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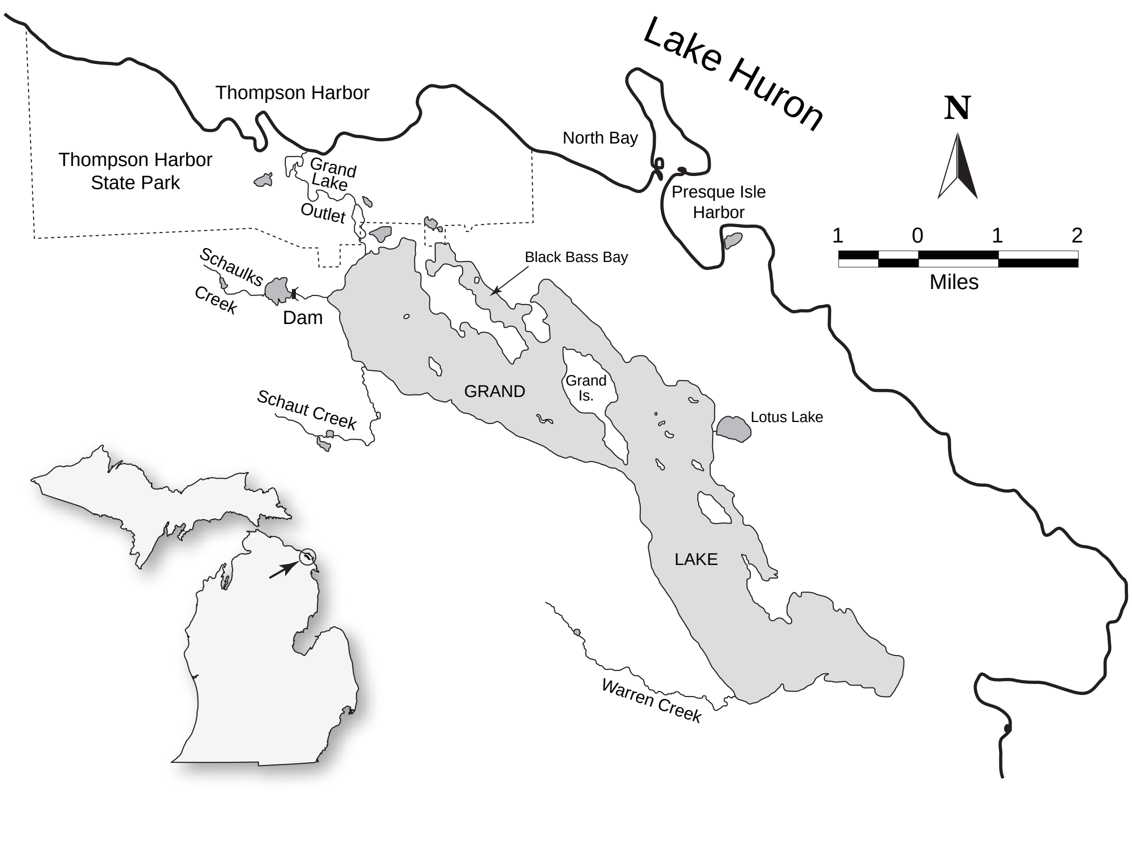
The Fish Community and Fishery of Grand Lake, Presque Isle County, Michigan in 2004-05 with Emphasis on Walleye, Northern Pike, and Smallmouth Bass

Patrick A. Hanchin



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Michigan Department of Natural Resources
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The Fish Community and Fishery of Grand Lake, Presque Isle County, Michigan in 2004–05 with Emphasis on Walleye, Northern Pike, and Smallmouth Bass

Patrick A. Hanchin

Michigan Department of Natural Resources, Charlevoix Fisheries Research Station
96 Grant Street, Charlevoix, Michigan 49720

Introduction

The Michigan Department of Natural Resources (MDNR), Fisheries Division surveyed fish populations and angler catch and effort at Grand Lake, Presque Isle County, Michigan from April 2004 through March 2005. This work was part of the Large Lakes Program, which is designed to improve assessment and monitoring of fish communities and fisheries in Michigan's largest inland lakes (Clark et al. 2004).

The Large Lakes Program has three primary objectives. The first objective is to produce consistent indices of abundance and estimates of annual harvest and fishing effort for walleye, northern pike, smallmouth bass, and muskellunge. These species were selected since they are susceptible to trap or fyke nets and are readily harvested by anglers. The intent is to produce statistics for important fishes to help detect major changes in their populations over time. The second objective is to produce estimates of abundance, growth, and mortality to evaluate the effects of fishing on those species which support valuable fisheries. This usually involves targeting species with nets or other gears to collect, sample, and mark sufficient numbers. I selected walleye (I will refer to fishes by common name in the text. I listed common and scientific names of fish species in the Appendix), northern pike, and smallmouth bass as target species in this survey of Grand Lake. The final objective is to evaluate the suitability of various statistical estimators for use in large lakes. For example, in the current survey I applied and compared two types of abundance and three types of exploitation rate estimators.

Study Area

Grand Lake drains a watershed of approximately 21,650 acres (Laarman 1976). The surface area is approximately 6,000 acres, with sources disagreeing only slightly on size. Humphrys and Green (1962) estimated an area of 6,080 surface acres by taking measurements from United States Geological Survey (USGS) maps using hand-held drafting tools, while Laarman (1976) reported 5,660 acres. Breck (2004) estimated 5,823 acres for Grand Lake by using computerized digitizing equipment and USGS topographical maps. He overlaid the boundaries of the lake polygon from the Michigan Digital Water Atlas Geographical Information System with aerial photos of the lake using ArcView©, and the two matched well. In the Large Lakes Program, comparisons of various measures of productivity will be made among lakes, such as number of fish per acre or harvest per acre, so an accurate measure of lake size is important. Therefore, I will use the more modern estimate of 5,823 acres as the size of Grand Lake in analyses.

Grand Lake is fed by Warren, Schaut, and Schalks creeks, the latter of which creates the Grand Lake pike spawning marsh when flooded (Figure 1). Lotus Lake also drains into the lake through a small culvert. The Grand Lake outlet (sometimes referred to as Thompson's Creek) is about two miles long and flows directly into Thompsons Harbor of Lake Huron. The control structure on the outlet is approximately 4 ft high and 40 ft long and is designed to maintain water level for summer recreation. The outlet allows downstream fish passage during most flows.

The shoreline of Grand Lake is partially developed with private residences (though extensive shoreline is undeveloped) and there are three public boat access sites (Figure 1). The shoreline development index is 3.6. There are nineteen islands in the lake, ranging in size from about 5,000 ft^2 to 263 acres. The maximum depth is 25 feet, with approximately 78% of the lake area less than 15 feet deep, and approximately 59% of the lake volume in water less than 15 ft deep (Figures 2 and 3). The substrate in the littoral zone consists largely of sand, gravel, and rock, while substrate in deeper areas is marl and organic matter. Submergent and emergent aquatic vegetation are sparse throughout the lake, though some shallow areas and bays have abundant vegetation.

Water chemistry analyses were completed on Grand Lake in the summer of 1950 (Laarman 1976). Dissolved oxygen concentrations ranged from 7.8–7.9 parts per million (ppm), both at the surface and on the bottom. A thermocline was not detected. The dissolved oxygen content was similarly high in the summer of 2004, when it ranged from 9.03 at the surface to 8.64 at the bottom. In 2004, the total alkalinity was 111 mg/L $CaCO_3$, chlorophyll-a was < 1.0 µg/L, total Kjeldahl nitrogen was 0.382 mg/L, and total phosphorous was < 0.0039 mg/L.

The fish community of Grand Lake includes species typical of lakes in northern Michigan. Families of fish currently in Grand Lake include, but are not limited to, *Amiidae, Cyprinidae, Catostomidae, Centrarchidae, Esocidae, Ictaluridae, Lepisosteidae, Percidae, and Salmonidae* (Appendix).

Recently (1979–2000), tiger muskellunge and northern pike have been stocked in Grand Lake (Table 1), though historically (1910–73) yellow perch, bluegill, warmouth, largemouth bass, smallmouth bass, walleyes, and northern pike were stocked (Laarman 1976). The last year that tiger muskellunge were stocked was 1982. In all but one year, the northern pike stocked were produced in the Grand Lake pike marsh; in 1988 northern pike were transplanted from another lake.

There have been ten State of Michigan Master Angler awards taken from Grand Lake from 1990 to 2006, including one tiger muskellunge, one bowfin, one brown bullhead, three smallmouth bass, two rock bass, one black bullhead, and one bluegill.

Methods

Fish populations in Grand Lake were sampled with fyke nets and trap nets from April 9 to 23, 2004. Three boats were used daily, each with a three-person crew, for 2 weeks. Each net-boat crew tended 10–15 nets, daily. 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 70- to 100-ft leads. Duration of net sets ranged from 1–2 nights, but most were 1 night. Latitude and longitude were recorded for all net locations and electrofishing runs using GPS. In 2004, a standardized survey using multiple gears (P. A. Hanchin, personal communication) was also conducted from June 28 to July 2.

Fish Community

The fish community was described in terms of species present, catch per unit effort, percent by number, and length frequencies. For nontarget species, lengths were measured to the nearest 0.1 in for subsamples 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.

I used Microsoft Access© to store and retrieve data collected during the tagging operation. I calculated mean catch per unit effort (CPUE) in fyke nets and trap nets as an indicator 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).

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

Walleye, Northern Pike, and Smallmouth Bass

Size structure and sex composition.–Total lengths of all walleyes, northern pike, and smallmouth bass were measured to the nearest 0.1 in. Size-structure data for target species (walleye, northern pike, and smallmouth bass) only included fish on their initial capture occasion. Walleyes and northern pike with flowing gametes were identified as male or female; fish with no flowing gametes were identified as unknown sex. For smallmouth bass, sex determination was usually not possible because the survey was several weeks prior to the spawning period.

Abundance.–I estimated the abundance of legal-size walleyes and northern pike using mark-and-recapture methods. Walleyes (≥15 in), northern pike (≥24 in), and smallmouth bass (≥14 in) were fitted with monel-metal jaw tags. To assess tag loss, tagged fish were double-marked by clipping the left pelvic fin. An approximate 1:1 ratio of $10-reward : nonreward tags was maintained. I did not think that an exact ratio was important, and maintaining an exact ratio would have been more difficult, given the multiple crews working simultaneously and numbers of fish tagged. Large tags (size 16) that were used on large northern pike (≥36 in) were all nonreward. Fish recaptured with nets or electrofishing gear were recorded as either tagged (tag numbers recorded) or fin-clipped.

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

I used two different methods for estimating abundance 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, I used the Schumacher-Eschmeyer formula for daily recaptures during the tagging operation. I used the following formula from Ricker (1975):

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

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

The variance formula was,

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

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

Variance of $1/N$ is:

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

The minimum number of recaptures necessary for an unbiased estimate was set a priori at four. Asymmetrical 95% confidence intervals were computed as:

$$\frac{1}{\frac{1}{N} \pm t(\sigma)}$$

The multiple-census method was used to estimate the abundance of both legal-size and adult walleyes and northern pike. Adult fish were defined as those greater than legal size, or less than legal size, but of identifiable sex by the extrusion of gametes.

For the single-census estimate, I used numbers of marked and unmarked fish observed by creel clerks in the companion angler survey, and by crews in the summer netting survey, as the “recapture-run” sample. I used the Chapman modification of the Petersen method (Ricker 1975) to generate population estimates and the minimum number of recaptures necessary for an unbiased estimate was set a priori at three (Ricker 1975). I used the following formula from Ricker (1975):

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

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

I calculated the variance as:

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

asymmetrical 95% confidence limits were calculated using values from the Poisson distribution for the 95% confidence limits on the number of recaptured fish (R), which were substituted into the equation for N above (Ricker 1975). I estimated numbers of adult walleyes and northern pike from the single-census estimates by dividing the estimates for legal-size fish by the proportion of legal-size fish on the spawning grounds, using the formula:

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

where N_a =estimated number of adult walleyes or northern pike; N_{sub} = number of sublegal and mature fish (<15 in for walleye, or <24 in for northern pike) caught; N_{leg} = number of legal fish caught; N = single-census estimate of legal-size walleyes or northern pike.

I calculated the variance as:

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

There were no prior abundance estimates for walleye, northern pike, or smallmouth bass in Grand Lake to help us gauge how many fish to mark. However, I used two regression equations developed for Michigan lakes to provide initial estimates of walleye abundance. These regressions predict legal and adult walleye abundance based on lake size and 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:

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

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

where N is the estimated number of adult walleyes and A is the surface area of the lake in acres. For Grand Lake, the equation gives an estimate of 12,189 adult walleyes, with a 95% prediction interval (Zar 1999) of 2,859 to 51,967.

The equation for legal walleyes was based on 21 estimates:

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

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

where N is the estimated number of legal walleyes and A is the surface area of the lake in acres. The equation gives an estimate of 8,991 legal walleyes, with a 95% prediction interval (Zar 1999) of 1,885 to 42,881. Based on these a priori abundance estimates, I thought that marking approximately 900 legal-size walleyes (>10%) of the population would be sufficient. I did not set a specific tagging goal for northern pike or smallmouth bass, but rather tagged as many as possible until the walleye goal was achieved.

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

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

Growth.–Dorsal spines were used to age walleyes and smallmouth bass, and dorsal fin rays were used to age northern pike. I used these structures because I thought they provided the best combination of ease of collection in the field and accuracy and precision of age estimates. I considered ease of collection important because staff worked in cold, windy conditions, dealt with large numbers of fish, and tagged fish in addition to measuring fish and collecting structures. Otoliths have been shown to be the most accurate and precise aging structure for older walleyes (Heidinger and Clodfelter 1987; Kocovsky and Carline 2000; Isermann et al. 2003) and otoliths or cleithra for northern pike (Casselman 1974; Harrison and Hadley 1979), but collecting these structures requires killing the fish, which was not an option with a tagging study. Results from several studies comparing aging structures for walleye agreed that spines are quicker to remove than scales, but they do not agree that spines are more accurate than scales (Campbell and Babaluk 1979; Kocovsky and Carline 2000; Isermann et al. 2003). Errors in ages from spines are often related to misidentifying the first annulus in older fish (Ambrose 1983; Isermann et al. 2003). There is also considerable disagreement as to whether spines or scales are more precise for walleye age estimation. Erickson (1983) and Campbell and Babaluk (1979) found that spines were more precise, Belanger and Hogler (1982) found spines and scales were equally precise, and Kocovsky and Carline (2000) found scales were more precise. Since northern pike older than 6 years are notoriously difficult to age with scales (Carlander 1969), in recent years MDNR field technicians have used dorsal fin rays. They are as quick and easy to remove in the field as spines for walleye. Studies have demonstrated that fin rays are a valid aging structure for a number of species (Skidmore and Glass 1953; Ambrose 1983), including northern pike (Casselman 1996), but no studies have been conducted to statistically compare accuracy and precision of fin rays to other aging structures for northern pike.

The collection goal was 15 male and 15 female walleyes and northern pike per inch group, and 15 smallmouth bass (males and females combined) per inch group. Samples were sectioned using a table-mounted high-speed rotary cutting tool. Sections approximately 0.5-mm thick were cut as close to the proximal end of the spine or ray as possible. Sections were examined at 40x–80x with transmitted light and were photographed with a digital camera. The digital image was archived for multiple reads. Two technicians independently aged samples, and ages were considered final when independent estimates were in agreement. Samples in dispute were aged by a third technician. Disputed ages were considered final when the third technician agreed with one of the first two. Samples were discarded if three technicians disagreed on age, though occasionally an average age was used when ages assigned to older fish (≥ age 10) were within ±10% of each other.

After a final age was identified for all samples, I calculated weighted mean lengths-at-age and age-length keys (Devries and Frie 1996) for male, female and all (males, females, and fish of unknown sex) walleyes and northern pike. I compared the mean lengths-at-age to those from previous surveys of Grand Lake and to other large lakes. I also computed a mean growth index to compare the data to Michigan state averages, as described by Schneider et al. (2000a). The mean growth index is the average of deviations (by age group) between the observed mean lengths and statewide seasonal average lengths. In addition, I fit mean length-at-age data to a von Bertalanffy growth equation using nonlinear regression, and calculated the total length at infinity (L_∞) for use as an index of growth potential. All growth curves were forced through the origin, by including a data point for age = 0, length = 0.

Mortality.–I calculated catch-at-age for males, females, and all fish (including males, female, and those of unknown sex), and estimated instantaneous total mortality rates using catch-curve analyses with assumptions described by Ricker (1975). My goal was to estimate total mortality for fish of legal size for comparison with fishing mortality, which was only estimated for fish of legal size. When choosing age groups to be included in the analyses, I considered several potential problems. First, an assumption of catch-curve analysis is that the mortality rate is uniform with age over the full range of age groups in analysis. Fish were collected with gears different from those used in the fishery and the size (age) of recruitment in the fishery was controlled by minimum-size-limit regulations. For fish smaller than the minimum size limit, mortality is M+H; for fish larger, mortality is M+H+F, where M, H, and F are natural, hooking (from catch and release), and fishing mortality, respectively. Thus, from the standpoint of uniformity in mortality, age groups used in a single catch curve should contain fish that are either all smaller than, or all larger than the minimum size limit in the fishery. Since I was interested in legal-size fish, I chose ages where the average length was greater than legal size. Second, walleyes and northern pike exhibit sexual dimorphism (Carlander 1969 and 1997), which could lead to differences in mortality between sexes. Thus, when sufficient data were available, I computed separate catch curves for males and females to determine if total mortality differed with sex. A catch curve was also computed for all fish that included males, females, and fish of unknown sex. Third, walleyes and northern pike were collected in the act of spawning, so I needed to be sure that fish in each age group were sexually mature and represented on the spawning grounds in proportion to their true abundance in the population. Thus, I included in the analyses only age groups with fish that I judged to be mostly mature. I based this judgment on a combination of information, including relative abundance and percent maturity by size. Given that the age-classes on the ascending limb and peak of the catch curve are captured less frequently, in relation to their abundance (Ricker 1975), the minimum age used in catch curves was generally one year older than the peak age. When no fish were collected for a particular age and data for older fish were available, I added one to the number-at-age for each age group [ln(1) = 0].

I 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. I 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 (adjusted for tag loss) returned by anglers. Probability of tag loss was calculated as the number of fish in a recapture sample with fin clips and no tag divided by all fish in the recapture sample that had been tagged, including fish that had lost their tag. Standard errors were calculated assuming a binomial distribution (Zar 1999). I made the assumption that mortality was negligible and that 100% of reward tags on fish caught by anglers would be returned. Although I did not truly assess nonreporting, I did compare the actual number of tag returns to the expected number (X) based on the ratio:

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

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

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

Voluntary tag returns were encouraged with a monetary reward ($10) denoted on approximately 50% of the tags. Tag return forms were made available at boater access sites, at MDNR offices, and from creel clerks. Additionally, tag return information could be submitted on-line at the MDNR website. All tag return data were entered into the database so that it could be efficiently linked to and verified against data collected during the tagging operation. I developed linked documents in Microsoft Word® so that payment vouchers and letters to anglers were automatically produced with relevant information from the database. Letters (for both reward and nonreward tags) sent to anglers described information regarding the length and sex of the tagged fish, and the location and date of tagging. Return rates were calculated separately for reward and nonreward tags.

The second and third estimates of exploitation were calculated as the estimated annual harvest from the angler survey divided by the multiple- and single-census abundance estimates for legal-size fish. For proper comparison with the single-census abundance estimate of legal fish in the spring, the estimated annual harvest was adjusted for fish that would have recruited to legal size over the course of the creel survey based on the percentage of fish observed in the creel survey that were determined to have been sublegal at the time of the spring survey (See *Abundance* subsection of the **Methods** section).

Recruitment.–I considered relative year-class strength represented by the residuals of the catch curve regression as an index of recruitment (Maceina 2003). I explored relationships among year-class strength and various environmental variables by using correlation analyses. Historic weather data were obtained from the National Weather Service observation station in Rogers City, Michigan (National Climate Data Center station 207094). Relationships with water quality were not explored, because I did not have any historic water quality data specific to Grand Lake. Variables that I 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. Statistical significance was set at $\alpha = 0.05$.

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, I identified conspicuous movement, such as to another lake or connected river.

Angler Survey

Fishing harvest seasons for walleye and northern pike during this survey were April 24, 2004–March 15, 2005, and seasons for smallmouth bass and largemouth bass were May 29 through December 31, 2004. Minimum size limits were 15 in for walleye and 24 in for northern pike. Daily bag limit was five fish of any combination of walleyes, northern pike, smallmouth bass, or largemouth bass, with harvest of no more than two northern pike permitted. Minimum size limit was 14 in for both smallmouth bass and largemouth bass.

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

Direct contact angler creel surveys were conducted during one spring-summer period - April 24 to October 13, 2004–and one winter period–December 17, 2004 through March 26, 2005.

Summer.–The summer creel survey used a roving count-roving interview design (Lockwood 2000b). Fishing boats were counted by one clerk working from a boat while another clerk working from a boat collected angler interview data. Both weekend days and three randomly-selected weekdays were selected for counting and interviewing during each week of the survey season. No count or interview data were collected on holidays. Holidays during the period were Memorial Day (May 31, 2004), Independence Day (July 4, 2004), and Labor Day (September 6, 2004). Counting and interviewing were done on the same days, and one instantaneous count of fishing boats was made per day.

The starting location and direction (clockwise or counter-clockwise) for counts were randomized (Figure 4). Only fishing boats were counted (i.e., watercrafts involved in alternate activities, such as water skiing, were not counted). Time of count was randomized to cover daylight times within the sample period. Count information was recorded on standard creel survey forms, and included: date, count time, and number of fishing boats.

Minimum fishing time prior to interview (incomplete-trip interview) was 1 h (Lockwood 2004). Historically, minimum fishing time prior to interviewing has been 0.5 h (Pollock et al. 1997). However, recent evaluations have shown that roving interview catch rates from anglers fishing a minimum of 1 h are more representative of access interview (completed-trip interview) catch rates (Lockwood 2004). Access interviews include information from complete trips and are appropriate standards for comparison. All roving interview data were collected by individual angler to avoid party size bias (Lockwood 1997). While this survey was 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 of a completed trip.

Interview information collected included: date, fishing mode (shore or boat), start time of fishing trip, interview time, species targeted, bait used, number of fish harvested by species, number of fish caught and released by species, length of harvested walleyes, northern pike, and smallmouth bass, and applicable tag number(s). Number of anglers in each party was recorded on one interview form for each party. One of two shifts was selected each sample day for interviewing (Table 2). Interview starting location and direction were randomized daily.

Winter.–The winter creel survey used a roving count-roving interview design (Lockwood 2000b). One clerk working from a snowmobile collected count data while another clerk working from a snowmobile collected interview data. Both weekend days and three randomly-selected weekdays were selected for sampling during each week of the survey season. No holidays were sampled. Holidays during the winter sampling period were: New Year’s Day (January 1, 2005), Martin Luther King Day (January 17, 2005), and President’s Day (February 21, 2005). The starting location and direction (clockwise or counter-clockwise) for counts and interviews was randomized (Figure 4). One of two shifts was selected each sample day for interviewing (Table 2).

Progressive counts of open-ice anglers and occupied shanties were made once per day. Count information collected included: date, fishing mode (open ice or shanty), count time, and number of units (anglers or occupied shanties) counted. Similar to summer interview methods, minimum fishing time prior to interviewing was 1 h for all incomplete-trip interviews. No anglers were interviewed while counting (Wade et al. 1991). Interview forms, information, and techniques used during the winter survey period were the same as those used during the summer survey period.

Estimation methods.–Catch and effort estimates were made using a multiple-day method (Lockwood et al. 1999). Effort is the product of mean counts for a given period day type (weekday or weekend), days within the period, and the expansion value for that period (Table 2). Thus, the angling effort and catch reported here are for those periods and times sampled, and no expansions were made to include periods and times not sampled (e.g., 0100 to 0400 hours).

Most interviews (>80%) collected during summer and winter survey periods were of a single type (roving). However, during some shorter periods (i.e., day type within a month for a section) fewer than 80% of interviews were of a single type. When 80% or more of interviews within a time period (weekday or weekend day within a month) were of an interview type, the appropriate catch-rate estimator for that interview type (Lockwood et al. 1999) was used on all interviews. When less than 80% 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 n1 interviews and $\overline{R}$ 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 $\overline{R}$.

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

All creel estimates are given with 2 SE. Error bounds (2 SE), provided statistical significance, assuming normal distribution shape and N ≥ 10, of 75–95% (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, statistical significance 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, northern pike, and smallmouth bass. These data were used to estimate tag loss and to determine the ratio of marked-unmarked fish for single-census abundance estimates.

Results

Fish Community

A total of 20,906 fish of 16 species were collected during the spring netting survey (Table 3). Total sampling effort was 163 trap-net lifts and 294 fyke-net lifts. Crews captured 3,295 walleyes, 232 northern pike, and 2,125 smallmouth bass, which represented 15.8, 1.1, and 10.2% of the total catch, respectively. Other game species collected in order of abundance were: yellow perch, rock bass, pumpkinseed, bluegill, and largemouth bass.

Yellow perch comprised 18.4% of the catch by number, and had a mean length of 7.1 inches. Rock bass made up 11.7% of the total catch, and mean length was 6.9 inches. Pumpkinseed and bluegill made up 2.6% and 1.5% of the total catch, and had mean lengths of 5.9 and 6.2 inches, respectively. Largemouth bass are present in Grand Lake, but were rather uncommon based on spring survey catches. White suckers are ubiquitous in Grand Lake (Table 3) and comprised 36.3% of the total number of fish collected in the spring. White suckers were collected over a broad distribution of sizes, with 50% less than 10 inches and 50% greater than 10 inches. The overall fish community composition in Grand Lake was 27.5% piscivores, 34.4% pelagic planktivores-insectivores, and 38.1% benthivores (Table 3).

Walleye, Northern Pike, and Smallmouth Bass

Size structure and sex composition.–The percentages of walleyes, northern pike, and smallmouth bass that were legal size were 43, 49, and 40, respectively (Table 4). The population of spawning walleyes was dominated by 14- to 20-inch walleyes, though there were numerous immature walleyes collected as well. Northern pike size structure was widely distributed among 10- to 42-inch groups, with the majority from 20 to 27 inches. Smallmouth bass appeared to have a tri-modal length distribution, with peaks at the 7-, 10-, and 16-inch groups.

Male walleyes outnumbered females in the spring survey, however many fish were of unknown sex. Of all walleyes captured, 43% were male, 15% were female, and 42% were unknown sex, which corresponds with a sex ratio (M : F) of 2.9:1.0. Of legal-size walleyes captured, 61% were male, 33% were female, and 6% were unknown sex, which corresponds to a sex ratio of 1.8:1.0. Of all northern pike captured, 54% were male, 29% were female, and 17% were unknown sex, corresponding to a sex ratio of 1.9:1.0. Of legal-size northern pike captured, 43% were male, 48% were female, and 11% were unknown sex, corresponding to a sex ratio of 0.9:1.0. Crews did not identify the sex of enough smallmouth bass to accurately report the ratio of males to females.

Abundance.–Crews tagged 1,138 legal-size walleyes (551 reward and 587 nonreward tags) and clipped fins of 1,515 sublegal walleyes. Two recaptured walleyes were observed to have died or lost their tag during the spring netting/electrofishing survey, thus the effective number tagged was 1,136.

The angler survey clerk observed a total of 32 walleyes on Grand Lake, of which seven were tagged. In the summer netting survey, crews observed an additional eight walleyes, of which three were marked. I reduced the number of unmarked walleyes in the single-census calculation by nine fish to adjust for sublegal fish that grew over the minimum size limit during the fishing season. Crews did not observe any fish that had a fin clip, no tag, and were determined to have been legal size at the time of tagging; thus, I assumed a tag loss rate of 5% based on previous estimates.

The estimated number of legal-size walleyes was 2,308 using the multiple-census method and 3,308 using the single-census method (Table 5). The estimated number of adult walleyes was 3,634 using the multiple-census method, and 4,641 using the single-census method. The coefficient of variation (CV = standard deviation/estimate) was 0.05 for the two multiple-census estimates, and was 0.23 for the single-census estimates.

Crews tagged 100 legal-size northern pike (60 reward and 40 nonreward tags). Two fish were observed to have died or lost tags during the spring netting/electrofishing survey, so the effective number tagged was 98. Crews also clipped fins of 103 sublegal northern pike. The creel clerk observed five northern pike, of which three were tagged. Crews did not observe any legal northern pike in the summer netting survey. I reduced the number of unmarked northern pike in the single-census calculation by one fish that grew over the minimum size limit during the fishing season. I could not make an estimate of tag loss, but assumed a tag loss rate of 5% based on previous estimates.

The estimated number of legal-size northern pike was 331 (CV = 0.23) using the multiple-census method, and was 124 (CV = 0.20) using the single-census method. The estimated number of adult northern pike was 808 (CV = 0.19) using the multiple-census method and 280 (CV = 0.20) using the single-census method (Table 5).

Crews tagged 764 legal-size smallmouth bass (401 reward and 363 nonreward tags). No recaptured fish were observed to have died or lost tags during the spring netting/electrofishing survey. Crews also clipped fins of 1,156 sublegal smallmouth bass. The creel clerk observed 95 smallmouth bass, of which 12 were tagged. In the summer netting survey crews observed an additional 43 smallmouth bass, of which 11 were marked. I reduced the number of unmarked smallmouth bass by 49 in the single-census calculation to adjust for sublegal fish that grew over the minimum size limit during the fishing season. Two of 23 recaps observed had lost their tags; thus the estimated tag loss rate was 8.7%. The estimated number of legal-size smallmouth bass was 2,756 (CV = 0.10) using the multiple-census method and 2,869 (CV = 0.17) using the single-census method (Table 5).

Growth.–For walleye, there was 60% agreement between the first two spine readers. For fish that were aged by a third reader (remaining 40%), agreement was with first reader 21% of the time and with second reader 79% of the time; thus, there appeared to be some bias among readers (i.e., agreement was with one reader more often than the other). Six percent of samples were discarded due to poor agreement, and an average age was used 2% of the time when ages assigned to older fish (≥ age 10) were within ±10% of each other. At least two out of three readers agreed 92% of the time. I calculated a mean growth index for walleye of -1.6. Mean length-at-age data for male, female, and all walleyes were fit to a von Bertalanffy growth curve, and the resulting L_∞ values were 18.5, 26.3, and 24.8 inches, respectively. Female walleyes had higher mean lengths-at-age than males when samples were sufficient for comparison; for example, females were 2.7 inches longer than males at age 8 (Table 6).

For northern pike, there was 70% agreement between the first two fin ray readers. For fish that were aged by a third reader (remaining 30%), agreement was with the first reader 48% of the time and with the second reader 52% of the time; thus, there appeared to be little bias among readers. Six percent of samples were discarded due to poor agreement; thus, at least two out of three readers agreed 94% of the time. I calculated a mean growth index for northern pike of +1.0. Mean length-at-age data for male, female, and all northern pike were fit to a von Bertalanffy growth curve, and the resulting L_∞ values were 27.5, 39.4, and 34.8 in, respectively. Female northern pike generally had higher mean lengths-at-age than males; for example, females were 3.0 inches longer than males at age 4.

For smallmouth bass, there was 79% agreement between the first two spine readers. For fish that were aged by a third reader (remaining 21%), agreement was with the first reader 36% of the time and with the second reader 64% of the time; thus, there appeared to be some bias among readers. At least two out of three readers agreed 95% of the time. Three percent of samples were discarded due to poor agreement, and an average age was used 2% of the time. I calculated a mean growth index for smallmouth bass of +0.8. Mean length-at-age data for smallmouth bass (Table 8) were fit to a von Bertalanffy growth curve, and the resulting L_∞ value was 19.3 in.

Mortality.–For walleye, I estimated catch at age for 1,130 males, 399 females, and 2,643 total walleyes, including those fish of unknown-sex (Table 9). I used ages 6 and older in all catch-curve analyses to represent the legal-size population(s) (Figure 5). The catch-curve regressions for walleye were all significant ($P < 0.05$), and produced total instantaneous mortality rates for legal-size fish of 0.808 for males, 0.439 for females, and 0.570 for all fish combined (Figure 5). These instantaneous rates corresponded to annual mortality rates of 55% for males, 36% for females, and 43% for all walleyes combined (Table 5).

Anglers returned a total of 66 tags (35 reward and 31 nonreward) from harvested walleyes, and one tag (nonreward) from a released walleye in Grand Lake in the year following tagging. The creel clerk did not observe any tagged fish in the possession of anglers that were not subsequently reported to the central office by the anglers. The estimate of annual exploitation of walleye was 6.7% (Table 5) after adjusting for an average tag loss rate (5%) derived from twelve lakes. Anglers reported reward tags at a higher rate than nonreward tags (6.4% versus 5.5%), and they likely did not fully report either type. The reporting rate of nonreward tags relative to reward tags (λ in Pollock et al. 1991) was 83%. Based on all tagged walleyes known to be caught, the reported release rate was 1.5%. The estimated exploitation rate for walleye was 11.5% (CV = 0.29) based on dividing harvest by the multiple-census abundance estimate, and 8.0% (CV = 0.37) based on dividing harvest by the single-census creel survey abundance estimate (Table 5). The harvest estimate used here was first adjusted for nonsurveyed 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, I estimated catch at age for 113 males, 59 females, and 203 total northern pike, including those fish of unknown-sex (Table 9). I used ages 4 and older in the catch-curve analyses to represent the legal-size northern pike population(s) (Figure 6). The catch-curve regressions for northern pike were all significant ($P < 0.05$). Total instantaneous mortality rates were 0.659 for males, 0.402 for females, and 0.682 for all fish combined (Figure 6). These instantaneous rates corresponded to annual mortality rates of 48% for males, 33% for females, and 50% for all northern pike combined (Table 5).

Anglers returned a total of 9 tags (4 reward and 5 nonreward) from harvested northern pike and one tag from a released northern pike in Grand Lake in the year following tagging. The creel clerk did not observe any tagged fish in the possession of anglers that were not subsequently reported to the central office by the anglers. The estimate of annual exploitation of northern pike was 9.7% after adjusting for an average tag loss rate of 5%. Anglers reported reward tags at a similar rate to nonreward tags (8.3% versus 12.5%), given the low number of tagged fish and returns in general. The reporting rate of nonreward tags relative to reward tags (λ in Pollock et al. 1991) was 151%. Based on all tagged northern pike known to be caught, the reported release rate was 10%. The estimated exploitation rate for northern pike was 16.1% (CV = 0.59) based on dividing harvest by the multiple-census abundance estimate, and 43.1% (CV = 0.58) based on dividing harvest by the single-census creel survey abundance estimate (Table 5).

For smallmouth bass, I estimated catch at age for 1,917 fish (Table 9). I used ages 5 and older in the catch-curve analysis to represent the legal-size smallmouth bass population (Figure 7). The catch-curve regression for smallmouth bass was significant ($P < 0.05$; Figure 7). The total instantaneous mortality rate was 0.451, which corresponds with an annual mortality rate of 36% (Table 5).

Anglers returned a total of 57 tags (39 reward and 18 nonreward) from harvested smallmouth bass, and 57 tags (39 reward and 18 nonreward) from released smallmouth bass in Grand Lake in the year following tagging. The creel clerk observed one tagged fish in the possession of an angler that was not subsequently reported to the central office. The estimate of annual exploitation of smallmouth bass was 10.7% after adjusting for tag loss. Anglers reported reward tags at a higher rate than nonreward tags (19.5% versus 9.9%), and they likely did not fully report either type. The reporting rate of nonreward tags relative to reward tags (λ in Pollock et al. 1991) was 51%. Based on all tagged smallmouth bass known to be caught, the reported release rate was 50%. The estimated exploitation rate for smallmouth bass was 14.2% (CV = 0.25) based on dividing harvest by the multiple-census abundance estimate, and 13.6% (CV = 0.28) based on dividing harvest by the single-census creel survey abundance estimate (Table 5).

Recruitment.–Variability in year-class strength can be inferred from the statistics of the catch-curve regression. For walleye, the amount of variation explained by the age variable was 0.72 (Figure 5). I did not find any relationships between climatological variables and walleye year-class strength in Grand Lake, but water temperature and water quality data specific to the lake are lacking. For northern pike, the amount of variation explained by the age variable (R^2) was 0.86 (Figure 6). I found no relationships between climatological variables and northern pike year-class strength in Grand Lake. For smallmouth bass, the amount of variation explained by the age variable (R^2) was 0.89 (Figure 7), and I found no relationships between climatological variables and year-class strength.

Movement.–Based on voluntary tag returns, there was no movement of walleyes, northern pike, or smallmouth bass out of Grand Lake.

Angler Survey

Summer.–The clerk interviewed 864 boating anglers during the summer 2004 survey on Grand Lake. Most interviews (96%) were roving (incomplete-fishing trip). Anglers fished an estimated 19,928 angler hours and made 6,624 angler trips (Table 10). The total harvest of 4,245 fish consisted of seven different species (Table 10). Yellow perch were most numerous with an estimated harvest of 2,754. Anglers harvested 273 walleyes, 50 northern pike, and 606 smallmouth bass, and reported releasing 137 walleyes (33% of total walleye catch), 24 northern pike (32% of total northern pike catch), and 2,933 smallmouth bass (83% of total smallmouth bass catch).

Winter.–The clerk interviewed 142 open-ice anglers and 444 shanty anglers. Most open-ice (96%) and shanty (95%) interviews were roving type. Open-ice and shanty anglers fished 13,109 angler hours and made 3,727 trips on Grand Lake (Table 11). The total harvest of 6,378 fish during the winter period consisted of three species. Yellow perch were most numerous with an estimated harvest and release of 6,298 and 14,934, respectively. Anglers also harvested 70 walleyes and 10 northern pike, and reported releasing 24 walleyes (26% of total walleye catch) and 14 northern pike (58% of total northern pike catch). Anglers reported catching and releasing twelve ciscoes (lake herring).

Annual totals for summer and winter.–In the annual period from April 24 through March 26, 2005, anglers fished 33,037 hours and made 10,350 trips to Grand Lake (Table 12). Of the total annual fishing effort, 60% occurred in the open-water summer period and 40% occurred during ice-cover winter period.

The total annual harvest was 10,621 fish, of which 60% occurred during the winter period. The estimated total annual harvest of yellow perch was 9,051, making up 85% of the total harvest. The estimated total annual harvest of walleyes, northern pike, and smallmouth bass was 344, 59, and 606 making up 3.2, 0.6, and 5.7% of the total harvest, respectively. The only other species harvested were rock bass, pumpkinseed, and bluegill at 492, 41, and 28, respectively.

The total annual catch (harvest + release) was 46,494 fish, of which 54% occurred in the summer, and 46% in the winter period. Yellow perch were the predominant species caught (harvested + released) at 40,775, with a resulting catch rate (catch per h) of 1.234. The total catch of walleyes was 505, with a catch rate of 0.015. Walleye catch peaked in June, corresponding with the highest monthly catch rate (0.045). Anglers released 32% of all walleyes caught. Estimated total annual catch of northern pike was 97, with a resulting catch rate of 0.003. Anglers released 39% of northern pike caught. Estimated total annual catch of smallmouth bass was 3,559, with a resulting catch rate of 0.108. Smallmouth bass catch peaked in June, corresponding with the highest monthly catch rate (0.399). Total catch of smallmouth bass (1,133) and catch rate (0.327) were also high in September/October. 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 I did not differentiate between sublegal and legal released fish, I assume that a large proportion of the released walleyes and northern pike were sublegal.

There was no survey from mid-October through mid-December, because it was believed that relatively little fishing occurred during that time of year. In fact, only one tag return (northern pike) was reported from mid-October through mid-December, prior to the start of the winter creel survey. Thus, the total annual northern pike harvest was actually about 11.7% higher than the direct survey estimate, or 67 northern pike. No tag returns were reported for walleye or smallmouth bass during the nonsurveyed months (Table 13). We did not conduct surveys in April because walleye, northern pike, muskellunge, and smallmouth bass seasons are closed at that time.

Nine species that were captured during spring netting operations did not appear in the angler harvest – brown bullhead, yellow bullhead, white sucker, bowfin, common shiner, longnose gar, largemouth bass, green sunfish, and common carp. However, four of these species – brown bullhead, largemouth bass, longnose gar, and white sucker – were caught and released. One species (cisco, or lake herring) was caught by anglers, but was not captured during the spring survey.

Discussion

Fish Community

Grand Lake has a relatively long survey history that describes the fish community since 1950. Several surveys from the 1950s and 1960s were employed using gill nets and seines, and thus are less valuable for comparison with the current survey. However, one item of particular importance about these early surveys is the presence of cisco, or lake herring. Lake herring were collected by a commercial trap-netter in 1945-46 (Crowe 1946), and using gill nets in 1950, though they have not been collected in netting surveys of Grand Lake since. Walleye, northern pike, and smallmouth bass, however, were all collected with a frequency sufficient to suggest that populations were likely self-sustaining since the 1950s.

The current survey of Grand Lake was the most comprehensive fisheries survey of the lake given that more fish were collected than any previous survey. Two previous surveys of Grand Lake were conducted in the spring with impoundment gear, and are most appropriate for comparison. In April of 1981 and May of 1995 the MDNR used trap nets and fyke nets to survey the fish population in Grand Lake. Both surveys collected substantially fewer fish than the 2004 survey, though sample sizes were still sufficient for comparisons of species composition. The percent composition of major predators (walleye, northern pike, and smallmouth bass) by number decreased from 51.5 in 1981, to 40.6 in 1995, and finally to 27.1 in 2004. This was especially apparent for northern pike, which had percentages by number of 12.3, 2.7, and 1.1 for 1981, 1995, and 2004, respectively. The relative abundance (catch per trap-net lift) of northern pike also appeared to support this trend (4.6, 0.9, and 1.1 for the three surveys, respectively). The apparent trend for predators was contrasted by a trend of increasing prey abundance (Figure 8). The total percentage of suckers, panfish, and minnows (combined, by number) increased from 47.9 in 1981, to 52.1 in 1995, to 70.7 in 2004. Yellow perch are the only individual prey species that showed a distinct trend over the three surveys, making up 0.7, 0.8, and 18.4% by number, respectively. Although suckers did not show a trend across the three surveys, they made up the highest percentage of the total catch in 2004 at 36.3%. These data suggest that there may currently be a predator-prey imbalance in Grand Lake; however, differences in survey timing of as little as one week can have large impacts on species composition. Given the high temporal variation of species composition that can be observed in surveys and the low number of surveys available for comparison, additional evaluation of these trends is recommended.

The seasonal and gear biases associated with this 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 this 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 Grand Lake such as various species of shiners, darters, and minnows. For example, 15 species of fish have been collected or observed in Grand Lake in other surveys that were not collected in the spring of 2004 (see Appendix). However, among other lakes surveyed as part of the Large Lakes Program, the relative proportions of fish in different feeding guilds in Grand Lake (28% piscivores, 34% pelagic planktivores-insectivores, and 38% benthivores) were most similar to those of Crooked and Pickerel lakes and Burt Lake, which were surveyed in 2001. Crooked and Pickerel lakes had 24% piscivores, 49% pelagic planktivores-insectivores, and 27% benthivores, while Burt Lake had 26% piscivores, 20% pelagic planktivores-insectivores, and 54% benthivores.

Walleye, Northern Pike and Smallmouth bass

Size structure and sex composition.–There was no apparent temporal trend in the size structure of walleye from Grand Lake; i.e., when results from the 1981, 1995, and 2004 surveys were compared. In general, walleye size structure in Grand Lake was below average when compared to other large lakes. In thirteen Large Lakes Program surveys to date, the average percentage of walleyes over legal size was 68, which is 58% higher than that for Grand Lake. Based on the observed distribution of lengths, walleyes in Grand Lake are unlikely to attain lengths much greater than 24 in, though there is the potential to reach 28 in.

There was an apparent positive trend in the size structure of northern pike from the time of the historic (1981 and 1995) spring surveys to the 2004 survey. The percentages of northern pike 24 in or larger were 15, 35, and 49, respectively. However, the minimum size limit of 20 inches in 1981 may have contributed to a lower size structure to some degree for that year. Although there are no past estimates of density, the percentage composition and catch per unit effort from past surveys did suggest decreasing northern pike abundance. The current high size structure of northern pike is at least in agreement with this possible density-dependent relationship.

Currently, the size structure of northern pike in Grand Lake is above average. In twelve Large Lakes Program surveys to date, the average percentage of northern pike over legal size was 28, compared to the 49% found for Grand Lake. Based solely on the lengths of northern pike observed in the survey, northern pike in Grand Lake are likely to attain legal size, and there is the potential to exceed 40 in.

The size structure of smallmouth bass in Grand Lake appeared to be very good. Although the percentage of legal-size fish (40) was lower than the average (65) for 11 Large Lakes Program surveys to date, there was a high proportion of fish from 9 to 11 in, which biased this metric. Smallmouth bass in Grand Lake are likely to attain lengths of 17 in, and have the potential to reach 20 in. The current survey of Grand Lake is comparable to historic surveys with respect to the good size structure of smallmouth bass.

Male walleyes outnumbered females in the survey both when all sizes and when fish of legal size were considered. 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). In Grand Lake, the male : female ratio for adult

(2.9:1.0) and legal (1.8:1.0) walleyes was less than the averages (adult = 3.8:1.0, legal = 2.6:1.0) from thirteen Large Lakes Program surveys.

Male northern pike outnumbered females in Grand Lake when all sizes were considered. However, females 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) may also contribute to this disparity, and the estimate of mortality for male northern pike was higher than for females. In other large lakes, the same disparity in sex ratio of all northern pike versus northern pike of legal size was found (Clark et al. 2004, Hanchin et al. 2005a, 2005c, 2008). The male to female ratios for adult and legal northern pike in Grand Lake were both higher than the averages (adult = 1.3:1.0, legal = 0.4:1.0) from twelve Large Lakes Program surveys.

For northern pike from other lakes, males dominate sex composition in spawning-season samples, but not at other times of the year (Preigel 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 : female), but the overall sex ratio for an entire year of sampling was not significantly different from 1:1.

Abundance.–These were the first estimates of walleye abundance in Grand Lake. I was successful in obtaining reasonable multiple-census and single-census estimates for both legal-size and adult walleyes. The multiple-census estimates were lower than the single-census estimates; however, given the low abundance overall, the differences between estimates were not severe. 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 (1997) 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 (single-census estimate) allowed for better mixing of marked and unmarked fish, and so was theoretically less biased. While Pierce (1997) worked with northern pike, previous Large Lakes Program surveys support the hypothesis that these biases are similar for walleye. Multiple-census estimates for walleye have been lower than single-census estimates in nine of ten lakes surveyed (Clark et al. 2004; Hanchin et al. 2005a, 2005b, 2005c). In these nine lakes, multiple-census estimates averaged 33% lower for legal-size walleyes and 21% lower for adult walleyes. Both the multiple-census and single-census estimates fit well with other independently-derived statistics, such as the number of walleyes harvested. Given that the single-census method violates fewer assumptions than the multiple-census, I think they are the best estimates of walleye abundance in Grand Lake.

Whether I use the multiple-census estimate of 3,634 or the single-census estimate of 4,641, it seems obvious that the population density of adult walleyes in Grand Lake is below average. The Michigan regression model predicts much higher adult walleye abundance for Grand Lake than I found. The population density of adult walleyes in Grand Lake (0.8 per acre) was well below average when compared to estimates from other lakes, and was actually the second lowest density observed thus far in the Large Lakes Program. Adult walleye density has averaged 3.5 per acre in thirteen 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. The population density of legal-size walleyes in Grand Lake was also well below average relative to other lakes in Michigan and elsewhere. The best estimate of 3,308 for 15-in-and-larger walleyes converts to a population density of 0.6 per acre. Density of legal-size walleyes estimated recently for thirteen large lakes in Michigan has averaged 2.1, and has ranged from 0.4 to 4.6 per acre (Clark et al. 2004, Hanchin et al. 2005a, 2005b, 2005c).

I had mixed success in obtaining abundance estimates for northern pike. The minimum number of recaptures was obtained for multiple-census estimates, but the recapture sample for single-census estimates was low, and likely not sufficient. Therefore, the multiple-census estimate is the best estimate for northern pike. However, I suspect the true abundance is somewhat higher, because the multiple-census estimate is usually biased low.

Compared to other large lakes sampled in Michigan, population density for adult northern pike in Grand Lake is below average. The best estimate of 808 adult northern pike converts to a density of 0.1 adult northern pike per acre. Adult northern pike abundance has averaged 1.0 per acre (range 0.1 – 2.9) in twelve large lakes surveyed thus far in Michigan. 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, where the density ranged from 4.5 to 22.3 per acre for fish age 2 and older. The population density for legal-size northern pike in Grand Lake is also below average relative to other lakes in Michigan. Based on the best estimate of 331 fish, the population density of legal-size northern pike in Grand Lake is only 0.06 per acre. Density of legal-size northern pike estimated recently for eleven large lakes in Michigan has averaged 0.14, and has ranged from 0.01 to 0.53 per acre (Clark et al. 2004, Hanchin et al. 2005a, 2005b, 2005c).

I had success in obtaining abundance estimates for smallmouth bass. The minimum number of recaptures was obtained for both types of estimates and both estimates were remarkably similar. Both estimates also appeared reasonable when judged in relation to the independently-derived harvest estimate. Both the multiple-census and single-census abundance estimates convert to population density of 0.5 legal-size smallmouth bass per acre.

A thorough comparison of smallmouth bass density in Grand Lake 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 in deriving the estimates that do exist. In Michigan lakes, Big Manistique (Hanchin and Kramer 2007), South Manistique (Hanchin and Kramer 2008a), and South Leelanau (Hanchin et al. 2007) had legal smallmouth bass densities of 0.1, 0.07 and 1.0 per acre, respectively. 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. About 20% more 12- to 14-inch smallmouth bass were collected, based on length frequencies, but if the abundance estimates are increased by 20%, there are at most 0.6 adult smallmouth bass per acre in Grand Lake. 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 (approximately ≥ 8–9 in) in Nebish Lake, Wisconsin. Finally, Newmann and Hoff (2000) reported a density in Palette Lake, Wisconsin (more similar to mine) of 0.3 smallmouth bass (>16.0 in) per acre.

I believe it would be possible to improve abundance estimates for Grand Lake 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. Three crews collected and marked 1,138 walleyes using 10 to 15 nets each. Based on my experience from making abundance estimates on other lakes (Clark et al. 2004, Hanchin et al. 2005a, 2005b, 2005c), this is enough fish to get a reasonable single–census population estimate. Thus, the most practical solution for improving the abundance estimates would be to supplement the recapture sample with additional summer, or fall netting.

Growth.–Reader agreement (first two reads) for walleye spines on this survey 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 twelve Michigan large lakes surveyed to date has ranged from 39 to 84% with an average of 57%. Similarly, Miller (2001) found that at least two of three readers agreed 94% of the time.

Walleye mean lengths-at-age for Grand Lake were lower than the state average, indicating poor growth. 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). The mean growth index for Grand Lake is not that far from the acceptable range of +/- one inch from the statewide average (Schneider et al. 2000a), and it would likely be within that range if spines were used to calculate the statewide average. The MDNR is in the process of calculating new state averages based on spines, which will improve future comparisons.

Walleye growth was assessed for Grand Lake by DNR Fisheries Division in 1950, 1961, 1962, 1970, 1981, 1995, and 2004. Although sample sizes were often small, growth rates have been consistently low throughout the time series; the mean growth index was -2.2, -1.8, -2.3, -6.8, -2.7, and -2.4 in 1950, 1961, 1962, 1970, 1981, and 1995, respectively. The mean growth index for 2004 is actually the best observed thus far in Grand Lake, and this is despite the use of new aging structures that would potentially underestimate growth with respect to statewide averages calculated using scales. Assuming growth is inversely related to population density, the current favorable growth of walleye supports the hypothesis of low predator abundance in Grand Lake. Walleye growth in Grand Lake was similar to Hubbard Lake, but was less than some of the other large lakes in the Northern Lake Huron Management Unit (Table 14).

The values calculated for L_∞ provide some insight into the growth potential of individuals in a population. The growth potential of female walleyes is much higher than that of males in Grand Lake, and overall the growth potential is good. The L_∞ in Grand Lake (24.8) is higher than the average (23.5 in) for other populations surveyed as part of the Large Lakes Program.

Reader agreement for northern pike was similar to other studies. Reader agreement (first two reads) in eleven Michigan large lakes surveyed to date has ranged from 59 to 88%, with an average of 73%. Additionally, the mean lengths-at-age for finray-aged northern pike were above average compared to other lakes in Michigan. The mean growth index (+1.0) is rather high, and would potentially be higher if there is a negative bias of using finrays compared to scales for aging. The average mean growth index for northern pike populations surveyed as part of the Large Lakes Program is -0.2. Although northern pike exhibited positive growth indices in surveys of Grand Lake during the 1950s and 1960s, from 1971 to 1973 the mean growth index ranged from -0.6 to -1.4. In 1981 the growth index was +2.9, but was calculated using only ages 2 through 5. In 1995 the growth index was back down to -0.8. The variation in northern pike mean lengths-at-age over time is likely a result of varying population density. Northern pike growth was similar to other large lakes in the Northern Lake Huron Management Unit and elsewhere in Michigan (Table 15).

Length infinity (L_∞) values for northern pike suggest that growth potential is about average in Grand Lake. The average for twelve populations surveyed under the Large Lakes Program is 35.7 in. Female pike in Grand Lake typically attain legal size (24 in) by age 3, while males attain this size from age 4 to 6.

Reader agreement in aging smallmouth bass was high, though there are few other studies for comparison. Reader agreement (first two reads) in South and Big Manistique lakes was 58 and 64%, respectively (Hanchin and Kramer 2007, 2008a). Mean lengths-at-age for smallmouth bass in Grand Lake were above average compared to other lakes in Michigan. The mean growth index (+0.8) for smallmouth bass was high, and could be potentially higher if there is a negative bias associated with using spines (compared to scales) for aging smallmouth bass. The best evidence for this occurring in smallmouth bass was reported by Maraldo and MacCrimmon (1979) who found that scales underestimated true age for largemouth bass relative to spines. The mean growth indices for South and Big Manistique lakes, also surveyed as part of the Large Lakes program, were +1.5 and +1.3, respectively. In surveys of Grand Lake done in the 1960s and 1970s, the mean growth index for smallmouth bass ranged from -0.9 to -2.6, though sample sizes were generally low. In 1981 and 1995 the mean growth indices were -1.3 and -0.6, respectively. Acknowledging the potential biases of low samples size, it appears that growth of smallmouth bass has improved over the past 20 to 30 years. Similar to northern pike, smallmouth bass growth was comparable to other large lakes in the Northern Lake Huron Management Unit and elsewhere in Michigan (Table 16).

Length infinity (L_∞) values for smallmouth bass suggest that growth potential is about average in Grand Lake. The L_∞ values for smallmouth bass in South and Big Manistique lakes, also surveyed recently under Large Lakes Program protocols, were 18.9 in and 19.1 in, respectively.

Mortality.–This was the first attempt to estimate total mortality of walleye from Grand Lake. Total annual mortality (48%) of walleye was relatively high, and there were few older (age ≥ 10) fish collected. The lack of older walleyes in Grand Lake is probably a result of a series of years of low recruitment, since angler mortality makes up only a small portion of total mortality. Given that angler mortality is low, natural mortality must be relatively high. High natural mortality is conceivable, given the high summer water temperatures and lack of a thermocline in Grand Lake.

In thirteen walleye populations surveyed previously as part of the Large Lakes Program, mortality has ranged from 29 to 51% with an average of 38%. 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 (1978) 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 walleye 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%.

The three estimates of annual walleye exploitation in Grand Lake encompassed a rather small range (6.7–11.5%). Considering the biases for the three methods used, the true annual exploitation of walleye in Grand Lake is probably around 10%. I consider the tag return estimate to be an underestimate because I did not adjust for tagging mortality or nonreporting, and if these problems occurred to any degree, I would have underestimated exploitation (Miranda et al. 2002). I did not detect any tag loss. However, Isermann and Knight (2005) recently reported tag loss rates of 23–50% for walleyes jaw-tagged with similar methods in a tributary to Lake Erie. Although I do not believe the tag loss rate was that high in this study, I used an average rate of 5% from previous estimates on lakes surveyed as part of the Large Lakes Program.

I did not make a true estimate of nonreporting, but there was evidence that it occurred to some degree since the number of tags voluntarily returned by anglers (67) was less than the predicted number of returns (74) based on the ratio described previously in the **Methods** section. I attempted to get some measure of nonreporting of tags by offering a $10 reward on about half of the tags and comparing return rates of reward to nonreward tags. I found that reporting rate for reward tags (6.4%) was slightly higher than for nonreward tags (5.5%), which would be expected given that the reward amount was relatively low compared to those used by other authors (Miranda et al. 2002; Taylor et al. 2006). 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 nonreward 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 in that system (Hanchin et al. 2005a).

Compared to exploitation rates for walleye from other lakes in Michigan and elsewhere, the estimate for Grand Lake is below average. The average exploitation rate for walleye from thirteen large lakes surveyed to date was 15.8% with a range of 3.5–35.2%. 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 walleye across its range is large. For example, Schneider (1978) gave a range of 5–50% for lakes in Midwestern North America, and Carlander (1997) gave a range of 5–59% 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 Grand Lake. The estimate of 50% total annual mortality for fish of legal size was average, compared to estimates from other lakes. In twelve populations surveyed as part of the Large Lakes Program total annual mortality of northern pike has averaged 50.2%, with a range of 31–70%. Pierce et al. (1995) estimated total mortality for northern pike in seven small (<300 acres) lakes in Minnesota to be 36–65%. 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 (24.4%) and Lac Vieux Desert (36.2%).

The three estimates of annual northern pike exploitation in Grand Lake comprised a rather broad range (9.7–43.1%). This may be due to problems with the single-census estimate, as the exploitation estimate calculated as harvest divided by the single-census abundance estimate appears to be an outlier. If abundance was underestimated, it follows that exploitation was overestimated. In contrast, the exploitation estimate (16.1%) derived from dividing harvest by the multiple-census abundance estimate was closer to the exploitation estimate from tag returns. I consider the tag return estimate to be a minimum because it was not adjusted for tagging mortality or nonreporting, and if these problems occurred to any degree, exploitation would have been underestimated (Miranda et al. 2002). I did not estimate tagging mortality, and did not detect any tag loss; however, tag loss likely occurred to some degree. I did not make a true estimate of nonreporting, but there was some evidence that it occurred since the number of tags voluntarily returned by anglers (10) was less than the predicted number of returns (40) based on the ratio described previously in the **Methods** section. I do not have much faith in this assessment, however, since the ratio was based on a sample of three out of five marked northern pike observed in the angler survey. Considering the biases for the three methods used, the true annual exploitation of northern pike in Grand Lake is probably in the 10–20% range. Even considering the upper end of this range, angler mortality does not contribute as much as natural mortality to the total mortality rate of northern pike.

Compared to exploitation rates for northern pike from other lakes in Michigan and elsewhere, this estimate of 10–20% for Grand Lake is about average. Latta (1972) reported northern pike exploitation in two Michigan lakes, Grebe Lake (12–23%) and Fletcher Pond (38%). Pierce et al. (1995) reported rates of 8–46% for fish over 20 in for seven lakes in Minnesota. Carlander (1969) gave a range of 14–41% for a sample of lakes throughout North America. Finally, the average exploitation rate for northern pike from eleven large lakes surveyed to date was 19.2%, with a range of 7.8–31.4%.

The total mortality estimate for smallmouth bass of 36% 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 an estimate of 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. In the Michigan lakes Leelanau, Big Manistique, and South Manistique, the total mortality of smallmouth bass was 39, 45, and 25%, respectively (Hanchin et al. 2007, Hanchin and Kramer 2007, 2008a).

The three estimates of annual smallmouth bass exploitation in Grand Lake comprised a rather narrow range (10.7–14.2%). Annual tag loss was 9%. I did not make a true estimate of nonreporting of reward tags, and there was little evidence that it occurred since the number of tags voluntarily returned by anglers (114) was greater than the predicted number of returns (83) based on the ratio described previously in the **Methods** section. Considering the biases for the three methods, the true annual exploitation of smallmouth bass in Grand Lake is probably in the 10–15% range, and angler mortality contributes about 50% of the total mortality rate.

The estimate for smallmouth bass exploitation appears reasonable when compared to exploitation rates for smallmouth bass from other lakes in Michigan and elsewhere. Latta (1975) reported a range of 9–33% 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, 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. In the Michigan lakes Leelanau, Big Manistique, and South Manistique, angler exploitation of smallmouth bass was 14, 21, and 4%, respectively (Hanchin et al. 2007, Hanchin and Kramer 2007, 2008a).

Recruitment.–Walleyes in Grand Lake were represented by 14 year classes (ages 1–11 and 13–15) in the samples. Year-class strength was variable (R^2=0.82 in Figure 5), though this is normal for walleye populations. In thirteen other Michigan walleye populations surveyed as part of the Large Lakes Program to date, the R^2 has ranged from 0.50 to 0.98, with an average of 0.82. Considering the relative consistency of year-class strength and the lack of walleye stocking, natural reproduction of walleye appears adequate in Grand Lake.

It is interesting to note that the 1992 and 1993 year classes corresponded with negative residuals (Figure 5). Many lakes in the Midwest had poor walleye year classes in 1992 and 1993, possibly due to the eruption of Mount Pinatubo and subsequent cooling (Schupp 2002).

Northern pike in Grand Lake were represented by 10 year classes (ages 1 through 10). Variability in year-class strength was about average. In twelve other Michigan northern pike populations surveyed as part of the Large Lakes Program to date, the R^2 has ranged from 0.67 to 1.00, with an average of 0.87. Similar to northern pike, the variability in smallmouth bass year-class strength in Grand Lake was rather consistent, with an R^2 of 0.89 for the catch curve regression (Figure 7). In the Michigan lakes Leelanau, Big Manistique, and South Manistique, the R^2 of the catch curve regressions for smallmouth bass were 91, 90, and 61%, respectively (Hanchin et al. 2007, Hanchin and Kramer 2007, 2008a).

Movement.–As previously stated, I did not document any movement of walleye, northern pike, or smallmouth bass out of Grand Lake. Movement out of the lake is not impossible, though documenting movement from tag returns is not probable due to the low fishing effort in the tributaries and outlet of Grand Lake. Rodeheffer and Day (1952) reported anecdotal evidence of northern pike migrating to Lotus Lake; however, an open-bottom bridge connected the two lakes instead of a small culvert. Perhaps the existing culvert prevents or deters movement of northern pike from Grand Lake to Lotus Lake.

Angler Survey

The fishery of Grand Lake is dominated by yellow perch, which comprised 85% of the total annual harvest, and 88% of the released fish. Smallmouth bass offer the best angling opportunity for a large predator, and were the second most commonly harvested and released species, comprising 6% of the total annual harvest, and 8% of the released fish. Walleye and northern pike do not appear to present much angling opportunity, though some anglers likely target them at certain times of the year. Walleye harvest peaked in June, corresponding with the highest catch rates. Catch rate for walleye was highest in June (0.045/hour), though even at its peak was never very high. Yellow perch harvest was highest in February, and the winter period accounted for 70% of the annual harvest. Winter catch rates for yellow perch were higher than summer rates, but the opposite was true for walleye, northern pike, and smallmouth bass. The ice-cover winter period accounts for relatively greater effort than the summer period, considering its shorter duration. Overall, the fishery of Grand Lake is not very diverse, especially in the winter when yellow perch, walleye, and northern pike are the only species harvested. A few other species provide angling opportunity throughout the year, though not to any large degree. Perhaps the most interesting aspect of the angler survey data is the apparent presence of cisco (lake herring), of which a dozen were estimated as being caught and released. The catch of herring should be interpreted with caution, given that it was likely based on one or two interviews, with low reported catches.

Historical comparisons.–Previous harvest and effort estimates for Grand Lake were reported by Laarman (1976). A general creel census from 1939–50 and 1951–64 included Grand Lake, 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 are not directly comparable to the current estimates. However, considering the general census alone, yellow perch were the predominant species in the fishery during both periods, making up 67% and 85% of the catch. Rock bass were the second most abundant species, making up 5% and 18% of the catch during the two survey periods. Walleye made up 3% and 6% of the catch, while smallmouth bass made up 3% and 5% of the catch during the two periods. In terms of general species composition, the fishery of Grand Lake does not appear to have changed much since the 1964 survey.

In the winter of 1935, a special creel survey was conducted on Grand Lake. Ninety-eight anglers fished an estimated 480 hours and caught 211 fish, for a catch rate of 0.44 per hour. If I assume this “catch rate” is actually a harvest rate, it is comparable to the winter harvest rate of all species (0.49 per hour) observed in 2004. While the catch rate for all species was similar between survey periods, the species composition of the catch was slightly different. In the winter of 1935, yellow perch, northern pike, and walleye made up 81.5, 18.0, and 0.5% of the total catch, respectively, while in the winter of 2004 they made up 98.7, 0.2, and 1.1%, respectively. While the relative proportions of each species are similar, there was an apparent decrease in the relative abundance of northern pike between survey periods, which supports the findings of the current survey.

In 1970 and 1973, annual fishing effort on Grand Lake was estimated as 19,940 and 24,750 angler days, respectively, from mail surveys (Laarman 1976). Using current knowledge of the average number of trips per day (1.2 trip/day), and the average length of a trip (2.62 h/trip) from the 2004 creel survey, the 1970 and 1973 estimates equate to 62,691 and 77,814 hours of fishing effort, respectively. These two estimates are about double the 2004–05 annual estimate of effort (33,037 angler hours). While there were differences among estimation methods, it appears that effort has decreased from that observed in 1970 and 1973.

Comparison to other large lakes.–In general, surveys conducted in Michigan in the past 10 years used the same methods as the current study of Grand Lake, but most of them still differ from this survey in seasonality. For example, few other surveys were done in consecutive summer and winter periods. Regardless, for comparison, I used recent angler survey results for Michigan's large inland lakes from 1993 through 1999 as compiled by Lockwood (2000b) and results from the Large Lakes Program.

I estimated 33,037 angler hours of effort on Grand Lake during the year from April 24, 2004 through March 26, 2005. This corresponds to an effort of 5.7 hours per acre, which is below average compared to other large lakes in Michigan (Table 17). The harvest per acre for Grand Lake was 1.8 per acre, which is also low relative to other large lakes. Michigan lakes with a high harvest per acre generally have popular bluegill fisheries that bolster the total harvest (e.g. Houghton Lake; Clark et al. 2004).

For walleye, the estimated annual harvest from Grand Lake was 0.06 fish per acre, which is low relative to the average (0.64) for thirteen lakes surveyed as part of the Large Lakes Program. In fact, it is the lowest observed thus far in the Large Lakes Program. Walleye production from other large lakes has ranged from 0.16 per acre for Big Manistique Lake to 1.61 per acre for South Manistique Lake. The average harvest from six other large Michigan Lakes (>1,000 acres) reported by Lockwood (2000a) 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. The low harvest per acre of walleye in Grand Lake is likely a result of both low productivity and low angler effort directed at this species.

For northern pike, the estimated annual harvest from Grand Lake was 0.01 fish per acre. This harvest was also below average compared to other waters in Michigan and elsewhere. The average harvest in eleven other lakes sampled in the Large Lakes Program was 0.098 northern pike per acre, ranging from 0.003 in North Manistique Lake (Hanchin and Kramer 2008b) to 0.464 in Houghton Lake (Clark et al. 2004). The average harvest from seven other large Michigan lakes (> 1,000 acres) reported by Lockwood (2000a) 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.

In contrast to the walleye and northern pike fisheries, the smallmouth bass fishery in Grand Lake is quite good. The total catch (harvest + release) in Grand Lake was 3,559, which 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. 2005c), and Burt Lake (796; Hanchin et al. 2005b). On a per acre basis, the annual harvest of smallmouth bass from Grand Lake was 0.104, which is about average compared to other waters in Michigan. The average harvest in eleven other lakes surveyed in the Large Lakes Program was 0.097 smallmouth bass per acre, ranging from 0.007 in Burt Lake (Hanchin et al. 2005b) to 0.416 in the Cisco Chain (Hanchin et al. 2008). The average harvest from seven other large Michigan lakes (>1,000 acres) reported by Lockwood (2000a) 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. The total catch (harvest + released) per hour of smallmouth bass in Grand Lake was 0.108, which is the highest observed thus far in the Large Lakes Program. Thus, even with the biases resulting from calculating catch rates with general fishing effort, the smallmouth bass fishery in Grand Lake is of high quality.

The other species that offers considerable fishing opportunity in Grand Lake is yellow perch. The estimated annual harvest per acre of yellow perch was 1.6 for Grand Lake. In comparison, harvest per acre of yellow perch was 3.4 for Burt Lake (Hanchin et al. 2005b), 2.5 in Houghton Lake (Clark et al. 2004), and 1.8 in Crooked and Pickerel lakes (Hanchin et al. 2005c). The associated harvest rate for yellow perch in Grand Lake was 0.274 per hour, compared to 0.440 per hour for Burt Lake, 0.099 per hour for Houghton Lake, and 0.113 per hour for Crooked and Pickerel lakes. Although yellow perch anglers in Grand Lake release many (presumably small) fish, the fishery compares well with other large lakes that have well-known yellow perch fisheries.

Summary

The current walleye fishery in Grand Lake is of lower quality than other large lakes in Michigan. In 2004–2005, the lake contained an estimated 0.6 legal walleyes per acre and anglers harvested 0.06 per acre, at a rate of 0.010 per hour fished. These are among the lowest values found in large lakes in Michigan. While the walleye population may have been larger in the past, abundance was likely never much different from what is reported here. The population is not limited by poor natural reproduction, but is rather maintaining an equilibrium corresponding with the productivity of the lake.

Northern pike have the lowest abundance of the three predator species targeted in this survey, when fish of legal size are considered. The Grand Lake population is of low- to average-density, with above-average growth. However, northern pike are likely less abundant than they were in the past. This is likely a result of reduced frequency in stocking and reduced numbers of fish stocked, though spawning habitat loss may have contributed to the decline. Only 0.012 northern pike per acre were harvested, at a rate of 0.002 per hour. Both these figures are low compared to those estimated in other large lakes. Total mortality is acceptable; thus, I assume that while natural reproduction and stocking have been relatively consistent recently, the total number of recruits produced has been consistently low.

In contrast to the walleye and northern pike fisheries, the smallmouth bass fishery in Grand Lake is rather good. Although the densities of smallmouth bass and walleye were similar, anglers harvested more smallmouth bass per acre and at a higher rate. Anglers harvested 0.104 smallmouth bass per acre, at a rate of 0.018 per hour, which are average and above-average numbers, respectively, for large lakes in northern Michigan. Additionally, there were numerous smallmouth bass caught and released, and the total catch per acre (0.611) was high relative to the median (0.379) for eleven lakes surveyed under the Large Lakes Program. The catch-and-release component of the smallmouth bass fishery in Grand Lake is important, with an impressive 50% of legal smallmouth bass released. Population density of smallmouth bass is similar to other large, northern Michigan lakes, though there are few populations for comparison. Total mortality and growth rates are in acceptable ranges and natural reproduction appears consistent from year to year.

The number of fish harvested per acre in Grand Lake was below average for other large lakes in Michigan, which is a result of low fishing effort on a lake with low productivity. Grand Lake is primarily a smallmouth bass and perch fishery, with less important walleye and northern pike fisheries. The yellow perch fishery in Grand Lake is rather good, but is still less productive (harvest = 1.55 per acre) than the average (3.46) and median (2.15) for twelve large lakes surveyed recently. Given the relatively high abundance of prey such as yellow perch and white suckers, the predator population could tolerate some type of augmentation. Since the smallmouth bass population is adequate, and the walleye population has slow growth, it would make sense to supplement the northern pike population. This may be achieved through more frequent operation of the spawning marsh, though there may be another longer-term solution. The culvert that connects Lotus Lake should be evaluated in terms of length and velocity to ensure proper fish passage. Flows observed in the culvert during the spring survey were considerable, and could potentially prevent upstream passage to Lotus Lake. This was also mentioned by Rodeheffer and Day (1952) as a potential hindrance to northern pike reproduction after an open-bottom wooden bridge was replaced with an 18-inch culvert. If the culvert is unsuitable for fish passage, a larger, open-bottom arch culvert, or bridge should be considered to improve access to spawning habitat.

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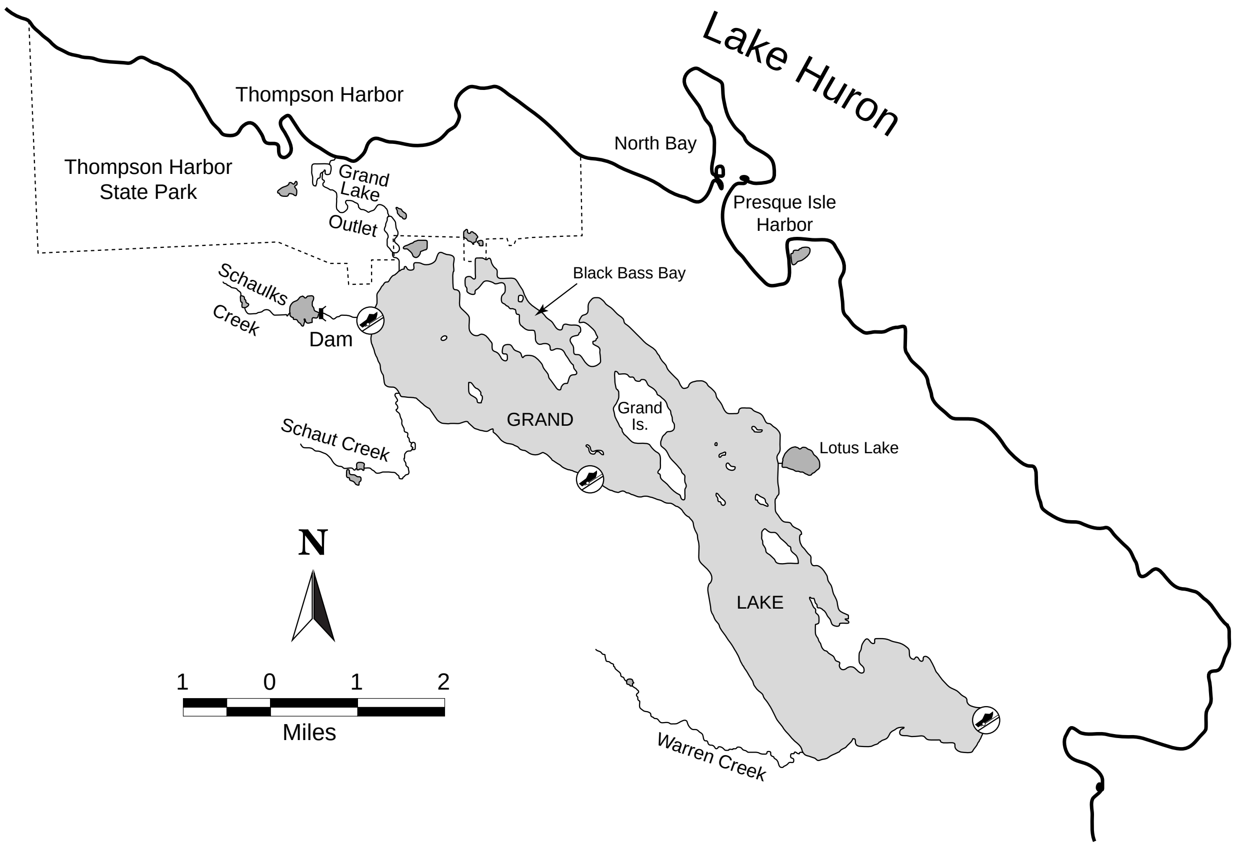

Figure 1.–Map of Grand Lake, Presque Isle County, Michigan.

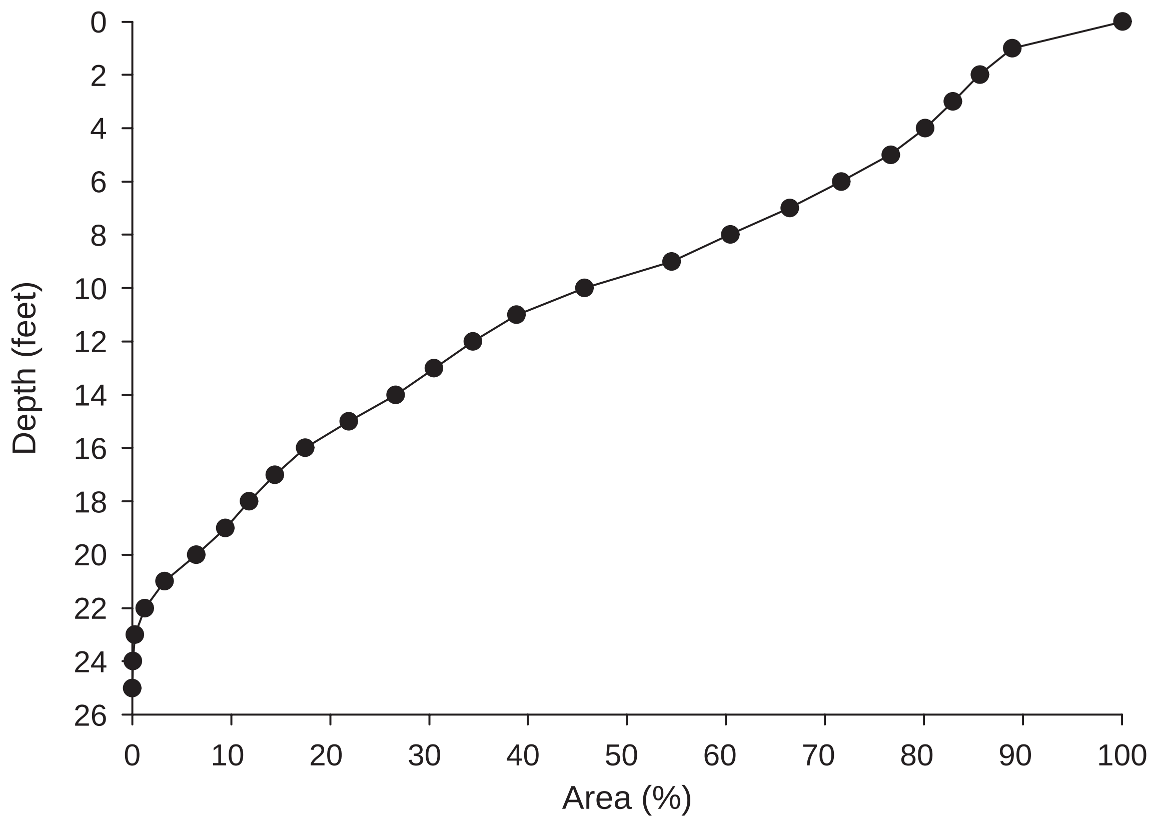

Figure 2.–Percent of area equal to or greater than a given depth for Grand Lake. Data taken from MDNR Digital Water Atlas.

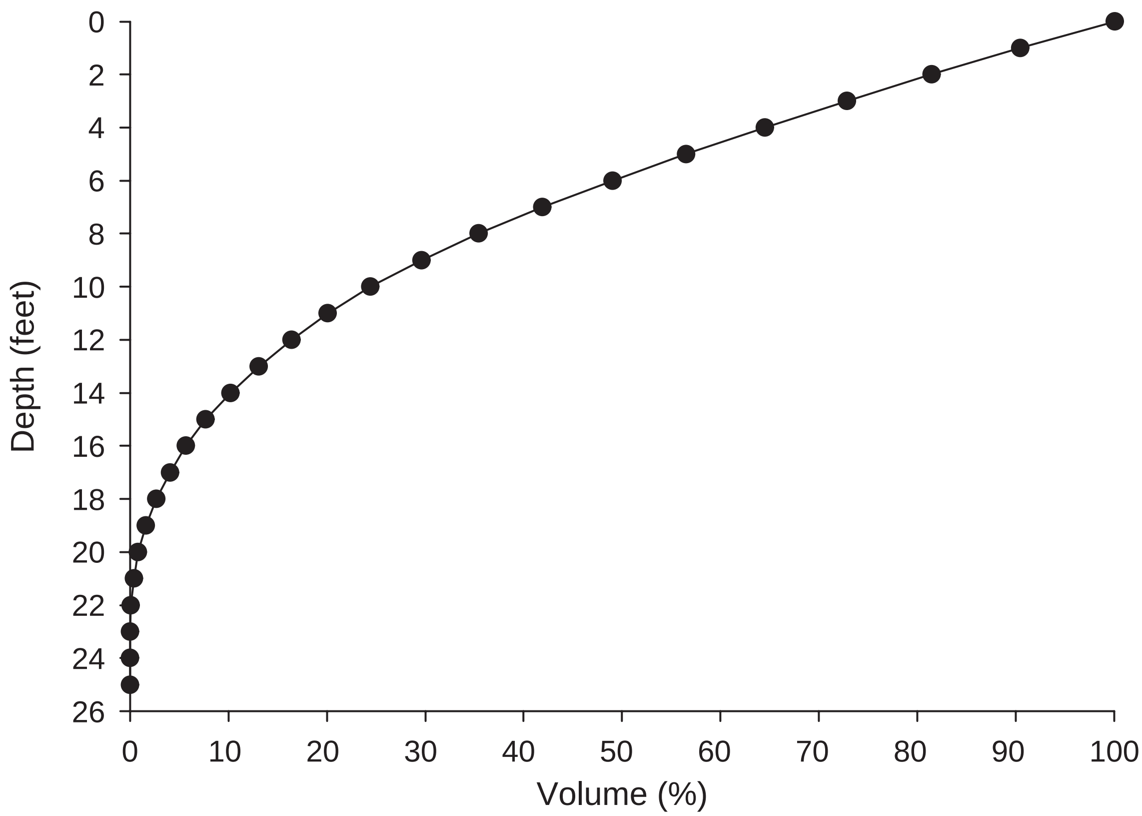

Figure 3.–Percent of volume equal to or greater than a given depth for Grand Lake. Data taken from MDNR Digital Water Atlas.

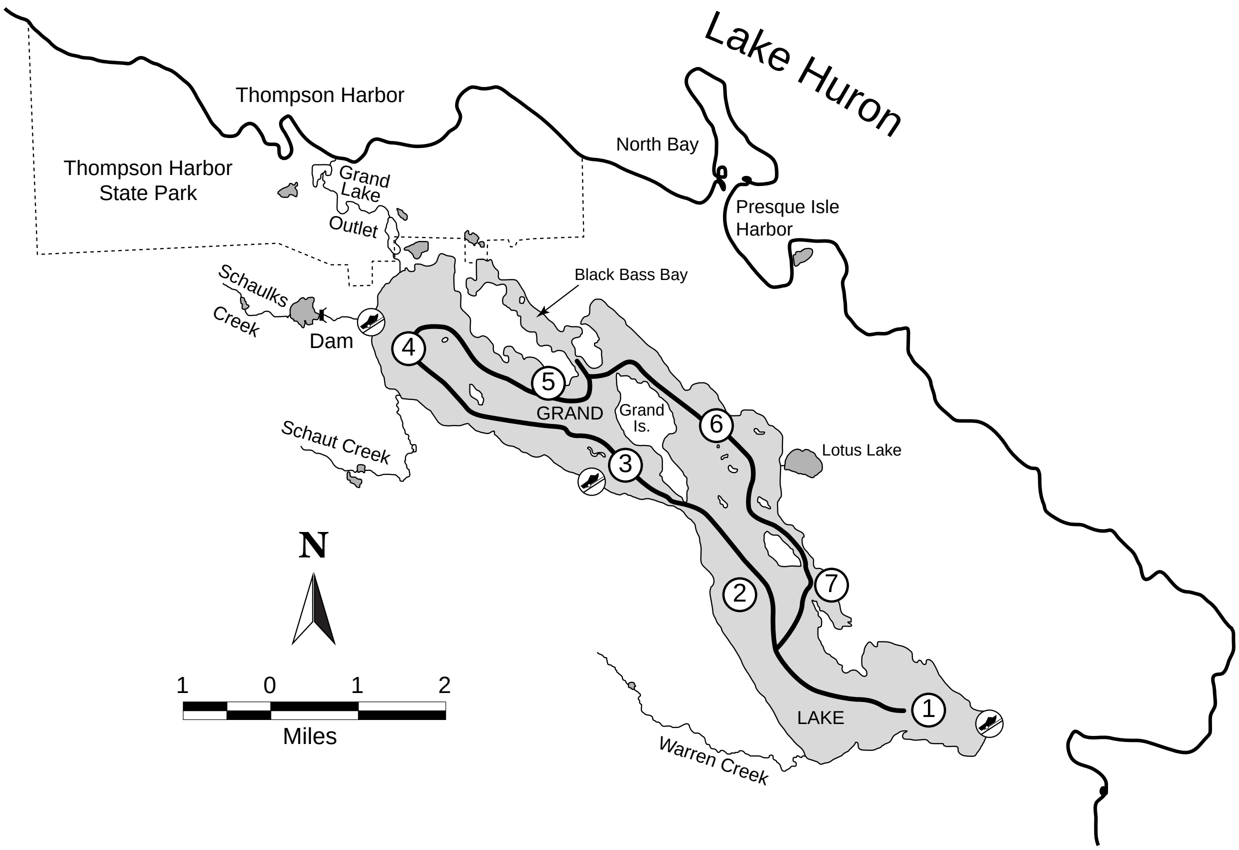

Figure 4.–Counting path, associated count pathway points, and interview locations for the Grand Lake, summer 2004 and winter 2005 survey.

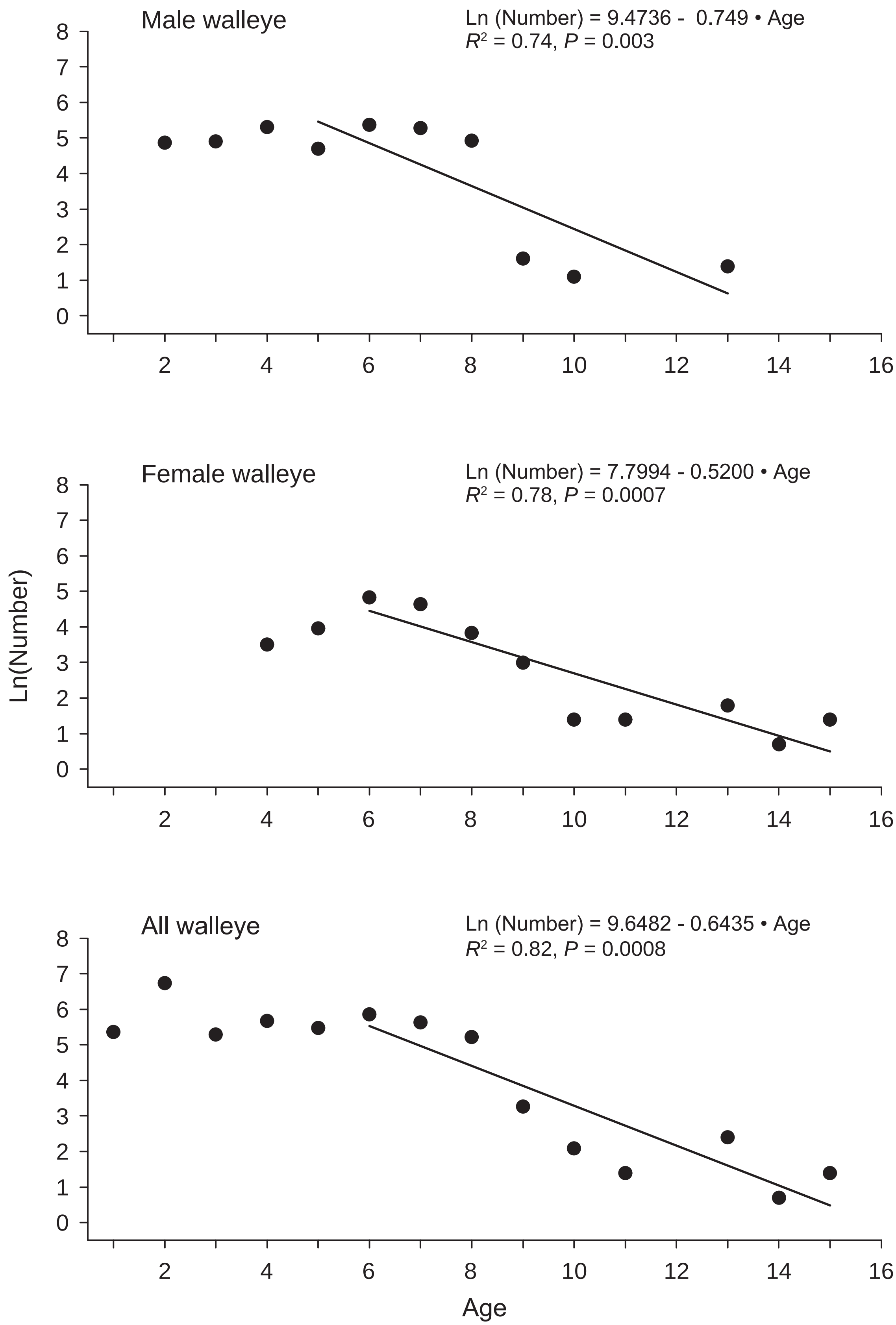

Figure 5.–Plots of observed ln(number + 1) versus age for male, female, and all (including males, females, and unknown sex) walleyes in Grand Lake. Lines are plots of regression equations given beside each graph.

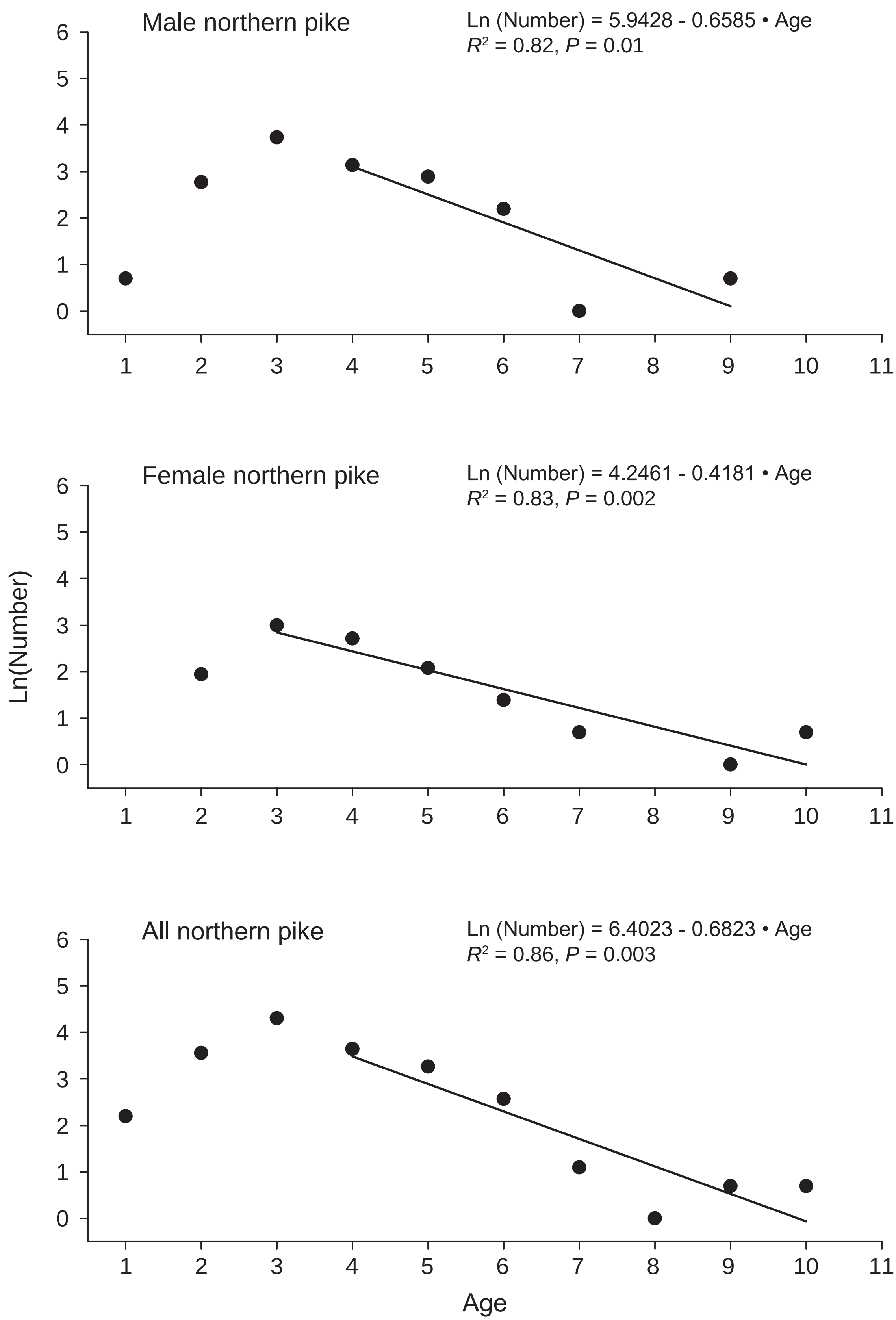

Figure 6.–Plots of observed ln(number) or ln(number + 1) versus age for male, female, and all (including males, females, and unknown sex) northern pike in Grand Lake. Lines are plots of regression equations given beside each graph.

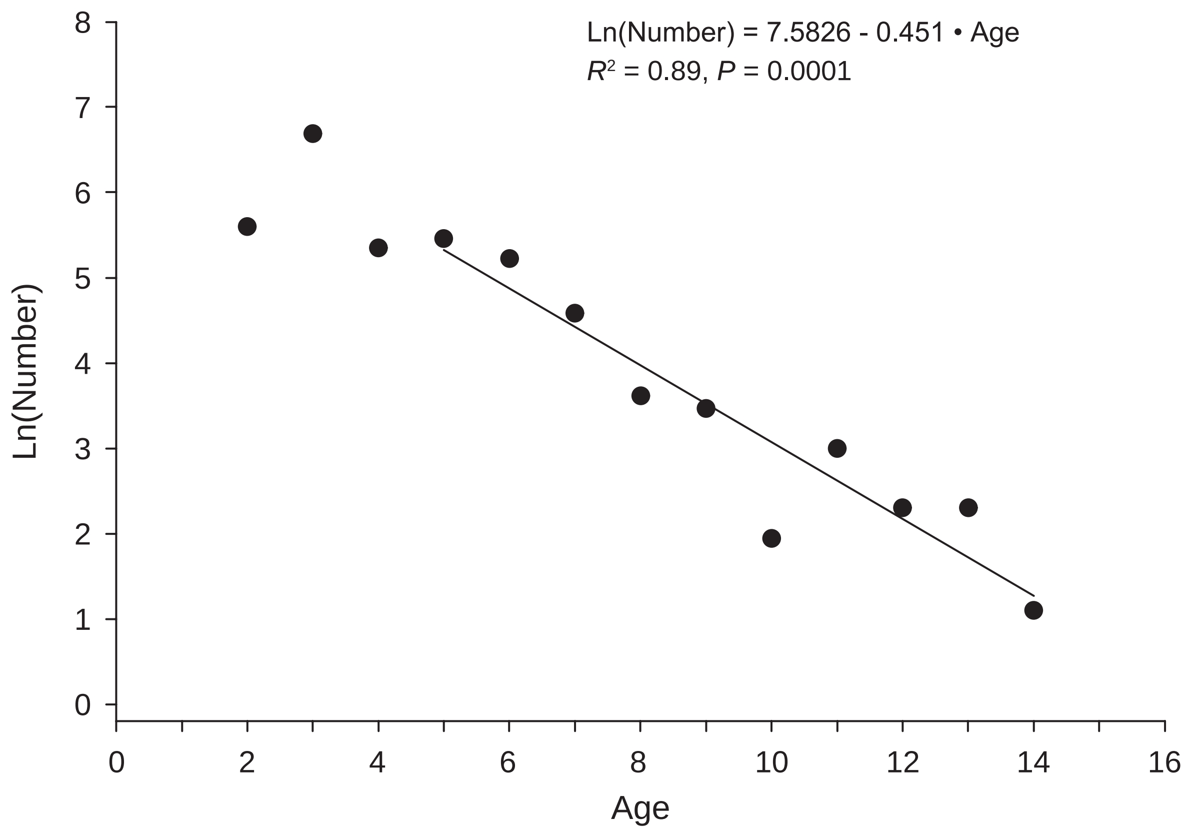

Figure 7.–Plots of observed ln(number) versus age for smallmouth bass in Grand Lake. Line is plot of regression equation given beside graph.

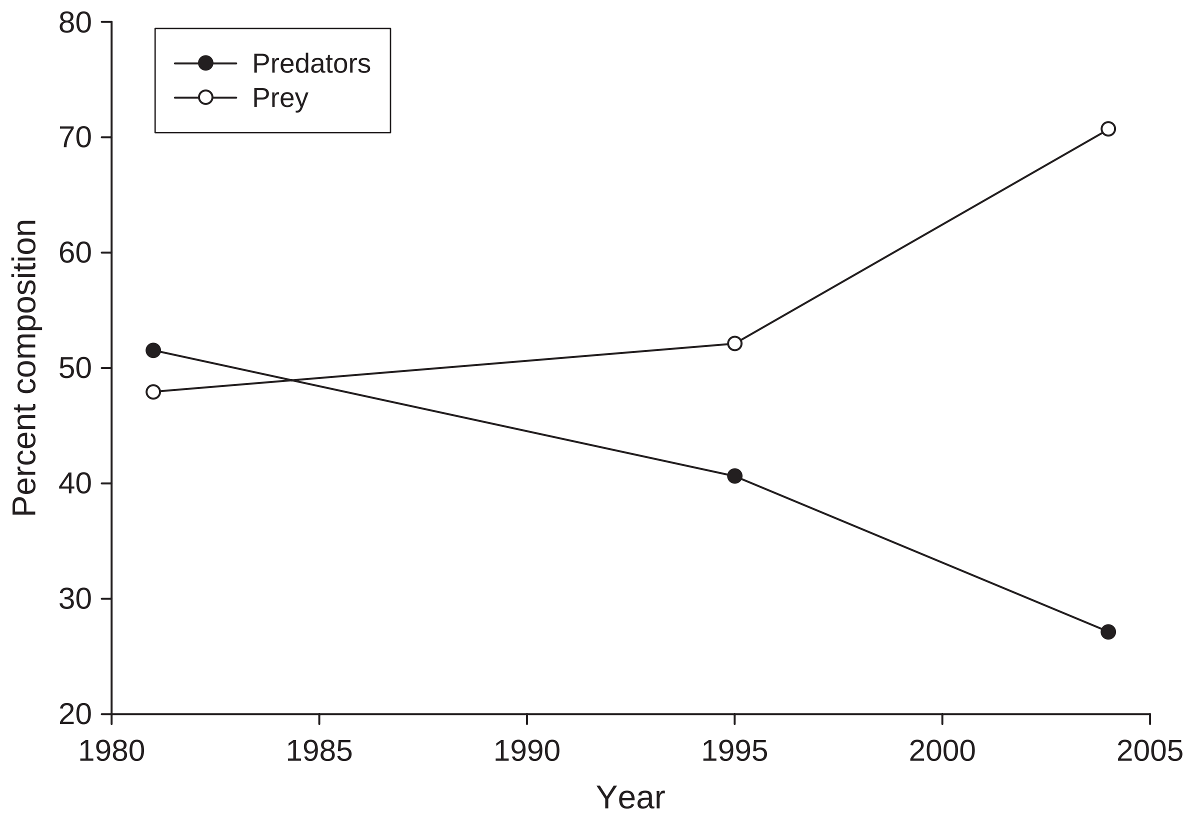

Figure 8.–Percentage composition (by number) of predators (walleyes, northern pike, and smallmouth bass) and prey (suckers, panfish, and minnows) in three spring netting surveys of Grand Lake.

Table 1.–Number and size of fish stocked in Grand Lake 1979 through 2000.

Year	Species	Number	Average size (in)
1979	Northern pike	6,000	4.2
1979	Tiger muskellunge	10,000	5.2
1980	Northern pike	50,000	3.7
1980	Tiger muskellunge	10,000	7.4
1982	Northern pike	25[a]	3.6
1982	Tiger muskellunge	10,000	6.8
1983	Northern pike	25,000	2.7
1988	Northern pike	20,000	2.0
		2,000	10.2
1989	Northern pike	32,000	3.0
1990	Northern pike	6,000	5.1
1991	Northern pike	8,000	6.1
1992	Northern pike	6,000	6.1
1993	Northern pike	5,000	6.1
1994	Northern pike	4,000	3.0
1995	Northern pike	2,000	2.5
1996	Northern pike	2,500	3.0
1998	Northern pike	4,500	3.0
2000	Northern pike	7,000	2.0

[a] Very poor survival

Table 2.–Survey periods, sampling shifts, and expansion values "F" (number of fishing hours within a sample day) for the Grand Lake angler survey, spring 2004 through winter 2005.

Survey period	Sample shift (h)		F
April 24–May 31	0600–1430	1330–2200	16
June	0600–1430	1330–2200	16
July	0600–1430	1300–2130	16
August	0630–1500	1230–2100	15
September	0630–1500	1200–2030	14
October 1–13	0630–1500	1100–1930	13
December 17–January 31	0700–1530	1100–1930	13
February	0700–1530	1100–1930	13
March 1–26	0700–1530	1100–1930	13

Table 3.–Fish collected from Grand Lake using a total sampling effort of 163 trap-net lifts and 294 fyke-net lifts from April 9–23, 2004.

Species	Total catch[a]	Percent by number	Mean CPUE[a,b]		Length range (in)	Average length (in)[c]	Number measured[c]
			trap net	fyke net			
White sucker	7,586	36.3	32.2	6.7	6.0–20.9	12.4	821
Yellow perch	3,848	18.4	14.3	5.1	4.3–13.5	7.1	836
Walleye	3,295	15.8	11.2	4.7	4.9–28.0	14.0	2,660
Rock bass	2,451	11.7	5.5	4.9	3.1–12.0	6.9	1,119
Smallmouth bass	2,125	10.2	5.5	3.7	3.0–20.2	12.8	1,920
Pumpkinseed	537	2.6	1.9	0.7	3.0–12.6	5.9	474
Brown bullhead	377	1.8	1.7	0.3	6.2–17.0	13.8	319
Bluegill	309	1.5	1.1	0.4	2.8–9.8	6.2	307
Northern pike	232	1.1	1.1	0.2	10.9–42.0	23.3	203
Bowfin	79	0.4	0.4	<0.1	12.1–28.9	23.3	77
Common shiner	38	0.2	<0.1	0.1	5.1–7.3	6.3	34
Longnose gar	15	0.1	0.1	<0.1	12.7–41.5	29.6	15
Largemouth bass	9	<0.1	<0.1	<0.1	8.2–21.1	14.2	9
Yellow bullhead	3	<0.1	<0.1	<0.1	11.5–12.3	11.9	3
Green sunfish	1	<0.1	<0.1	<0.1	3.7	3.7	1
Common carp	1	<0.1	<0.1	<0.1	32.7	32.7	1

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

Table 4.–Number of fish per inch group caught and measured on Grand Lake, April 9–23, 2004.

	Species															
Inch group	White sucker	Yellow perch	Walleye	Rock bass	Smallmouth bass	Pumpkinseed	Brown bullhead	Bluegill	Northern pike	Bowfin	Common shiner	Longnose gar	Largemouth bass	Yellow bullhead	Green sunfish	Common carp
2	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–
3	–	–	–	49	2	28	–	16	–	–	–	–	–	–	1	–
4	–	12	1	118	–	51	–	43	–	–	–	–	–	–	–	–
5	–	137	8	166	–	160	–	88	–	–	9	–	–	–	–	–
6	8	322	47	186	22	160	1	46	–	–	18	–	–	–	–	–
7	151	212	122	248	65	57	–	67	–	–	7	–	–	–	–	–
8	214	67	43	236	57	13	1	42	–	–	–	–	2	–	–	–
9	28	38	5	71	123	4	4	4	–	–	–	–	–	–	–	–
10	12	18	100	34	454	–	2	–	1	–	–	–	–	–	–	–
11	25	18	433	10	274	–	16	–	2	–	–	–	–	1	–	–
12	21	8	360	1	79	1	41	–	2	1	–	1	1	2	–	–
13	13	4	126	–	80	–	79	–	6	–	–	–	–	–	–	–
14	3	–	270	–	118	–	118	–	6	1	–	–	3	–	–	–
15	25	–	319	–	206	–	43	–	3	–	–	–	–	–	–	–
16	82	–	353	–	235	–	13	–	2	2	–	–	1	–	–	–
17	100	–	225	–	127	–	1	–	5	–	–	–	1	–	–	–
18	91	–	128	–	59	–	–	–	4	2	–	–	–	–	–	–
19	38	–	51	–	18	–	–	–	6	–	–	–	–	–	–	–
20	10	–	25	–	1	–	–	–	12	2	–	–	–	–	–	–
21	–	–	15	–	–	–	–	–	15	15	–	1	1	–	–	–
22	–	–	11	–	–	–	–	–	17	7	–	–	–	–	–	–
23	–	–	9	–	–	–	–	–	22	9	–	–	–	–	–	–
24	–	–	4	–	–	–	–	–	34	12	–	–	–	–	–	–
25	–	–	2	–	–	–	–	–	21	13	–	1	–	–	–	–
26	–	–	2	–	–	–	–	–	15	9	–	1	–	–	–	–
27	–	–	–	–	–	–	–	–	10	2	–	–	–	–	–	–
28	–	–	1	–	–	–	–	–	5	2	–	3	–	–	–	–
29	–	–	–	–	–	–	–	–	3	–	–	2	–	–	–	–
30	–	–	–	–	–	–	–	–	3	–	–	1	–	–	–	–
31	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–
32	–	–	–	–	–	–	–	–	1	–	–	1	–	–	–	1
33	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
34	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
35	–	–	–	–	–	–	–	–	2	–	–	–	–	–	–	–
36	–	–	–	–	–	–	–	–	2	–	–	–	–	–	–	–
37	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
38	–	–	–	–	–	–	–	–	1	–	–	1	–	–	–	–
39	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
40	–	–	–	–	–	–	–	–	2	–	–	–	–	–	–	–
41	–	–	–	–	–	–	–	–	–	–	–	2	–	–	–	–
42	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–
Total	821	836	2,660	1,119	1,920	474	319	307	203	77	34	15	9	3	1	1

Table 5.–Estimates of abundance, angler exploitation rates, and instantaneous fishing mortality rates for Grand Lake walleye, northern pike, and smallmouth bass using the different methods described in text. Asymmetrical 95% confidence intervals for estimates are given in parentheses, where applicable.

Parameter	Walleye	Northern pike	Smallmouth bass
Number tagged	1,138	100	764
Total tag returns	67	10	114
Number of legal-size[a] fish			
Multiple-census estimate	2,308	331	2,756
	(2,091–2,575)	(222–646)	(2,271–3,504)
Single-census estimate	3,308	124	2,869
	(1,876–6,278)	(51–306)	(1,939–4,419)
Michigan model prediction[b]	8,991	–	–
	(1,885 –42,881)		
Number of adult[c] fish			
Multiple-census method	3,634	808	–
	(3,268–4,092	(570–1,389)	
Single-census estimate	4,641	280	–
	(2,633–8,809)	(115–693)	
Michigan model prediction[d]	12,189	–	–
	(2,859–51,967)		
Annual exploitation rates			
Based on reward tag returns	6.7%	9.7%	10.7%
Based on harvest/abundance[e]	11.5%	16.1%	14.2%
	(4.9%–18.1%)	(0%–35.2%)	(7.1%–21.2%)
Based on harvest/abundance[f]	8.0%	43.1%	13.6%
	(2.1%–13.9%)	(0%–93.3%)	(5.9–21.4%)
Total annual mortality rates	43%	50%	36%

[a] Walleyes ≥ 15 in, northern pike ≥ 24 in, and smallmouth bass ≥ 14 in.
[b] Michigan model prediction of legal walleye abundance based on lake area, N = 21.
[c] Fish of legal-size and sexually mature fish of sub-legal size on spawning grounds.
[d] Michigan model prediction of adult walleye abundance based on lake area, N = 35.
[e] Multiple-census estimate of legal-size walleye abundance.
[f] Single-census estimate of legal-size walleye abundance.

Table 6.–Weighted mean total lengths (in) and sample sizes by age and sex for walleyes collected from Grand Lake, April 9–23, 2004. Standard deviation is in parentheses.

	Mean length			Number aged		
Age	Males	Females	All fish[a]	Males	Females	All fish[a]
1	–	–	7.3 (0.6)	–	–	15
2	12.1 (0.3)	–	11.8 (0.5)	24	–	47
3	13.7 (0.4)	–	13.5 (0.7)	22	–	26
4	14.6 (0.4)	15.4 (0.6)	14.8 (0.6)	18	8	29
5	15.4 (0.5)	16.0 (0.6)	15.2 (1.3)	7	12	20
6	16.0 (0.6)	17.3 (1.0)	16.5 (1.0)	14	26	40
7	16.7 (0.6)	18.0 (1.0)	17.2 (0.9)	16	24	40
8	17.4 (0.8)	20.1 (1.0)	18.3 (1.4)	26	26	54
9	18.6 (0.0)	20.9 (1.5)	20.3 (1.7)	2	12	14
10	19.4 (0.0)	21.6 (1.7)	20.5 (1.6)	2	3	5
11	–	23.4 (0.9)	23.4 (0.9)	–	4	4
12	–	–	–	–	–	–
13	19.2 (0.0)	25.1 (2.0)	22.4 (3.4)	3	5	8
14	–	24.2 (0.9)	24.2 (0.9)	–	2	2
15	–	24.4 (0.5)	24.4 (0.5)	–	4	4

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

Table 7.–Weighted mean total lengths (in) and sample sizes by age and sex for northern pike collected from Grand Lake, April 9–23, 2004. Standard deviation is in parentheses.

	Mean length			Number aged		
Age	Males	Females	All fish[a]	Males	Females	All fish[a]
1	12.7 (0.8)	–	12.3 (1.0)	2	–	9
2	18 (2.2)	19.2 (3.1)	17.6 (2.6)	13	7	26
3	22.8 (1.6)	25.1 (1.3)	23.5 (1.9)	31	17	58
4	23.9 (1.3)	26.9 (2.5)	25 (2.4)	15	13	30
5	25.2 (2.3)	30.1 (4.6)	26.8 (3.9)	12	6	20
6	24.8 (1.4)	30.1 (5.8)	27 (4.0)	6	3	11
7	29.2 (–)	38.4 (2.3)	35.3 (5.5)	1	2	3
8	–	–	27.4 (–)	–	–	1
9	23.7 (–)	32.4 (–)	28.1 (6.2)	1	1	2
10	–	41.3 (1.1)	41.3 (1.1)	–	2	2

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

Table 8.–Weighted mean total lengths (in) and sample sizes for smallmouth bass (males and females combined) collected from Grand Lake, April 9–23, 2004. Standard deviation is in parentheses.

Age	Mean length	N
2	8.8 (1.3)	53
3	10.9 (1.0)	73
4	13.9 (1.2)	32
5	15.6 (0.6)	23
6	16.3 (0.5)	17
7	17.3 (0.4)	15
8	17.4 (0.5)	6
9	18.1 (0.5)	9
10	17.6 (0.7)	2
11	18.5 (0.2)	7
12	19.0 (0.2)	7
13	18.9 (0.5)	5
14	19.2 (0)	2

Table 9.–Catch at age estimates (apportioned by age-length key) by sex for walleye, northern pike, and smallmouth bass from Grand Lake, April 9–23, 2004.

	Year	Walleye			Northern pike			Smallmouth bass
Age	class	Males	Females	All fish[a]	Males	Females	All fish[a]	All fish[a]
1	2003	–	–	212	2	–	9	–
2	2002	129	–	843	16	7	35	270
3	2001	134	–	197	42	20	74	801
4	2000	201	33	291	23	15	38	210
5	1999	109	52	238	18	8	26	234
6	1998	214	125	347	9	4	13	185
7	1997	194	103	276	1	2	3	98
8	1996	137	46	184	–	–	1	37
9	1995	5	20	26	2	1	2	32
10	1994	3	4	8	–	2	2	7
11	1993	–	4	4	–	–	–	20
12	1992	–	–	–	–	–	–	10
13	1991	4	6	11	–	–	–	10
14	1990	–	2	2	–	–	–	3
15	1989	–	4	4	–	–	–	–
Total		1,130	399	2,643	113	59	203	1,917

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

Table 10.–Angler survey estimates for summer 2004 from Grand Lake. Survey period was from April 24 through October 13, 2004. Catch per hour is harvest and release rate, respectively (fish per hour). Two standard errors are given in parentheses.

		Month					
Species	Catch per hour	April–May	June	July	August	Sep–Oct	Season
		Number harvested					
Smallmouth bass	0.030 (0.014)	27 (42)	107 (112)	63 (75)	132 (110)	277 (196)	606 (265)
Walleye	0.014 (0.009)	10 (19)	107 (112)	59 (62)	5 (10)	93 (110)	273 (170)
Yellow perch	0.138 (0.057)	0 (0)	217 (317)	881 (561)	859 (519)	797 (582)	2,754 (1,011)
Northern pike	0.003 (0.003)	0 (0)	6 (13)	28 (56)	15 (30)	0 (0)	50 (65)
Bluegill	0.001 (0.002)	0 (0)	0 (0)	0 (0)	19 (23)	10 (20)	28 (30)
Pumpkinseed	0.002 (0.002)	0 (0)	0 (0)	9 (19)	10 (20)	22 (35)	41 (44)
Rock bass	0.025 (0.017)	0 (0)	49 (67)	63 (86)	192 (206)	187 (215)	492 (317)
Total harvest	0.213 (0.068)	37 (46)	486 (361)	1,103 (579)	1,232 (570)	1,386 (661)	4,245 (1,109)
		Number released					
Smallmouth bass	0.147 (0.055)	72 (91)	1,265 (797)	277 (176)	463 (240)	856 (422)	2,933 (954)
Largemouth bass	<0.001 (0.001)	0 (0)	6 (13)	0 (0)	0 (0)	0 (0)	6 (13)
Walleye	0.007 (0.006)	0 (0)	48 (73)	60 (71)	9 (17)	20 (39)	137 (110)
Northern pike	0.001 (0.001)	0 (0)	0 (0)	0 (0)	0 (0)	24 (28)	24 (28)
White sucker	0.003 (0.004)	0 (0)	0 (0)	49 (70)	0 (0)	0 (0)	49 (70)
Rock bass	0.029 (0.015)	0 (0)	47 (67)	143 (163)	182 (162)	202 (150)	573 (283)
Brown bullhead	0.004 (0.005)	0 (0)	32 (64)	0 (0)	13 (26)	32 (64)	77 (94)
Gar	0.001 (0.002)	0 (0)	4 (7)	14 (28)	0 (0)	0 (0)	18 (29)
Bluegill	0.003 (0.004)	0 (0)	0 (0)	60 (85)	0 (0)	0 (0)	60 (85)
Pumpkinseed	0.008 (0.007)	0 (0)	0 (0)	29 (34)	69 (99)	68 (89)	167 (137)
Yellow perch	0.843 (0.284)	4 (9)	34 (34)	5,268 (2,404)	9,233 (3,946)	2,251 (1,221)	16,790 (4,779)
Total released	1.046 (0.310)	76 (92)	1,436 (806)	5,900 (2,420)	9,970 (3,958)	3,452 (1,306)	20,834 (4,887)
Total (harvested + released)	1.258 (0.340)	113 (103)	1,922 (883)	7,004 (2,488)	11,202 (3,999)	4,838 (1,464)	25,079 (5,011)
		Angler effort					
Angler hours		853 (797)	3,440 (1,146)	6,181 (2,538)	5,985 (1,759)	3,469 (1,261)	19,928 (3,615)
Angler trips		252 (255)	847 (374)	2,181 (1,068)	2,366 (781)	978 (581)	6,624 (1,515)

Table 11.–Angler survey estimates for winter 2004–05 from Grand Lake. Survey period was from December 17, 2004 through March 26, 2005. Catch per hour is harvest and release rate, respectively (fish per hour). Two standard errors are given in parentheses.

		Month				
Species	Catch per hour	December	January	February	March	Season
		Number harvested				
Walleye	0.0054 (0.0060)	0 (0)	53 (70)	18 (23)	0 (0)	70 (74)
Yellow Perch	0.4804 (0.0934)	978 (758)	2,409 (1,644)	2,648 (1,087)	262 (172)	6,298 (2,118)
Northern pike	0.0007 (0.0012)	0 (0)	2 (4)	8 (15)	0 (0)	10 (16)
Total harvest	0.4865 (0.2386)	978 (758)	2,464 (1,645)	2,673 (1,087)	262 (172)	6,378 (2,119)
		Number released				
Cisco	0.0009 (0.0019)	0 (0)	12 (25)	0 (0)	0 (0)	12 (25)
Smallmouth bass	0.0015 (0.0020)	0 (0)	2 (5)	17 (27)	0 (0)	20 (27)
Walleye	0.0019 (0.0020)	0 (0)	10 (20)	7 (11)	7 (14)	24 (27)
Northern pike	0.0011 (0.0016)	0 (0)	2 (4)	10 (20)	2 (4)	14 (21)
Rock bass	0.0013 (0.0027)	0 (0)	0 (0)	0 (0)	18 (35)	18 (35)
Yellow perch	1.1393 (0.1996)	3,692 (2,716)	6,029 (3,598)	4,392 (1,735)	822 (554)	14,934 (4,862)
Total released	1.1460 (0.5553)	3,692 (2,716)	6,055 (3,598)	4,427 (1,735)	848 (555)	15,022 (4,862)
Total (harvested + released)	1.6325 (0.7144)	4,670 (2,820)	8,519 (3,956)	7,100 (2,048)	1,111 (581)	21,400 (5,304)
		Angler effort				
Angler hours		1,012 (855)	5,884 (4,369)	4,935 (1,484)	1,277 (573)	13,109 (4,727)
Angler trips		317 (289)	1,647 (1,211)	1,398 (557)	364 (190)	3,727 (1,377)

Table 12.–Angler survey estimates for summer and winter 2004–05 from Grand Lake. Survey period was April 24 through October 13, 2004 and December 17, 2004 through March 26, 2005. Catch per hour is harvest and release rate, respectively (fish per hour). Two standard errors are given in parentheses.

Species	Catch per hour	Month: Apr–May	Jun	Jul	Aug	Sep–Oct
		Number harvested				
Smallmouth bass	0.0183 (0.0087)	27 (42)	107 (112)	63 (75)	132 (110)	277 (196)
Walleye	0.0104 (0.0059)	10 (19)	107 (112)	59 (62)	5 (10)	93 (110)
Yellow perch	0.2740 (0.0865)	0 (0)	217 (317)	881 (561)	859 (519)	797 (582)
Northern pike	0.0018 (0.0021)	0 (0)	6 (13)	28 (56)	15 (30)	0 (0)
Bluegill	0.0009 (0.0009)	0 (0)	0 (0)	0 (0)	19 (23)	10 (20)
Pumpkinseed	0.0013 (0.0014)	0 (0)	0 (0)	9 (19)	10 (20)	22 (35)
Rock bass	0.0149 (0.0100)	0 (0)	49 (67)	63 (86)	192 (206)	187 (215)
Total harvest	0.3220 (0.0928)	37 (46)	486 (361)	1,103 (579)	1,232 (570)	1,386 (661)
		Number released				
Cisco	0.0004 (0.0007)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Smallmouth bass	0.0894 (0.0331)	72 (91)	1,265 (797)	277 (176)	463 (240)	856 (422)
Largemouth bass	0.0002 (0.0004)	0 (0)	6 (13)	0 (0)	0 (0)	0 (0)
Walleye	0.0049 (0.0036)	0 (0)	48 (73)	60 (71)	9 (17)	20 (39)
Northern pike	0.0011 (0.0011)	0 (0)	0 (0)	0 (0)	0 (0)	24 (28)
White sucker	0.0015 (0.0021)	0 (0)	0 (0)	49 (70)	0 (0)	0 (0)
Rock bass	0.0179 (0.0092)	0 (0)	47 (67)	143 (163)	182 (162)	202 (150)
Brown bullhead	0.0023) (0.0029	0 (0)	32 (64)	0 (0)	13 (26)	32 (64)
Gar	0.0005 (0.0009)	0 (0)	4 (7)	14 (28)	0 (0)	0 (0)
Bluegill	0.0018 (0.0026)	0 (0)	0 (0)	60 (85)	0 (0)	0 (0)
Pumpkinseed	0.0051 (0.0043)	0 (0)	0 (0)	29 (34)	69 (99)	68 (89)
Yellow perch	0.9603 (0.2693)	4 (9)	34 (34)	5,268 (2,404)	9,233 (3,946)	2,251 (1,221)
Total released	1.0854 (0.2860)	76 (92)	1,436 (806)	5,900 (2,420)	9,970 (3,958)	3,452 (1,306)
Total (harvested + released)	1.4073 (0.3362)	113 (103)	1,922 (883)	7,004 (2,488)	11,202 (3,999)	4,838 (1,464)
		Angler effort				
Angler hours		853 (797)	3,440 (1,146)	6,181 (2,538)	5,985 (1,759)	3,469 (1,261)
Angler trips		252 (255)	847 (374)	2,181 (1,068)	2,366 (781)	978 (581)

Table 12.–Extended.

Species	Dec	Jan	Feb	Mar	Season
	Month				
	Number harvested				
Smallmouth bass	0 (0)	0 (0)	0 (0)	0 (0)	606 (265)
Walleye	0 (0)	53 (70)	18 (23)	0 (0)	344 (185)
Yellow perch	978 (758)	2,409 (1,644)	2,648 (1,087)	262 (172)	9,051 (2,347)
Northern pike	0 (0)	2 (4)	8 (15)	0 (0)	59 (67)
Bluegill	0 (0)	0 (0)	0 (0)	0 (0)	28 (30)
Pumpkinseed	0 (0)	0 (0)	0 (0)	0 (0)	41 (44)
Rock bass	0 (0)	0 (0)	0 (0)	0 (0)	492 (317)
Total harvest	978 (758)	2,464 (1,645)	2,673 (1,087)	262 (172)	10,621 (2,392)
	Number released				
Cisco	0 (0)	12 (25)	0 (0)	0 (0)	12 (25)
Smallmouth bass	0 (0)	2 (5)	17 (27)	0 (0)	2,953 (954)
Largemouth bass	0 (0)	0 (0)	0 (0)	0 (0)	6 (13)
Walleye	0 (0)	10 (20)	7 (11)	7 (14)	161 (114)
Northern pike	0 (0)	2 (4)	10 (20)	2 (4)	38 (35)
White sucker	0 (0)	0 (0)	0 (0)	0 (0)	49 (70)
Rock bass	0 (0)	0 (0)	0 (0)	18 (35)	591 (285)
Brown bullhead	0 (0)	0 (0)	0 (0)	0 (0)	77 (94)
Gar	0 (0)	0 (0)	0 (0)	0 (0)	18 (29)
Bluegill	0 (0)	0 (0)	0 (0)	0 (0)	60 (85)
Pumpkinseed	0 (0)	0 (0)	0 (0)	0 (0)	167 (137)
Yellow perch	3,692 (2,716)	6,029 (3,598)	4,392 (1,735)	822 (554)	31,724 (6,817)
Total released	3,692 (2,716)	6,055 (3,598)	4,427 (1,735)	848 (555)	35,857 (6,894)
Total (harvested + released)	4,670 (2,820)	8,519 (3,956)	7,100 (2,048)	1,111 (581)	46,494 (7,297)
	Angler effort				
Angler hours	1,012 (855)	5,884 (4,369)	4,935 (1,484)	1,277 (573)	33,037 (5,951)
Angler trips	317 (289)	1,647 (1,211)	1,398 (557)	364 (190)	10,350 (2,047)

Table 13.–Voluntary angler tag returns (reward and non-reward, harvested and released combined) from walleye by month for the year following tagging in Grand Lake. Percentage of total is in parentheses.

	Species		
Month	Walleye	Northern pike	Smallmouth bass
4	0 (0)	0 (0)	0 (0)
5	5 (7.3)	2 (20.0)	24 (21.0)
6	12 (17.6)	2 (20.0)	39 (34.2)
7	23 (33.8)	1 (10.0)	15 (13.2)
8	1 (1.5)	1 (10.0)	11 (9.6)
9	6 (8.8)	0 (0)	9 (7.9)
10	1 (1.5)	0 (0)	15 (13.2)
11	0 (0)	0 (0)	0 (0)
12	4 (5.9)	1 (10.0)	0 (0)
1	8 (11.8)	1 (0)	0 (0)
2	4 (5.9)	1 (10.0)	1 (0)
3	4 (5.9)	1 (10.0)	0 (0)
Total	68	10	114

Table 14.–Mean total lengths (in) of walleye (males and females combined) from the 2004 survey of Grand Lake compared to other surveys. Number aged in parentheses.

		Lake/Survey year						
Age	State average[a]	Grand Lake 2004[b]	Grand Lake 1995[c]	Grand Lake 1981[c]	Hubbard Lake 1996[c]	Black Lake 1997[c]	Long Lake 2000[c]	Mullett Lake 1998[c]
1	7.1	7.3 (15)			5.7 (10)			8.4 (1)
2	10.4	11.8 (47)	11.3 (4)	10.9 (4)		10.6 (2)	11.1 (3)	11.1 (38)
3	13.9	13.5 (26)	12.8 (5)	12.5 (19)		14.6 (5)	14.5 (13)	15.1 (31)
4	15.8	14.8 (29)	14.1 (21)	13.7 (16)	15.0 (2)	15.7 (8)	15.7 (9)	16.8 (19)
5	17.6	15.2 (20)	15.3 (12)	15.0 (8)	16.3 (17)	16.6 (9)	17.2 (3)	18.3 (28)
6	19.2	16.5 (40)	16.3 (15)	15.7 (20)	18.1 (35)	17.9 (11)	19.4 (2)	19.2 (33)
7	20.6	17.2 (40)	17.2 (8)	17.2 (9)	18.7 (21)	18.9 (9)	21.1 (1)	19.9 (21)
8	21.6	18.3 (54)	18.4 (32)	18.6 (12)	20.0 (4)			20.4 (27)
9	22.4	20.3 (14)	20.4 (9)	21.0 (1)			22.0 (2)	21.3 (31)
10	23.1	20.5 (5)		22.2 (4)	22.5 (2)		23.4 (2)	22.6 (26)
11		23.4 (4)			21.9 (2)			23.9 (20)
12		– –	25.1 (1)			26.4 (1)	26.3 (1)	26.7 (4)
13		22.4 (8)						
14		24.2 (2)						
15		24.4 (4)						
16								
17								
Mean growth index[d]		-1.6	-2.4	-2.7	-1.5	-0.8	+0.3	-0.1

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

Table 15.–Mean total lengths (in) of northern pike (males and females combined) from the 2004 survey of Grand Lake compared to other surveys. Number aged in parentheses.

		Lake/Survey year						
	State	Grand Lake			Hubbard Lake	Black Lake	Long Lake	Mullett Lake
Age	average[a]	2004[b]	1995[c]	1981[c]	1996[c]	1997[c]	2000[c]	1998[c]
1	11.7	12.3 (9)			12.6 (1)			14.1 (2)
2	17.7	17.6 (26)	19.1 (16)	19.2 (49)	19.1 (6)	18.7 (24)	21.2 (4)	18.3 (4)
3	20.8	23.5 (58)	20.7 (24)	22.4 (26)	22.1 (9)	20.7 (22)	22.9 (1)	21.8 (29)
4	23.4	25.0 (30)	24.4 (13)	26.0 (13)	24.9 (18)	23.4 (42)	24.0 (4)	23.5 (37)
5	25.5	26.8 (20)	25.3 (4)	31.2 (6)	25.3 (8)	26.0 (13)	26.1 (1)	26.9 (19)
6	27.3	27.0 (11)	29.0 (2)	34.3 (1)	34.0 (5)	28.8 (8)		29.8 (16)
7	29.3	35.3 (3)	34.5 (2)	26.7 (1)	35.5 (2)	30.3 (1)		33.2 (8)
8	31.2	27.4 (1)	37.7 (1)	38.2 (1)				36.4 (3)
9		28.1 (2)	39.2 (3)		37.8 (2)	34.7 (1)		
10		41.3 (2)	39.5 (1)		36.1 (1)	36.3 (3)		
11						41.3 (1)		
12								
Mean growth index[d]		+1.0	-0.8	+2.9	+2.0	+0.7	–	+1.6

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

Table 16.–Mean total lengths (in) of smallmouth bass (male and females combined) from the 2004 survey of Grand Lake compared to other surveys. Number aged in parentheses.

		Lake / Survey year							
	State	Grand Lake			Big Manistique	Hubbard Lake	Black Lake	Long Lake	Mullett Lake
Age	average[a]	2004[b]	1995[c]	1981[c]	2003[b]	1996[c]	1997[c]	2000[c]	1998[c]
1	3.8					3.7 (6)		5.1 (2)	
2	7.5	8.8 (53)	7.7 (1)		10.2 (8)	8.9 (4)		6.6 (25)	7.3 (5)
3	10.8	10.9 (73)	9.0 (1)	9.0 (7)	12.1 (21)	12.4 (14)	9.9 (2)	9.3 (28)	11.2 (33)
4	12.6	13.9 (32)	11.4 (27)	11.3 (9)	14.0 (27)	14.1 (7)	13.6 (4)	10.6 (7)	13.7 (30)
5	14.4	15.6 (23)	13.4 (16)	12.5 (20)	15.3 (29)	15.2 (19)	15.5 (1)	11.9 (7)	15.5 (10)
6	15.3	16.3 (17)	14.7 (23)	14.3 (15)	16.6 (15)	16.1 (16)	17.2 (1)	14.1 (30)	16.5 (9)
7	16.3	17.3 (15)	16.0 (14)	15.8 (9)	17.6 (8)	16.5 (7)	17.7 (2)	15.7 (10)	17.1 (7)
8	17.3	17.4 (6)	17.1 (18)	16.7 (4)	17.6 (9)	18.3 (1)		16.6 (12)	17.9 (8)
9	18.1	18.1 (9)	17.7 (9)		18.1 (2)			17.7 (8)	18.4 (8)
10	18.9	17.6 (2)	18.5 (10)		19.9 (1)			18.5 (7)	19.0 (6)
11		18.5 (7)	19.0 (11)		17.9 (2)	19.9 (1)		18.8 (1)	19.6 (7)
12		19.0 (7)							20.0 (7)
13		18.9 (5)							
14		19.2 (2)							
15									
16									
17									
Mean growth index[e]		+0.8	-0.6	-1.3	+1.3	+0.8	–	-1.1	+0.7

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

Table 17.–Comparison of recreational fishing effort and total harvest on Grand Lake to estimates from other selected Michigan lakes. Lakes are listed from highest to lowest total fishing effort. Lake size from Laarman (1976).

Lake	County	Size (Acres)	Survey period	Fishing effort (Hours)	Fish harvested (Number)	Fish harvested per hour	Hours fished per acre	Fish harvested per acre
Houghton	Roscommon	20,075	Apr 2001– Mar 2002	499,048	386,287	0.77	24.9	19.2
Cisco Chain	Gogebic, Vilas	3,987	May 2002–Feb 2003	180,262	120,412	0.67	45.2	30.2
Muskegon	Muskegon	4,232	Apr 2002–Mar 2003	180,064	184,161	1.02	42.5	43.5
Burt	Cheboygan	17,120	Apr 2001–Mar 2002	134,205	68,473	0.51	7.8	4.0
South Manistique	Mackinac	4,133	May 2003–Mar 2004	142,686	43,654	0.31	34.5	10.6
Lake Leelanau	Leelanau	8,607	Apr 2002–Mar 2003	112,112	15,464	0.14	13.0	1.8
Big Manistique	Luce, Mackinac	10,346	May 2003–Mar 2004	88,373	71,652	0.81	8.5	6.9
Mullett	Cheboygan	16,630	May–Aug 1998	87,520	18,727	0.21	5.3	1.1
Crooked and Pickerel	Emmet	3,434	Apr 2001–Mar 2002	55,894	13,665	0.24	16.3	4.0
Michigamme Reservoir	Iron	6,400	May 2001–Feb 2002	52,686	10,899	0.21	8.2	1.7
Grand	Presque Isle	5,822	Apr 2004–Mar 2005	33,037	10,621	0.32	5.7	1.8
Bond Falls Flowage	Ontonagon	2,127	May–Oct 2003	21,182	3,193	0.15	10.0	1.5
North Manistique	Luce	1,709	May 2003–Mar 2004	10,614	7,603	0.72	6.2	4.4
Average				122,899	73,447	0.47	17.5	10.1
Median				88,373	18,727	0.32	10.0	4.0

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David J. Borgeson, Reviewer
David F. Clapp, Editor
Deborah L. MacConnell, Desktop Publisher
Alan D. Sutton, Graphics
Approved by Tammy J. Newcomb

Appendix

Appendix–Fish species collected in Grand Lake from 1950 through 2004.

Common name	Scientific name
Species collected in spring 2004 with trap nets and fyke nets	
Bluegill	*Lepomis macrochirus*
Bowfin	*Amia calva*
Brown bullhead	*Ameiurus nebulosus*
Common carp	*Cyprinus carpio*
Common shiner	*Luxilus cornutus*
Green sunfish	*Lepomis cyanellus*
Largemouth bass	*Micropterus salmoides*
Longnose gar	*Lepisosteus osseus*
Northern pike	*Esox lucius*
Pumpkinseed	*Lepomis gibbosus*
Rock bass	*Ambloplites rupestris*
Smallmouth bass	*Micropterus dolomieu*
Walleye	*Sander vitreus*
White sucker	*Catostomus commersonii*
Yellow bullhead	*Ameiurus natalis*
Yellow perch	*Perca flavescens*
Additional species collected in summer 2004 with mini-fyke nets	
Bluntnose minnow	*Pimephales notatus*
Logperch	*Percina caprodes*
Spottail shiner	*Notropis hudsonius*
Additional species collected in fall 1996 and 1997 with electrofishing	
Emerald shiner	*Notropis atherinoides*
Sand shiner	*Notropis stramineus*
Additional species collected in summer 1950 with trap nets, seines, and gill nets	
Lake herring	*Coregonus artedi*
Longnose sucker	*Catostomus catostomus*
Longear sunfish	*Lepomis megalotis*
Mimic shiner	*Notropis volucellus*
Central mudminnow	*Umbra limi*
Blacknose shiner	*Notropis heterolepis*
Banded killifish	*Fundulus diaphanus*
Johnny darter	*Etheostoma nigrum*
Hornyhead chub	*Nocomis biguttatus*
Creek chub	*Semotilus atromaculatus*