551)	646 (316)	1,421 (1,188)	2,548 (1,347)
		Number caught and released			
Walleye	0.0213 (0.0151)	62 (94)	178 (176)	165 (178)	404 (267)
Northern pike	0.0027 (0.0036)	28 (56)	0 (0)	23 (36)	51 (67)
Muskellunge	0.0044 (0.0089)	84 (167)	0 (0)	0 (0)	84 (167)
Yellow perch	0.0032 (0.0062)	60 (117)	0 (0)	0 (0)	60 (117)
Total released	0.0316 (0.0197)	233 (232)	178 (176)	187 (182)	599 (343)
Total (harvested + released)	0.1658 (0.0843)	714 (598)	824 (362)	1,609 (1,202)	3,147 (1,390)
		Fishing effort			
Angler hours		6,628 (2,830)	6,396 (1,734)	5,953 (3,424)	18,977 (4,769)
Angler trips		2,161 (993)	1,923 (792)	2,339 (1,746)	6,423 (2,159)

Table 22.–Angler survey estimates for summer and winter 2002–03 from Lake Leelanau. Survey period was April 27 through September 30, 2002 and January 1, 2003 through March 30, 2003. Two standard errors are given in parentheses.

Species	Catch/hour	April–May	June	July	August	September	January	February	March	Season
		Number harvested								
Brook trout	0.0002 (0.0004)	24 (49)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	24 (49)
Lake trout	0.0038 (0.0026)	52 (64)	26 (52)	143 (193)	0 (0)	0 (0)	0 (0)	120 (104)	87 (173)	427 (292)
Lake herring	0.0007 (0.0014)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	78 (155)	0 (0)	78 (155)
Smallmouth bass	0.0036 (0.0019)	106 (105)	93 (87)	0 (0)	64 (76)	146 (133)	0 (0)	0 (0)	0 (0)	408 (205)
Walleye	0.0839 (0.0190)	124 (74)	1,799 (766)	2,804 (974)	2,860 (1,053)	1,323 (685)	28 (54)	245 (186)	224 (189)	9,406 (1,787)
Yellow perch	0.0384 (0.0171)	0 (0)	53 (70)	132 (153)	453 (403)	1,918 (1,244)	453 (549)	189 (172)	1,107 (1,160)	4,305 (1,848)
Northern pike	0.0014 (0.0011)	30 (44)	51 (73)	63 (73)	0 (0)	0 (0)	0 (0)	14 (29)	4 (8)	162 (117)
Bluegill	0.0007 (0.0008)	0 (0)	17 (35)	0 (0)	0 (0)	60 (87)	0 (0)	0 (0)	0 (0)	77 (94)
Largemouth bass	0.0002 (0.0004)	0 (0)	20 (40)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	20 (40)
Rock bass	0.0048 (0.0031)	5 (11)	9 (17)	129 (148)	41 (54)	349 (299)	0 (0)	0 (0)	0 (0)	533 (339)
White sucker	0.0002 (0.0004)	0 (0)	22 (44)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	22 (44)
Total harvested	0.1379 (0.0289)	341 (158)	2,090 (782)	3,270 (1,018)	3,418 (1,132)	3,796 (1,460)	481 (551)	646 (316)	1,421 (1,188)	15,464 (2,627)
		Number caught and released								
Lake trout	0.0020 (0.0029)	0 (0)	71 (143)	148 (295)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	219 (328)
Smallmouth bass	0.0480 (0.0130)	735 (363)	2,287 (972)	706 (393)	489 (278)	1,167 (612)	0 (0)	0 (0)	0 (0)	5,384 (1,297)
Largemouth bass	0.0010 (0.0009)	20 (24)	13 (26)	44 (87)	20 (41)	19 (23)	0 (0)	0 (0)	0 (0)	116 (105)
Walleye	0.2103 (0.0491)	168 (101)	4,227 (2,027)	9,324 (3,079)	5,385 (2,018)	4,065 (2,033)	62 (94)	178 (176)	165 (178)	23,574 (4,677)
Northern pike	0.0202 (0.0068)	246 (145)	444 (279)	550 (351)	270 (176)	708 (490)	28 (56)	0 (0)	23 (36)	2,269 (705)
Muskellunge	0.0007 (0.0015)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	84 (167)	0 (0)	0 (0)	84 (167)
White sucker	0.0013 (0.0011)	0 (0)	90 (109)	40 (57)	14 (27)	0 (0)	0 (0)	0 (0)	0 (0)	144 (126)
Rock bass	0.0132 (0.0053)	15 (22)	305 (220)	526 (387)	285 (200)	348 (277)	0 (0)	0 (0)	0 (0)	1,479 (562)
Bowfin	0.0019 (0.0016)	0 (0)	182 (170)	0 (0)	0 (0)	28 (35)	0 (0)	0 (0)	0 (0)	210 (173)
Bluegill	0.0008 (0.0008)	0 (0)	0 (0)	0 (0)	67 (85)	19 (37)	0 (0)	0 (0)	0 (0)	86 (93)
Yellow perch	0.0151 (0.0064)	25 (27)	30 (59)	725 (462)	200 (152)	654 (466)	60 (117)	0 (0)	0 (0)	1,695 (686)
Total released	0.3145 (0.0590)	1,209 (406)	7,650 (2,290)	12,063 (3,197)	6,731 (2,062)	7,008 (2,246)	233 (232)	178 (176)	187 (182)	35,260 (5,004)
Total (harvested + released)	0.4524 (0.0750)	1,550 (436)	9,740 (2,420)	15,333 (3,355)	10,149 (2,352)	10,805 (2,679)	714 (598)	824 (362)	1,609 (1,202)	50,724 (5,652)
		Fishing effort								
Angler hours		8,595 (2,913)	22,838 (7,135)	28,453 (6,133)	17,008 (4,750)	16,241 (6,863)	6,628 (2,830)	6,396 (1,734)	5,953 (3,424)	112,112 (13,762)
Angler trips		2,774 (1,319)	6,962 (2,515)	11,744 (7,073)	4,723 (1,744)	5,169 (2,873)	2,161 (993)	1,923 (792)	2,339 (1,746)	37,795 (8,605)

Table 23.–History of fish surveys conducted on Lake Leelanau by MDNR, Fisheries Division.

Time period (location)	Gear	Purpose	Reference
July and August 1949 (north and south basins)	Great Lakes gill nets and seines	General inventory	Laarman (1976)
May 1967 (north and south basins)	Great Lakes gill nets	General inventory	Laarman (1976)
July 1978 (south basin)	Great Lakes gill nets	Brown trout evaluation	MDNR Traverse City field office
June 1988 (north and south basins)	Great Lakes gill and fyke nets	General inventory, special emphasis on brown trout	MDNR Traverse City field office
April/May 1992 (south basin)	Great Lakes gill and fyke nets	Walleye evaluation	MDNR Traverse City field office
May 1993 (south basin)	Great Lakes gill and fyke nets	Walleye evaluation	MDNR Traverse City field office
May 1994 (south basin)	Great Lakes gill and fyke nets	General inventory, special emphasis on walleye	MDNR, Fish Collection System
July 2000 (north basin)	Great Lakes gill and fyke nets	Brown and lake trout evaluation	MDNR, Fish Collection System
April 2002 (north and south basins)	Trap and fyke nets, and electrofishing	Large Lakes Study, emphasis on walleyes, northern pike and smallmouth bass	MDNR, Fish Collection System
November 2005 (south basin)	Electrofishing	Walleye evaluation	MDNR, Fish Collection System

Table 24.–Mean lengths of walleyes from the 2002 survey of the south basin of Lake Leelanau compared to other surveys. Number aged in parentheses.

Age	State average [a]	Mean lengths 1978 [b]		1988 [c]		1992 [d]		1993 [e]		1994 [f]		2002 [g]	
0													
1	7.1									6.9	(1)		
2	10.4			14.5	(1)			11	(1)	10.7	(2)	9.9	(7)
3	13.9	17.7	(28)	18.6	(1)	13.4	(13)	13.5	(8)	13.2	(1)	13.3	(21)
4	15.8					16.9	(14)	15.7	(21)	15.3	(10)	14.9	(31)
5	17.6			21.6	(4)	20.3	(3)	19.4	(1)	17.4	(23)	15.0	(42)
6	19.2	24.4	(2)	23.3	(14)	22.2	(3)	21.3	(1)	20.8	(3)	15.9	(53)
7	20.6	25.4	(1)	23.4	(5)			22.2	(2)	23.9	(1)	17.0	(58)
8	21.6	27.8	(1)	26.2	(1)							17.3	(38)
9	22.4											18.3	(35)
10	23.1											17.4	(18)
11												20.8	(32)
12												21.1	(26)
13												22.7	(2)
Mean growth index [h]		+2.5		+3.1		+0.3		-0.3		-0.4		-2.8	

[a] Jan–May averages from Schneider et al (2000), aged using scales.
[b] Fish collected in July and aged using scales.
[c] Fish collected in June and aged using scales.
[d] Fish collected in April and aged using scales.
[e] Fish collected May and aged using spines.
[f] Fish collected in May and aged using spines.
[g] Fish collected in April and aged using spines.
[h] The mean deviation from the statewide quarterly average. Only age groups where $N \geq 5$ were used.

Table 25.–Mean lengths of walleyes from the 2002 survey of the north basin of Lake Leelanau compared to the 2000 survey. Number aged in parentheses.

Age	State average [a]	Mean lengths 2000 [b]		Mean lengths 2002 [c]	
0					
1	7.1				
2	10.4	14.7	(1)	11.5	(4)
3	13.9	15.8	(3)	13.4	(6)
4	15.8	18.1	(4)	16.6	(11)
5	17.6	19.5	(15)	16.8	(8)
6	19.2	20.4	(5)	18.5	(8)
7	20.6	23.2	(2)	18.0	(14)
8	21.6			19.2	(7)
9	22.4	22.0	(6)	21.1	(2)
10	23.1	25.5	(4)	23.6	(2)
11				22.3	(9)
12				23.8	(4)
13				25.0	(2)
Mean growth index [d]		+0.6		-1.0	

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

Table 26.–Comparison of recreational fishing effort and total harvest on Lake Leelanau to those of other selected Michigan lakes. Lakes are listed from highest to lowest total fishing effort.

Lake *County*	Size (acres)	Survey period	Fishing effort (h) total	Fishing effort (h) per acre	Fish harvested total	Fish harvested per h	Fish harvested per acre
Michigan [a] *many*	–	Jan–Nov 2001	2,684,359	–	677,360	0.25	–
Huron [a] *many*	–	Jan–Oct 2001	1,807,519	–	1,057,819	0.59	–
Houghton *Roscommon* (all year)	20,075	Apr 2001–Mar 2002	499,048	24.9	386,287	0.77	19.2
Erie [a] *Wayne/Monroe*	–	Apr–Oct 2001	490,807	–	378,700	0.77	–
Superior [a] *many*	–	Apr–Oct 2001	180,428	–	60,947	0.34	–
Cisco Chain *Gogebic/Vilas* [b]	3,987	May 2002–Feb 2003	180,262	45.2	120,412	0.67	30.2
Muskegon Lake *Muskegon*	4,232	April 2002–Mar 2003	180,064	42.5	184,161	1.02	43.5
Fletcher Pond *Alpena/Montmorency*	8,970	May–Sep 1997	171,521	19.1	118,101	0.69	13.2
Burt *Cheboygan*	17,120	April 2001–Mar 2002	134,205	7.8	68,473	0.51	4.0
Gogebic *Ontonagon/Gogebic*	13,380	May 1998–Apr 1999	121,525	9.1	26,622	0.22	2.0
Lake Leelanau *Leelanau*	8,607	April 2002–March 2003	112,112	13.0	15,464	0.14	1.8
Mullett *Cheboygan*	16,630	May–Aug 1998	87,520	5.3	18,727	0.21	1.1
Crooked & Pickerel *Emmet*	3,434	April 2001–Mar 2002	55,894	16.3	13,665	0.24	4.0
Michigamme Reservoir *Iron*	6,400	May 2001–Feb 2002	52,686	8.2	10,899	0.21	1.7

[a] Does not include charter boat harvest or effort.
[b] Vilas County, Wisconsin.

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Appendix A.–Fish species captured in Lake Leelanau from 1978 through 2005 using various gear types.

Survey year Common name	Scientific name
2002	
Black bullhead	*Ameiurus melas*
Bluegill	*Lepomis macrochirus*
Bowfin	*Amia calva*
Brown bullhead	*Ameiurus nebulosus*
Brook trout	*Salvelinus fontinalis*
Brown trout	*Salmo trutta*
Burbot	*Lota lota*
Central mudminnow	*Umbra limi*
Lake herring	*Coregonus artedi*
Largemouth bass	*Micropterus salmoides*
Longnose gar	*Lepisosteus osseus*
Northern pike	*Esox lucius*
Pumpkinseed	*Lepomis gibbosus*
Rainbow smelt	*Osmerus mordax*
Rock bass	*Ambloplites rupestris*
Smallmouth bass	*Micropterus dolomieu*
Walleye	*Sander vitreus*
White sucker	*Catostomus commersonii*
Yellow bullhead	*Ameiurus natalis*
Yellow perch	*Perca flavescens*
2000	
Lake whitefish	*Coregonus clupeaformis*
1988	
Splake	*Salvelinus fontinalis*Salvelinus namaycush*
Creek chub	*Semotilus atromaculatus*
Emerald Shiner	*Notropis atherinoides*
1967 [a]	
Lake trout	*Salvelinus namaycush*
1949 [a]	
Longear sunfish	*Lepomis megalotis*
Mimic shiner	*Notropis volucellus*
Common shiner	*Luxilus cornutus*
Sand shiner	*Notropis stramineus*
Spottail shiner	*Notropis hudsonius*
Golden shiner	*Notemigonus crysoleucas*
Bluntnose minnow	*Pimephales notatus*
Blackchin shiner	*Notropis heterodon*
Blacknose shiner	*Notropis heterolepis*
Pugnose shiner	*Notropis anogenus*
Johnny darter	*Etheostoma nigrum*
Iowa darter	*Etheostoma exile*
Logperch	*Percina caprodes*

[a] From Laarman (1976).

Appendix B.–Angler survey estimates for summer and winter 2002–03 from the north basin of Lake Leelanau. Survey period was April 27 through September 30, 2002 and January 1, 2003 through March 30, 2003. Two standard errors are given in parentheses.

Species	Catch/hour	Apr–May	June	July	August	Sept	January	February	March	Season
		Number harvested								
Lake trout	0.0155	52	26	143	0	0	0	120	87	427
	(0.0109)	(64)	(52)	(193)	(0)	(0)	(0)	(104)	(173)	(292)
Lake herring	0.0028	0	0	0	0	0	0	78	0	78
	(0.0057)	(0)	(0)	(0)	(0)	(0)	(0)	(155)	(0)	(155)
Smallmouth bass	0.0050	46	62	0	18	12	0	0	0	139
	(0.0047)	(93)	(73)	(0)	(37)	(23)	(0)	(0)	(0)	(126)
Walleye	0.0553	0	631	452	220	51	0	154	16	1,524
	(0.0242)	(0)	(440)	(340)	(173)	(61)	(0)	(161)	(32)	(608)
Yellow perch	0.0216	0	0	0	252	87	0	36	218	594
	(0.0190)	(0)	(0)	(0)	(356)	(131)	(0)	(60)	(340)	(513)
Northern pike	0.0020	0	20	19	0	0	0	14	0	54
	(0.0023)	(0)	(41)	(39)	(0)	(0)	(0)	(29)	(0)	(63)
Rock bass	0.0036	0	0	87	0	12	0	0	0	99
	(0.0052)	(0)	(0)	(140)	(0)	(23)	(0)	(0)	(0)	(142)
Total harvest	0.1058	99	740	701	490	162	0	402	321	2,914
	(0.0374)	(113)	(451)	(417)	(398)	(148)	(0)	(256)	(383)	(885)
		Number released								
Lake trout	0.0079	0	71	148	0	0	0	0	0	219
	(0.0120)	(0)	(143)	(295)	(0)	(0)	(0)	(0)	(0)	(328)
Smallmouth bass	0.0577	237	830	273	148	103	0	0	0	1,591
	(0.0302)	(269)	(661)	(255)	(150)	(108)	(0)	(0)	(0)	(779)
Largemouth bass	0.0021	0	13	44	0	0	0	0	0	57
	(0.0033)	(0)	(26)	(87)	(0)	(0)	(0)	(0)	(0)	(91)
Walleye	0.0041	0	25	87	0	0	0	0	0	112
	(0.0065)	(0)	(37)	(175)	(0)	(0)	(0)	(0)	(0)	(178)
Northern pike	0.0037	31	24	0	31	0	0	0	17	103
	(0.0034)	(62)	(35)	(0)	(46)	(0)	(0)	(0)	(35)	(92)
Rock bass	0.0146	0	99	204	101	0	0	0	0	404
	(0.0127)	(0)	(118)	(296)	(122)	(0)	(0)	(0)	(0)	(342)
Yellow perch	0.0246	0	0	455	61	100	60	0	0	676
	(0.0168)	(0)	(0)	(406)	(93)	(107)	(117)	(0)	(0)	(446)
Total released	0.1148	268	1,062	1,211	341	203	60	0	17	3,162
	(0.0430)	(276)	(688)	(666)	(220)	(152)	(117)	(0)	(35)	(1,039)
Total (harvested and released)	0.2205	366	1,802	1,912	831	365	60	402	338	6,076
	(0.0635)	(298)	(823)	(785)	(455)	(212)	(117)	(256)	(385)	(1,365)
		Fishing effort								
Angler hours		1,830	5,931	6,370	2,568	1,728	2,837	4,094	2,193	27,552
		(1,343)	(2,946)	(2,165)	(1,095)	(726)	(1,653)	(1,538)	(1,652)	(4,972)
Angler trips		681	2,400	2,453	782	638	960	1,261	773	9,949
		(643)	(1,812)	(2,959)	(496)	(421)	(629)	(726)	(654)	(3,772)

Appendix C.–Angler survey estimates for summer and winter 2002–03 from the south basin of Lake Leelanau. Survey period was April 27 through September 30, 2002 and January 1, 2003 through March 30, 2003. Two standard errors are given in parentheses.

Species	Catch/hour	Apr–May	June	July	August	Sept	January	February	March	Season
		Number harvested								
Brook trout	0.0003	24	0	0	0	0	0	0	0	24
	(0.0006)	(49)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(49)
Smallmouth bass	0.0032	59	31	0	45	134	0	0	0	269
	(0.002)	(48)	(48)	(0)	(67)	(131)	(0)	(0)	(0)	(162)
Walleye	0.0932	124	1,167	2,352	2,641	1,272	28	91	207	7,883
	(0.0244)	(74)	(627)	(913)	(1,039)	(683)	(54)	(92)	(186)	(1,680)
Yellow perch	0.0439	0	53	132	201	1,831	453	153	889	3,711
	(0.022)	(0)	(70)	(153)	(188)	(1,237)	(549)	(162)	(1,109)	(1,775)
Northern pike	0.0013	30	30	44	0	0	0	0	4	108
	(0.0012)	(44)	(60)	(62)	(0)	(0)	(0)	(0)	(8)	(98)
Bluegill	0.0009	0	17	0	0	60	0	0	0	77
	(0.0011)	(0)	(35)	(0)	(0)	(87)	(0)	(0)	(0)	(94)
Largemouth bass	0.0002	0	20	0	0	0	0	0	0	20
	(0.0005)	(0)	(40)	(0)	(0)	(0)	(0)	(0)	(0)	(40)
Rock bass	0.0051	5	9	42	41	338	0	0	0	434
	(0.0037)	(11)	(17)	(50)	(54)	(298)	(0)	(0)	(0)	(308)
White sucker	0.0003	0	22	0	0	0	0	0	0	22
	(0.0005)	(0)	(44)	(0)	(0)	(0)	(0)	(0)	(0)	(44)
Total harvest	0.1484	242	1,350	2,569	2,928	3,635	481	244	1,100	12,549
	(0.0369)	(111)	(639)	(929)	(1,059)	(1,453)	(551)	(186)	(1,125)	(2,474)
		Number caught and released								
Smallmouth bass	0.0449	498	1,457	432	342	1,064	0	0	0	3,793
	(0.014)	(244)	(713)	(299)	(234)	(602)	(0)	(0)	(0)	(1,037)
Largemouth bass	0.0007	20	0	0	20	19	0	0	0	60
	(0.0006)	(24)	(0)	(0)	(41)	(23)	(0)	(0)	(0)	(53)
Walleye	0.2775	168	4,202	9,236	5,385	4,065	62	178	165	23,462
	(0.0695)	(101)	(2,026)	(3,074)	(2,018)	(2,033)	(94)	(176)	(178)	(4,674)
Northern pike	0.0256	215	420	550	239	708	28	0	6	2,166
	(0.0091)	(131)	(277)	(351)	(169)	(490)	(56)	(0)	(10)	(699)
Muskellunge	0.0010	0	0	0	0	0	84	0	0	84
	(0.002)	(0)	(0)	(0)	(0)	(0)	(167)	(0)	(0)	(167)
White sucker	0.0017	0	90	40	14	0	0	0	0	144
	(0.0015)	(0)	(109)	(57)	(27)	(0)	(0)	(0)	(0)	(126)
Rock bass	0.0127	15	206	323	184	348	0	0	0	1,076
	(0.0056)	(22)	(186)	(249)	(158)	(277)	(0)	(0)	(0)	(446)
Bowfin	0.0025	0	182	0	0	28	0	0	0	210
	(0.0021)	(0)	(170)	(0)	(0)	(35)	(0)	(0)	(0)	(173)
Bluegill	0.0010	0	0	0	67	19	0	0	0	86
	(0.0011)	(0)	(0)	(0)	(85)	(37)	(0)	(0)	(0)	(93)
Yellow perch	0.0120	25	30	270	139	555	0	0	0	1,018
	(0.0064)	(27)	(59)	(220)	(120)	(453)	(0)	(0)	(0)	(522)

Appendix C.–Continued.

Species	Catch/hour	Apr–May	June	July	August	Sept	January	February	March	Season
Total released	0.3796	942	6,588	10,852	6,390	6,805	173	178	170	32,098
	(0.0817)	(298)	(2,184)	(3,127)	(2,050)	(2,241)	(200)	(176)	(178)	(4,895)
Total (harvested and released)	0.5280	1,184	7,938	13,421	9,318	10,440	654	422	1,270	44,648
	(0.1031)	(318)	(2,276)	(3,262)	(2,308)	(2,671)	(586)	(256)	(1,139)	(5,485)
		Fishing effort								
Angler hours		6,764	16,907	22,083	14,440	14,513	3,791	2,302	3,761	84,561
		(2,585)	(6,498)	(5,739)	(4,622)	(6,824)	(2,297)	(801)	(2,999)	(12,833)
Angler trips		2,093	4,562	9,290	3,941	4,532	1,201	662	1,565	27,846
		(1,152)	(1,744)	(6,424)	(1,672)	(2,842)	(768)	(317)	(1,619)	(7,735)