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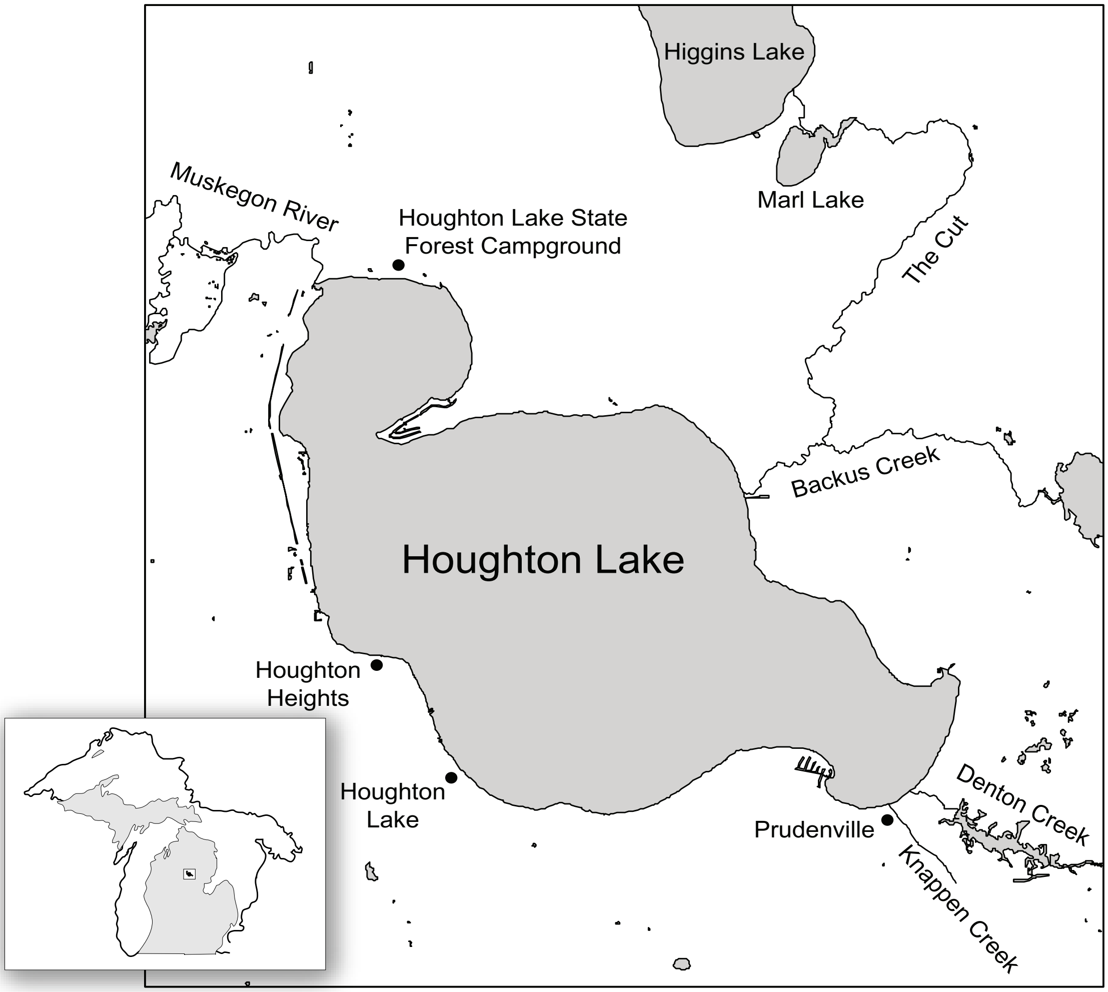

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The Fish Community and Fishery of Houghton Lake, Roscommon County, Michigan with Emphasis on Walleyes and Northern Pike

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Introduction

Michigan Department of Natural Resources (MDNR), Fisheries Division surveyed fish populations and angler catch and effort at Houghton Lake, Roscommon County, Michigan from January 2001 through March 2002. This work was part of a new, statewide program designed to improve assessment and monitoring of fish communities and fisheries in Michigan's largest inland lakes. Known as the Large Lakes Program, it is currently scheduled to survey about four lakes per year over the next ten years. This report on Houghton Lake is the first in a series that will document the work of the program.

In Michigan, any body of standing water other than the Great Lakes is generally defined as an inland lake. This includes both natural and man-made water bodies. The Large Lakes Program will target the 92 inland lakes that are 1,000 acres or more in size (Table 1). Combined, these lakes total about 360,000 acres and provide a significant proportion of the total fishing activity in the State. Yet, only 20 of these lakes have had modern angler harvest surveys within the last 50 years. The average fishing effort per year on the 20 lakes surveyed was 18.0 hours per acre. Assuming the 20 are representative of the other large lakes, then the combined annual fishing effort on all 92 lakes is probably about 6.5 million angler hours per year (18.0 times 360,000). And this rough estimate is probably on the low side, because the 18.0 hours per acre figure does not include the winter fisheries on most of the 20 lakes surveyed. By comparison, the combined annual fishing effort for all Michigan waters of the Great Lakes was only 5.2 million angler hours in 2001 (Rakoczy and Wessander-Russell 2002).

These larger inland lakes, especially those over 1,000 acres, present a special challenge to fisheries managers. While they support some of the most important, productive fisheries in the State, their size makes detailed biological assessment of fish populations and harvest difficult and costly. Area fisheries managers rarely have sufficient time, personnel, or equipment to conduct detailed surveys on large lakes. By establishing a statewide program, Fisheries Division was able to pool personnel and equipment to better conduct such surveys. Lakes will be selected for sampling under the Large Lakes Program based on fisheries management priorities. Some might be sampled every 5 years, while others might never be sampled. Even so, lakes not selected for sampling under this program will not be ignored. As in the past, they will continue to receive attention by local managers through smaller, less extensive surveys geared to answer specific management questions, and possibly, through other statewide programs, such as the Lakes Status and Trends[1] or general angler survey[2] programs.

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

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[1] A statewide program conducted by MDNR, Fisheries Division, Lansing to describe and monitor status of lake fish populations and habitat in Michigan. Lakes to be sampled are determined through a stratified, random sampling scheme. Sampling protocols include collection of fish, water chemistry, and physical habitat parameters.

[2] A statewide program conducted by MDNR, Fisheries Division, Lansing to estimate fish harvest by recreational anglers in important public waters in Michigan. Waters to be sampled are determined based on statewide and local management priorities. Sampling protocols are similar to angler survey procedures described in this report.

three types of abundance and two types of exploitation rate estimators for walleyes and northern pike in this survey of Houghton Lake.

The Large Lakes Program will maintain consistent sampling methods over lakes and time as much as possible. This will allow us to build a body of fish population and harvest statistics to directly evaluate differences between lakes or changes within a lake over time. Because Houghton was one of the first lakes to be sampled under the protocols of the program, we were sometimes limited in our ability to make valid comparisons in this report. For example, most types of quantitative comparisons between catch per effort in our netting operations and those of most other surveys would not be valid. Our netting targeted walleyes, northern pike, and other spring spawners during spawning. Most past netting surveys occurred later in the year. Of course, as our program progresses we will eventually have a large body of netting data collected under the same conditions in the future. This first report is meant as a general outline and model for future reports in the program.

Study Area

Houghton Lake is about 20,000 surface acres, but sources disagree on its exact size. Humphries and Green (1962) reported 19,600 acres, Laarman (1976) reported 20,044 acres, and MDNR, Michigan Digital Water Atlas[3] (2003) reported 20,075 acres. Houghton Lake is not subject to major water level fluctuations, so apparently, discrepancies in reported size are due to differences in methods of measurement. In our Large Lakes Program, we will want to compare various measures of productivity between lakes, such as number of fish per acre or harvest per acre, so a measure of lake size is fairly important. However, in the case of Houghton, the range in reported sizes varies only by about ±2%, which is trivial for our purposes. We will use the most recent estimate of 20,075 acres in our analyses.

The maximum depth of Houghton Lake is 22 feet, and the majority of the lake is shallow with an average depth of 8.4 feet and an estimated total volume of 165,072 acre-feet. Percent of area by depth is presented in Figure 1. Percent of volume by depth is presented in Figure 2. A map of Houghton Lake showing depth contours is available in the Michigan Digital Water Atlas (2003). This map also shows that numerous sand and gravel shoals exist throughout the lake.

Houghton Lake has several small tributary streams, including Backus, Denton, and Knappen creeks (Figure 3). The primary upstream flow comes from Backus Creek, which flows through a series of reservoirs about 6 miles upstream from Houghton Lake. Denton Creek also flows through a reservoir about 1 mile upstream. The Cut, a tributary of Backus Creek, connects Houghton Lake with 238-acre Marl Lake and 9,600-acre Higgins Lake. The distance between Houghton and Higgins lakes is about 10 stream miles. Downstream from Houghton Lake, the Muskegon River initially flows to the northwest but eventually curves to the southwest and flows for 212 miles to Lake Michigan (O'Neal 1997).

Human development within the watershed of Houghton Lake has significantly altered fisheries habitat within and around the lake. Affects of development have been typical of those reported for other north temperate lakes (Christensen et al. 1996; Radomski and Geoman 2001; Rust et al. 2002; Bryan and Scarnecchia 1992; Schindler et al. 2000; and Jennings et al. 1999). The shoreline of Houghton Lake is surrounded by private homes, cottages, and businesses, including the three small towns of Houghton Heights, Houghton Lake, and Prudenville (Figure 3). There are numerous public and private boat launch sites on the lake, and Houghton Lake State Forest Campground is located on the north shore. A water-level-control dam is located about ½ mile down the Muskegon River. The lake water level is defined by statute at 1138.1 ft elevation (Schrouder 1993). This is approximately 3.7 feet above natural levels of the lake (R. O'Neal, MDNR, personal communication). Partially in

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[3] A statewide program conducted by MDNR, Fisheries Division, Lansing to develop computerized maps and reference data for aquatic systems in Michigan.

response to the higher water levels, hardened seawalls have been constructed around most of the lake. Also, upstream of Houghton Lake, the water level of Higgins Lake is regulated by a dam on the Cut River, which sometimes leads to unnaturally low water levels in this tributary (R. O'Neal, MDNR, personal communication).

Laarman (1976) reported results of limited water chemistry, benthos, and zooplankton sampling conducted in Houghton Lake. Briefly, August surface and bottom temperatures in 1972 were 74° and 71° F, respectively. The lake does not develop a thermocline. Surface alkalinity ranges from 63 to 129 ppm, and pH ranges from 7.5 to 8.7. Additional water quality information was reported by Pecor et al. (1973) and Schrouder (1993), and more recent data are available in files of MDNR and Michigan Department of Environmental Quality.

Large beds of emergent plants, including wild-rice *Zizania aquatica*, were present historically in Houghton Lake. Now, wild-rice is nearly absent due to removal programs and maintenance of unnaturally high water levels (Ustipak 1995). Eurasian water-milfoil *Myriophyllum spicatum*, a non-indigenous, submergent aquatic plant, has been widespread and abundant in the lake. Riparian property owners began program to control water-milfoil, including treatment of the entire lake with the herbicide, Sonar®. Application of Sonar® occurred in summer 2002, after our fisheries surveys were completed (Heilman et al. 2003).

The current fish community of Houghton Lake includes species typical of cool, eutrophic lakes of the region. Families of fishes present include bowfin, gar, pike, minnow, sucker, catfish, sunfish, and perch. Coldwater fishes, such as trout, are occasionally found in the lake, but are most likely immigrants from the colder Higgins Lake. A number of species have been stocked over the years, including smallmouth bass *Micropterus dolomieu*, northern pike, yellow perch *Perca flavescens*, bluegills *Lepomis macrochirus*, and walleye (Schrouder 1993). Recently, only walleyes have been stocked (Table 2).

Methods

We will give a brief overview of methods first, and then describe them in more detail below. Briefly, nets and electrofishing gears were used to collect fish in April-May 2001. The timing coincides with spawning of primary targets – walleyes and northern pike. All fish captured were identified to species and counted. Fishing effort was recorded by net type, but not for electrofishing. Electrofishing was only used to increase the sample size of walleyes and northern pike tagged. Standard total lengths were measured for subsamples of each non-target species. All walleyes and northern pike were measured and legal-sized fish were tagged with individually numbered jaw tags. Tagged fish were also fin clipped to help evaluate tag loss. Angler catch and harvest surveys were conducted the year after tagging; one covering the summer fishery from April 28 through September 30, 2001 and one covering the winter fishery from January 1 through March 31, 2002. A preliminary harvest survey was also done the winter before tagging – January 13 through March 31, 2001. Tags were observed on walleyes and northern pike caught during angler surveys and the ratios of marked to unmarked fish were used to make abundance estimates for walleyes and northern pike. In addition, voluntary tag recoveries were requested. All tags contained a unique number and a mailing address for an MDNR field station. To encourage voluntary tag returns, about 50% of tags were identified as reward tags, and we paid $10 rewards to anglers returning them.

Angler Survey

Fishing harvest seasons for walleyes and northern pike during this survey were April 29, 2000 through March 15, 2001 and April 28, 2001 through March 15, 2002. Minimum size limits were 15 in for walleyes and 24 in for northern pike. Fishing harvest seasons for smallmouth bass and largemouth bass *Micropterus salmoides* were May 26, 2001 through December 31, 2001 and May 25, 2002 through December 31, 2002. Minimum size limit was 14 in for both smallmouth bass and largemouth bass. Daily bag limit was 5 fish of any combination of walleyes, northern pike, smallmouth bass, and largemouth bass.

Harvest was permitted all year for all other species present. Minimum size limit was 12 in for channel catfish *Ictalurus punctatus*. No minimum size limits were imposed for other species. Bag limit for yellow perch *Perca flavescens* was 50 per day. Bag limit for "sunfishes", including black crappie *Pomoxis nigromaculatus*, white crappie *Pomoxis annularus*, bluegill, pumpkinseed *Lepomis gibbosus*, and rock bass *Ambloplites rupestris* was 25 per day in any combination.

Direct-contact angler creel surveys were conducted during two winter periods – January 13 through March 31, 2001 and January 1 through March 31, 2002; and one spring-summer period – April 28 to September 30, 2001. Ice covers Houghton Lake in winter, requiring different methods for winter and summer surveys.

Winter

We used a progressive-roving design for winter surveys (Lockwood 2000b). One clerk working from a snowmobile collected count and interview data. Both weekend days and 3 randomly selected weekdays were selected for sampling during each week of the survey season. No holidays were sampled. The clerk followed a randomized count and interview schedule. One of two shifts was selected each sample day (Table 3). Houghton Lake was divided into 4 grids and one grid section was sampled each day (Figure 4). Each grid was created to encompass historic angling concentrations as defined by local managers. Starting location within a section and direction of travel were randomized for both counting and interviewing. Scanner-ready interview and count forms were used. Survey periods each year were divided into two major sampling periods: January 13 through February 28, 2001 and March 1 through March 31, 2001; and January 1 through February 14 and February 15 through March 31, 2002. These sampling periods were long enough to ensure multiple counts within each period for each grid.

Minimum fishing time prior to interview (incomplete-trip interview) was 1 h (Lockwood in press). 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 in press). Access interviews include information from complete trips and are appropriate standards for comparison. When anglers reported fishing in more than one grid, the clerk recorded the grid number where they spent most of that trip fishing. Global positioning system (GPS) coordinates were used to determine grid boundaries (Figure 4).

While this survey was designed to collect roving interviews, our clerk will occasionally encounter anglers as they complete 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.

Progressive (instantaneous) counts of open-ice anglers and occupied shanties were made once per day. No anglers were interviewed while counting (Wade et al. 1991). All roving interview data were collected by individual angler to avoid party size bias (Lockwood 1997). When all anglers within a grid were interviewed during a sample day, the clerk roamed the remaining grids interviewing anglers.

Count information collected included: date, grid, fishing mode (open ice or shanty), count time, and number of units (anglers or occupied shanties) counted. Interview information collected included: date, grid, fishing mode (open ice or shanty), start time of fishing trip, interview time, species targeted, bait used, number of fish harvested by species, number of fish caught and released by species, length of harvested walleyes and northern pike, and applicable tag number. During winter 2001 no catch and release data were recorded; during summer 2001 catch and release of smallmouth bass, largemouth bass, walleyes, and northern pike were recorded; and during winter 2002 catch and release of all species was recorded.

Number of anglers in each party was recorded on one interview form for each party.

Summer

We used an aerial-roving design for the summer survey (Lockwood 2000b). Fishing boats were counted by aircraft and one clerk working from a boat collected angler interview data. Survey period was from April 28 through September 30, 2001. Both weekend days and 3 randomly selected weekdays were selected for counting and interviewing during each week of the survey season. No interview data were collected on holidays; however, aerial counts were made on holidays. The holidays during the sample period were Memorial Day (May 28, 2001), Fourth of July, and Labor Day (September 3, 2001). Counting and interviewing were done on the same days (with exception to previously discussed holidays), and 1 instantaneous count of fishing boats was made per day. For sampling purposes, Houghton Lake was divided into 5 grids (Figure 5). Similar to the winter surveys, summer grids were designed to encompass rather than split concentrations of anglers, and grids were based on historic angler effort information. All count and interview data were collected and recorded by grid, and counting and interviewing were done in all grids each sample day. Similarly, effort and catch estimates were made by grid and summed for lake-wide estimates.

Aerial counts progressed from marker 1 to marker 10 or from marker 10 to marker 1 (Figure 6). This sequence was randomized. The pilot flew a predetermined route using GPS coordinates and Houghton Lake coordinates are given in Figure 6. Each flight was made at 500-700 ft elevation and took approximately 17 min to complete with air speed of about 85 mph. Counting was done by the contracted pilot and only fishing boats were counted (i.e. watercrafts involved in alternate activities, such as water skiing, were not counted). Time of count was randomized to cover daylight times within the sample period. Count information for each count was recorded on a lake map similar to Figure 6. This information included: date, count time, and number of fishing boats in each grid.

One of two shifts was selected each sample day for interviewing (Table 3). Interview starting location (area within Houghton Lake) and direction of travel (clockwise or counter-clockwise) were randomized daily. Interview forms, information, and techniques used during summer survey period were the same as those used during the winter survey period. When anglers reported fishing in more than one grid, the clerk recorded the grid number where they spent most of that trip fishing. GPS coordinates were used to determine grid boundaries (Figure 5).

Estimation methods

Catch and effort estimates were made by grid using multiple-day method (Lockwood et al. 1999). Expansion values (“F” in Lockwood et al. 1999) are given in Table 3. These values are the number of hours within sample days. Effort is the product of mean counts by grid for a given period day type and days within the period and the expansion value for that period. Thus, the angling effort and catch reported here are for those periods sampled, no expansions were made to include periods not sampled (e.g., 0100 to 0400 hours). Winter 2002 daily sampling period was 1 h longer than winter 2001. Extension of late shift by 1 h was done to cover the walleye fishery during early evening. Lake-wide estimates were the sum of grid estimates for each given time period and day type. Over 90% of interviews for any given time period were roving interviews. As a result, a mean-of-ratios catch rate estimator was used regardless of interview type.

From the angler creel data collected, catch and harvest by species were estimated and angling effort expressed as angler hours and angler trips. An angler trip is defined as the period an angler is at a lake (fishing site) and actively fishing. When an angler leaves the lake or stops fishing for a significant period of time (e.g., an angler leaving the lake to eat lunch), the trip has ended. Movement between fishing spots, for example, was considered part of the fishing trip. Mail or telephone surveys typically report angling effort as angler days (Pollock et al. 1994: Chapter 6). Angler trips differ from angler days because multiple trips can be made within a day. Historically, Michigan angler creel data averages 1.2 trips per angler day (MDNR Fisheries Division – unpublished data).

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

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

Fish Community

We described the status of the overall fish community in terms of species present, catch per net lift, percent by number, and length frequencies. We also collected more detailed data for walleyes and northern pike as described below. We sampled fish populations with trap nets, fyke nets, and electrofishing gears from April 9 to May 1, 2001. We used four boats daily to work nets, each with three-person crews, for 3 weeks. Each net-boat crew tended about 10 nets. Another electrofishing boat periodically collected walleyes and northern pike at night.

Trap nets were 8 ft by 6 ft by 3 ft with 2-in-stretch mesh and 125-ft leads. Fyke nets were 6 ft long and 4 ft diameter with 2-in stretch mesh and 125-ft leads. Duration of net sets ranged from 1-4 nights, but most were 1 night. A Smith-Root® boat equipped with six boom-mounted electrodes (DC) was used for electrofishing. Latitude and longitude were recorded for all net locations and electrofishing runs using GPS.

We identified species and counted all fish captured. Total lengths of all walleyes and northern pike were measured to the nearest 0.1 in. For other fishes, we measured total lengths 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.

We used Microsoft Access© to store and retrieve data collected during the tagging operation. Size-structure data only included fish on their initial capture occasion. We recorded mean catch per unit effort (CPUE) in both trap and fyke nets as indicators of relative abundance, using the number of fish per net night (including recaptures) for all net lifts that were determined to have fished effectively (i.e., without wave-induced rolling or human disturbance).

Walleyes and Northern Pike

Sex composition

We recorded sex of walleyes and northern pike. Fish with flowing sperm or eggs were categorized as male or female, respectively. Fish with no flowing sperm or eggs were categorized as unknown sex.

Abundance

We estimated abundance of legal-sized walleyes and northern pike using mark-and-recapture methods. Walleyes ($\geq$ 15 in) and northern pike ($\geq$ 24 in) were tagged on the upper left jaw (around both the maxilla and premaxilla) with metal, monel band tags. Also, in order to assess tag loss, we clipped the left pelvic fins from every walleye and northern pike collected. Reward ($10) and non-reward tags were issued in an approximate 1:1 ratio.

We compared two different abundance estimates from mark-and-recapture data, one derived from marked-unmarked ratios from the spring netting operation (multiple census) and the other derived from marked-unmarked ratios from the catch surveys from Summer 2001 through winter 2002 (single census).

For the multiple-census estimate, we used the Schumacher-Eschmeyer formula from daily recaptures during the tagging operation. Fish recaptured with nets or electrofishing gear were recorded as either tagged (numbers recorded) or fin-clipped. The minimum number of recaptures necessary for an unbiased estimate was set a priori at four. We used the following formula from Ricker (1975):

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

where:

N_1 = multiple-census population estimate (number of legal-sized fish);
C_d = $U_d + R_d$ = total number of fish caught during day 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,

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

where:

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

Variance of $1/N_1$ is:

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

Appropriate asymmetrical 95% confidence intervals were computed as $1/N_1 \pm t(\mathrm{SE})$.

For the single-census estimate, we used numbers of marked and unmarked fish seen by creel clerks in the companion catch survey as the "recapture-run" sample. The Chapman modification of the Petersen method (Ricker 1975) was used to generate population estimates, such that:

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

where:

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

We calculated the variance as:

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

And 95% confidence limits as:

$$N_2 \pm t_{0.05} \times \sqrt{Var(N_2)}.$$

No prior abundance estimates existed for either walleyes or northern pike in Houghton Lake to help us gauge how many fish to mark. For walleyes, we used a regression equation developed for Wisconsin lakes (Hansen 1989) to provide an a priori estimate of abundance. This regression predicts walleye abundance based on lake size. Parameters for this equation are re-calculated every year by Wisconsin Department of Natural Resources (WDNR). We used the same parameters used by WDNR in 2001 (Doug Beard, WDNR, personal communication):

$$\ln(N_3) = 1.6106 + 0.9472 \times \ln(A),$$

where N_3 is the estimated number of walleyes and A is the size of the lake in acres. This equation was derived from abundance estimates on 179 lakes in northern Wisconsin. For Houghton Lake, the equation predicted 59,576 walleyes, with a 95% confidence interval of 19,215 to 184,715.

We determined our tagging goal by evaluating the effect of increasing the proportion tagged on the precision of estimate. Based on results of previous angler catch surveys (MDNR – unpublished data), we assumed an angler exploitation of 0.25 and that our clerk would see 1.7% of total walleye harvest. We then estimated precision of estimate as:

$$\text{Precision}_{\text{i}} = \frac{2 \times SE_i}{N_3},$$

where N_3 is the estimated population of 59,576 walleyes and SE_i is the standard error of the estimated population with i fish marked. Based on this analysis, it was our judgment that marking 10% of the population would achieve a good compromise between marking effort and precision, assuming the fraction marked was a function of marking effort. Additional effort to mark more than 10% of population would have resulted in only minimal improvements in precision with each increased unit of marking effort (Figure 7). Thus, we set our tagging goal at 10% of the population or 5,958 walleyes.

Because the tagging goal for walleyes was quite ambitious, we did not set a specific tagging goal for northern pike. We assumed we would collect sufficient numbers if we simply tagged as many northern pike as possible until the walleye goal was achieved.

It is important to recognize the difference between walleye abundance predictions from the Wisconsin regression equation (N_3) and walleye abundance estimates we made (N_1 and N_2). The Wisconsin equation predicts abundance of adult walleyes on the spawning grounds, while we estimated abundance of walleyes ≥ 15 in. Wisconsin defined adult walleyes as legal size, or sublegal but sex can be determined. Because we clipped fins and recorded recaptures of all walleyes, we were also able to make a direct multiple-census estimate of adult walleyes for comparison by using the equation for N_2 and including the sublegal and mature fish that were marked and recaptured.

We estimated numbers of adult walleyes from our single-census estimate by dividing our estimate of walleyes ≥ 15 by the proportion of walleyes ≥ 15 in on the spawning grounds. That is, N_3 and N_a should be comparable where:

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

and,

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

We calculated the variance as:

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

For northern pike, we defined adult fish similar to walleyes, that is, those ≥ 24 in or <24 in but of identifiable sex.

We accounted for fish that recruited to legal size during the angler survey based on the estimated average growth for fish of slightly sublegal size. That is, because we were estimating abundance of legal-sized walleyes (≥ 15 in) and northern pike (≥ 24 in) at time of marking (spring) and growth of fish occurred during the recapture period, it was necessary to reduce the number of unmarked fish by the estimated number that recruited to legal size during the recapture period. For example, to make this adjustment for walleyes we determined the annual growth of slightly sublegal fish (i.e., 14.0 - 14.9-in fish) from mean length at age data. We then divided it by the length of the growing season in months (6) and rounded to the nearest 0.1 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 primary (single census) population estimate.

Unfortunately, we had a problem while conducting the summer 2001 angler survey, which affected the calculations for the single-census abundance estimates. Our survey clerk accepted another job at the beginning of July, and it took time to hire and fully train a new clerk. July through September was a transition period in which several different personnel assumed the duties of the missing clerk. While appropriate effort and catch data were collected during that time, fish lengths and ratios of marked to unmarked fish were not recorded. Consequently, our single-census estimate was made only from data collected in April through June 2001 and January through March 2002.

Mean lengths at age

We used dorsal spines to age walleyes and dorsal fin rays to age northern pike. We used these structures because we thought they provided the best combination of ease of collection in the field, and accuracy and precision of age estimates. We considered ease of collection important because our staff worked in cold, windy conditions, dealt with large numbers of fish, and tagged fish in addition to measuring and collecting structures.

Otoliths have been shown to be the most accurate and precise ageing structure for older walleyes (Heidinger and Clodfelter 1987; Koscovsky and Carline 2000; Isermann et al. 2003) and otoliths or cleithra for northern pike (Casselman 1974; Harrison and Hadley 1979), but collecting these structures requires killing the fish and we were tagging and releasing fish for later recapture. Results from several studies comparing aging structures for walleyes agreed that spines were quicker to remove than scales, but they do not agree that spines are more accurate than scales (Campbell and Babaluk 1979; Kocovsky and Carline 2000; Isermann et al. 2003). Errors in ages from spines were often related to misidentifying the first annulus in older fish (Ambrose 1983; Isermann et al. 2003). We also found considerable disagreement as to whether spines or scales were more precise for age estimation of walleyes. Campbell and Babaluk (1979) and Erickson (1983) 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.

Northern pike older than 6 years are notoriously difficult to age with scales (Carlander 1969). In recent years, field technicians and biologist in MDNR have been using dorsal fin rays instead. They are as quick and easy to remove in the field as spines for walleyes. Studies have demonstrated that fin rays are a valid aging structure for a number of species (Skidmore and Glass 1953; Ambrose 1983), including northern pike (Casselman 1996), but no comparisons have been made to statistically compare accuracy and precision of fin rays to other aging structures for northern pike.

Sample sizes for age analysis were based on historical Houghton Lake length at age data and methods given in Lockwood and Hayes (2000). Our goal was to collect 40 male and 40 female walleyes per inch group (10 per sex per inch group per crew) and 32 male and 32 female northern pike per inch group (8 per sex per inch group per crew).

Samples were sectioned using a table-mounted Dremel® rotary cutting tool. Sections approximately 0.5-mm thick were cut as close to the proximal end of the spine or ray as possible. Sections were examined at 40x-80x with transmitted light, and the image was recorded with a digital camera and stored in Joint Photographic Experts Group (.jpg) format using Image-Pro® software or a similar set-up. A computer filing system was developed to organize, store, and retrieve images.

Ages were determined by inspecting digital images of spine or fin-ray sections on a computer screen. We aged approximately 15 fish per sex per inch group. Two technicians independently aged walleyes. Ages for walleyes were considered correct when results of both technicians agreed. Samples in dispute were aged by a third technician. Disputed ages were considered correct when the third technician agreed with one of the first two. Samples were discarded if three technicians disagreed on age. Only two technicians aged northern pike. After independently determining ages, they worked together to resolve any differences.

After a final age was identified for all samples, mean lengths at age and age-length keys were computed (Devries and Frie 1996). We calculated weighted mean length at age by sex for both walleyes and northern pike.

We compared our mean lengths at age to those from previous surveys of Houghton and other large lakes. Also, we computed a mean growth index to compare our data to Michigan state averages as described by Schneider et al. (2000). Basically, the mean growth index is the sum of deviations over age groups of observed mean length minus state average length.

Mortality

We estimated instantaneous total mortality rates using catch-curve analyses (calculating the linear regression of the decline of natural logarithm of number versus age) with assumptions described by Ricker (1975). We used the fish collected during spring netting and electrofishing operations for this purpose. When choosing age groups to be included in the analyses, we considered several potential problems. First, an assumption of catch-curve analysis is that the mortality rate is uniform with age over the full range of age groups in analysis. We collected fish with gears different from those used in the fisheries and the size (age) of recruitment in the fisheries was controlled by minimum-size-limit regulations. For fish smaller than the minimum size limit, mortality is M+H; for fish larger, mortality is M+H+F, where M, H, and F are natural, hooking (from catch and release), and fishing mortality, respectively. Thus, from the standpoint of uniformity in mortality, age groups used in a single catch curve should contain fish that are either all smaller than, or all larger than the minimum size limit in the fishery.

Second, walleyes and northern pike exhibit sexual dimorphism (Carlander 1969 and 1997), which could lead to differences in mortality between sexes. Thus, when sufficient data were available, we computed separate catch curves for males and females to determine if total mortality differed with sex. We also computed a catch curve for all fish in the sample.

Third, we collected walleyes and northern pike in the act of spawning, so we needed to be sure that fish in each age group were sexually mature and represented on the spawning grounds in proportion to their true abundance in the population. Thus, we included in our analyses only age groups with fish that we judged to be mostly mature. We based this judgment on a combination of information, including relative abundance and mean size by age and percent maturity by size.

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

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

Voluntary tag returns were encouraged with a monetary reward ($10) available on approximately ½ of the tags. Tag return forms were made available at boater access sites, at MDNR offices, and from creel clerks. Additionally, tag return information could be submitted on-line at the MDNR website. Anglers were asked to mail forms to the address printed on the tags. Upon receiving tag return forms we entered data into the database so that it could be efficiently linked to and verified against data collected during the tagging operation. We developed linked documents in Microsoft Word® so that payment vouchers and reward letters were automatically produced with relevant information from the database. Letters (for both reward and non-reward 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 non-reward tags.

In the second method, we calculated exploitation as the estimated annual harvest from the angler survey divided by the estimated abundance of legal-sized fish from the single-census abundance estimate. For proper comparison with the abundance of legal fish as existed in the spring, the estimated annual harvest was adjusted for fish that would have recruited to legal size over the course of the creel survey.

Recruitment

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

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

As Maceina (2003), we will assume the residuals of our catch-curve regressions were indices of year-class strength, and for walleyes, we calculated a linear regression between catch-curve residuals and numbers stocked to determine if year-class strength was related to stocking.

Movement

We did not expect to find important fish movement in Houghton Lake, a relatively uncomplicated system. We included movement here, because this report was intended as a standard model for future Large Lake Program reports. Movement will be more important and interesting in some lake systems we will survey in the future. Moreover, fish were already tagged to estimate abundance and exploitation and tagging locations were known, so it made sense to record recapture locations.

For Houghton Lake, movement was assessed in a descriptive manner by examining the location of angling capture versus the location of initial capture at tagging. Capture locations provided by anglers were often vague; thus, statistical analysis of distance moved would be dubious. Instead, we identified only conspicuous movement for a season such as to another lake, or connected river.

Results

Henceforth, we will refer to fishes by common name in the text. We listed common and scientific names of all fish species captured during this study in the Appendix. Also, we will give confidence limits for various estimates in relevant tables, but not in the text.

Angler Survey

Winter 2001

The preliminary survey conducted during this period served to test general methods and provide background information. It will not be part of the general procedures for the Large Lakes Program in the future, but we will report the results here. No marked fish were present in lake during this time period.

Our clerk interviewed 1,217 open ice anglers and 785 shanty anglers. Most shanty (99%) and open ice (98%) interviews were roving type. Open ice and shanty anglers fished 78,908 angler hours and made 23,590 trips to Houghton Lake (Table 4).

The total harvest was 49,950 and consisted of seven different species (Table 4). Bluegill were most numerous with an estimated harvest of 21,089. Yellow perch were second at 15,070.

Anglers harvested 3,584 walleyes and 1,200 northern pike. Data on fish caught and released were not collected.

Summer 2001

Our clerk interviewed 3,027 boating anglers during the summer 2001 survey. Most interviews (95%) were roving type. Anglers fished an estimated 278,214 angler hours and made 106,969 angler trips (Table 5).

The total harvest was 325,148 fish and consisted of ten different species (Table 5). Bluegill were most numerous with an estimated harvest of 135,483. Pumpkinseed were second at 103,176. Anglers harvested 1,888 smallmouth bass and 340 largemouth bass, and reported releasing 1,146 smallmouth bass (38%) and 925 largemouth bass (73%). We do not know what proportion of the fish released was legal size. In future surveys, we recommend distinguishing between sublegal- and legal-sized fish released.

Anglers harvested 13,486 walleyes and 1,646 northern pike, and reported releasing 1,146 walleyes (11%) and 470 northern pike (22%).

Winter 2002

Our clerk interviewed 1,147 open ice anglers and 1,174 shanty anglers. Most open ice (92%) and shanty (96%) interviews were roving type. Open ice and shanty anglers fished 220,834 angler hours and made 92,087 trips to Houghton Lake (Table 6).

A total of 61,139 fish were harvested. Yellow perch were most numerous with an estimated harvest of 19,954. Bluegill were second at 16,754. No smallmouth bass or largemouth bass were harvested; at least we did not detect any. Harvest of bass was illegal during winter period. However, anglers did report releasing 15 smallmouth bass.

Anglers harvested 4,770 walleyes and 7,645 northern pike. They did not report releasing any walleyes, but reported releasing 2,230 northern pike (23% of total catch).

Annual totals for summer 2001 through winter 2002

In the annual period from April 2001 through March 2002, anglers fished 499,048 hours and made 199,056 trips to Houghton Lake (Table 7). Of the total annual fishing effort, 56% occurred in the open-water summer period and 44% occurred during ice-over winter period.

The estimated total annual harvest was 386,287 fish. Bluegill and pumpkinseed were most numerous with estimated harvests of 152,237 and 105,129, respectively. All panfish (bluegill, pumpkinseed, yellow perch, black crappie, and rock bass) made up 95% of the total harvest, while larger, predatory fish (walleyes, northern pike, smallmouth bass, and largemouth bass) made up about 5%. Panfish were harvested in far greater numbers in July and August than in other months. Sixty-eight percent of the annual panfish harvest occurred in July and August.

Ten species that we captured during spring netting operations did not appear in the angler harvest – bowfin, brown bullhead, yellow bullhead, common carp, black bullhead, longnose gar, golden shiner, longnose sucker, rainbow trout, and channel catfish.

The estimated total annual harvests of walleyes and northern pike were 18,265 and 9,291, respectively (Table 7). Harvest rates (harvest per hour) of walleyes and northern pike were 0.0366 and 0.0186, respectively. Monthly harvest of walleyes was fairly consistent over months surveyed, but harvest of northern pike was much greater in winter (Table 7). Eighty-two percent of the annual northern pike harvest occurred through the ice from January through March.

Our tagging of walleyes and northern pike provided an unexpected benefit. It showed that the annual harvest of walleyes and northern pike was actually somewhat larger than we estimated directly from the angler survey. We did not cover the months of October through December, because we thought that relatively little fishing occurred during those months. However, 39 walleye tags (13% of total annual return) and 3 northern pike tags (8% of total annual return) were returned and reported caught during October-December. Thus, total annual walleye harvest from Houghton Lake was actually about 13% higher than our direct survey estimate, or 20,640 walleyes. Likewise, total annual northern pike harvest was actually about 8% higher than our direct survey estimate, or 10,034 northern pike.

Fish Community

We collected 20 species of fish with trap nets, fyke nets, and electrofishing gear (Table 8), including 4,426 walleyes and 1,199 northern pike. In general, we captured a greater number of species than previous surveys using similar gears, but we used more fishing effort than previous surveys. Our total sampling effort was 265 trap-net lifts, 159 fyke-net lifts, and 14 electrofishing runs. By contrast, Crowe and Latta (1956) applied 133 trap net lifts, which was the next highest amount of effort used on Houghton Lake. They caught 17 species. Other general netting surveys reported in MDNR files used fewer than 40 trap and/or fyke net lifts or used different gear types such as seines.

Investigators using seines or other small-mesh nets generally caught more species than we did. Laarman (1976) reported 29 species were caught in various seining operations on Houghton Lake and Schrouder (1993) reported catching 21 species with a mix of large- and small-mesh trap and fyke nets.

We caught a higher percentage of large, spring-spawning fish than previous surveys (Table 9). For example, 73% of walleyes, 27% of northern pike, 84% of smallmouth bass, and 54% of largemouth bass in our samples were legal size, while 52%, 7%, 50%, and 28% of these species in Schrouder's (1993) samples were legal size, respectively.

Of fishes we caught, we were most impressed with the high abundance and large sizes of bowfin (Tables 8 and 9). Bowfin are spring spawners, so we might have gotten more and larger bowfin because we sampled during their spawning period. However, bowfin are known to thrive in weedy, stagnant waters where oxygen is insufficient for other fishes. They have a connection between the air bladder and the pharynx, so they are able to use the air bladder as a respiratory organ. Their high abundance in Houghton Lake could be a symptom of the lake's eutrophication and aquatic vegetation problems mentioned earlier.

Walleyes and Northern Pike

Sex composition

Males outnumbered females in our samples of walleyes and northern pike. This is typical for both walleyes (Carlander 1997) and northern pike (Preigel and Krohn 1975; Bregazzi and Kennedy 1980). Of all walleyes we collected, 54.8% were males, 17.9% were females, and 27.3% were unknown sex. Of legal-sized walleyes captured, 59.8% were male, 23.8% were female, and 16.4% were unknown sex.

Of all northern pike we collected, 44.5% were males, 33.4% were females, and 22.1% were unknown sex. Of legal-sized northern pike captured, 6.7% were male, 64.7% were female, and 28.7% were unknown sex.

Abundance

We tagged a total of 3,087 legal-sized walleyes (1,405 reward and 1,682 non-reward tags) and clipped fins of 1,171 sublegal walleyes. Our creel clerk observed a total of 367 walleyes, of which 16 were tagged. We reduced the number of unmarked walleyes in the single-census calculation by 44 fish to adjust for sublegal fish that grew over the minimum size limit during the fishing season.

The estimated numbers of legal-sized walleyes were 38,656 using the multiple-census method and 58,854 using the single-census method. The estimated numbers of adult walleyes were 50,109 using the multiple-census method and 68,495 using the single-census method (Table 10).

We tagged a total of 287 legal-sized northern pike (66 reward and 221 non-reward tags) and clipped fins of 789 sublegal northern pike. Our creel clerk observed 287 northern pike of which 3 were tagged. We reduced the number of unmarked northern pike in the single-census calculation by 141 fish to adjust for sublegal fish that grew over the minimum size limit during the fishing season.

The estimated numbers of legal-sized northern pike were 1,575 using the multiple-census method and 10,584 using the single-census method. The estimated numbers of adult northern pike were 5,696 using the multiple-census method and 32,846 using the single-census method (Table 10).

Abundance estimates for both species seemed fairly reasonable for a lake the size of Houghton, except for the multiple-census estimate of legal-sized northern pike, which seemed too low. Otherwise, it was not obvious which estimator was best. One fact we think could be important in determining the suitability of estimators was that multiple-census estimates were consistently lower than single-census estimates. This could indicate a systematic violation of assumptions in one or both of the methods. In the **Discussion**, we will consider possible violations of assumptions and evaluate abundance estimates in the context of the other estimates we made, such as estimates of harvest.

Mean lengths at age

For walleyes, there was 52.9% agreement between the first two readers. For fish that were aged by a third reader, agreement was with first reader 50.2% of the time and with second reader 49.8% of the time; thus, there appeared to be little bias among readers. Only 4.4% of samples were discarded due to poor agreement; thus, at least two readers agreed 95.6% of the time. Our initial reader agreement for walleye spines was somewhat less than other studies. Isermann et al. (2003) achieved 55% reader agreement and Kocovsky and Carline (2000) achieved 62%.

For northern pike, there was 72.4% agreement between the first two readers. The concert read tended to agree with one reader 78.4% of the time and the other reader 21.6% of the time. This bias was apparently due to identification of the first annulus. Only 0.7% of samples were discarded due to poor agreement. While there are no studies reporting reader agreement for northern pike fin rays, the 72.4% agreement we achieved was relatively good and generally supports the use of fin rays for northern pike.

Female walleyes grew significantly faster than males (Table 11). This is typical for walleye populations in general (Colby et al. 1979; Carlander 1997; Kocovsky and Carline 2000). We obtained sufficient sample sizes for a simple comparison of means through age 11, and females were more than 3 in longer than males at age 11 (Table 11).

We calculated a mean growth index for walleyes of -2.2, which means walleyes in our sample from Houghton Lake appeared to grow substantially slower than State average. However, this difference was likely due, at least in part, to biases between aging methods. State average mean lengths were estimated by scale aging, and Kocovsky and Carline (2000) found that ages estimated from scales were younger than ages estimated from spines for the same fish. If so, this would cause estimated mean lengths at age of scale-aged fish to be larger than spine-aged fish. Eventually, the Large Lakes Program will obtain enough data to recalculate new State averages based on spines, if we continue to use them, and this will improve future comparisons.

Female northern pike grew significantly faster than males (Table 12). As with walleyes, this is typical for northern pike populations in general (Carlander 1969; Craig 1996). We obtained sufficient sample sizes for comparison through age 6, and females were more than 4 in longer than males at age 6 (Table 12).

We calculated a mean growth index for northern pike of 0.82, which means northern pike in our sample from Houghton Lake appeared to grow somewhat faster than State average. However, unknown biases associated with use of fin rays for aging makes this result dubious. Again, as with walleyes, the Large Lakes Program will eventually obtain enough fin ray-aged northern pike to recalculate State averages for future comparisons.

Mortality

For walleyes, total mortality of males was less than females. We determined catch at age for 2,340 males, 761 females, and 713 unknown-sex walleyes (Table 13). The catch-curve regressions were significant ($P < 0.05$) and produced total instantaneous mortality rates for legal-sized walleyes of 0.3874 for males, 0.5255 for females, and 0.6240 for all fish combined

(Figure 8). These instantaneous rates correspond to annual percent mortality rates of 32% for males, 41% for females, and 46% for all fish combined.

We used ages 6 through 14 in the catch-curve analysis to represent legal-sized walleyes (Figure 8). We chose age 6 as the youngest age because: 1) average lengths of walleyes at age 6 was 16.2 in for males and 17.7 in for females (Table 11), so a high proportion (likely over 90%) of age-6 fish were over legal size at the beginning of fishing season; and 2) relative abundance of females younger than age 6 do not appear to be represented in proportion to their true abundance (Figure 8), suggesting that females were not fully mature at age 5. We chose age 14 as the oldest age because only 1 fish older than age 14 was aged (Table 11).

For northern pike, total mortality of males was greater than females, which is apparently typical for the species. Craig (1996) stated that male northern pike have higher natural mortality than females in most places. We determined catch at age for 490 males, 367 females, and 184 unknown-sex northern pike (Table 13). Few males were legal size (> 24 in), so we could not estimate total mortality of legal-sized males. Instead, we estimated total mortality for sublegal-sized males. Thus, our estimate of total mortality for males includes only natural and hooking mortality, while our estimate for females includes natural, hooking, and fishing mortality. The catch-curve regressions produced total instantaneous mortality rates of 1.0970 for sublegal-sized males, 0.5902 for legal-sized females, and 0.7134 for all legal-sized fish combined (Figure 9). These instantaneous rates correspond to annual percent mortality rates of 67% for sublegal-sized males, 45% for legal-sized females, and 51% for all legal-sized fish combined.

We used ages 3 through 5 in the catch-curve analysis to represent sublegal-sized male northern pike (Figure 9). We used ages 4 through 10 in the catch-curve analysis to represent legal-sized female and all northern pike. We chose age 4 as the youngest age because: 1) average length of females at age 4 was 25.2 in (Table 12), so a high proportion (likely over 90%) of age-4 fish were legal-sized at the beginning of fishing season; and 2) relative abundances of females appear to be represented in proportion to their true abundance by age 4 (Table 13, Figure 9), suggesting that they are fully mature by age 4, perhaps as young as age 3. Age 10 was the maximum age for our sample (Table 12).

Our estimates of annual exploitation rates were much lower using the tag-return method than harvest/abundance method for both walleyes and northern pike. For walleyes, estimates were 10.6% versus 27.3%, and for northern pike, estimates were 18.2% versus 44.7% (Table 10). We think the true exploitation rates for both species were likely between those made by the two different methods and are probably closer to the higher rates. We will address possible violations to assumptions for exploitation estimates later in the **Discussion** section.

For walleyes, the tag-return estimate was based on angler returns of 146 reward tags from 1,405 originally tagged. Anglers also returned 138 non-reward tags for a total of 284 tags returned. Included in these returns were 10 tagged walleyes (3 reward and 7 non-reward tags) that were not reported to the central office but were observed in the possession of anglers by our angler survey clerk. Thus, while anglers did report reward tags at a slightly greater rate than non-reward tags (10.6 % versus 8.2%, respectively), they did not fully report either one.

For northern pike, the tag-return estimate was based on angler returns of 12 reward tags from 66 originally tagged. Anglers also returned 27 non-reward tags for a total of 40 tags returned. Included in these returns was 1 non-reward tag that was not returned to the central office but was observed by our angler survey clerk in the possession of an angler. Anglers reported reward tags at a greater rate than non-reward tags (18.2% versus 12.2%, respectively).

Recruitment

For walleyes, variability in year-class strength was relatively high in Houghton Lake, and this can be seen in the statistics of the catch-curve regression. Residual values were relatively large (see scatter of observed values around the regression line for all walleyes in

Figure 8) and the amount of variation explained by the age variable was fairly low ($R^2 = 0.86$).

Stocking probably made a positive contribution to the population of walleyes in Houghton Lake, based on our regression analysis of catch-curve residuals. The regression was:

$$\text{Residuals} = -0.4351 + 0.0070 \times (\text{thousand stocked}),$$

$$R^2 = 0.33, P = 0.10.$$

The R^2 value suggested that stocking explained 33% of the variation in year-class strength, and the positive slope value suggested that stocking incrementally increased year-class strength.

For northern pike, variability in year-class strength was low in Houghton Lake, and this can be seen in the statistics of the catch-curve regression. Residual values were small (see scatter of observed values around the regression line for all northern pike in Figure 9) and the amount of variation explained by the age variable was high ($R^2 = 0.99$).

Movement

Based on voluntary tag returns, there was little movement of walleyes or northern pike out of Houghton Lake, but they moved extensively within the lake. Three walleye tag returns came from the Muskegon River: a 19.2-in fish was caught where the river flows out of Houghton Lake, a 17.8-in male was caught in an unidentified location, and a 24.9-in female was caught downriver of the county dam near the paper mill. Additionally, one 19.1-in male walleye was collected by MDNR personnel approximately 1 mile below Houghton Lake. Within the lake, most fish were recovered considerable distances from their tagging sites.

Carbine and Applegate (1946a and 1946b) tagged 100 walleyes and 846 northern pike in Houghton Lake coincident with northern pike spawning investigations. They found extensive movement within the lake. Walleyes were recaptured from 0.5 to 7.5 miles from their tagging sites, and northern pike from 0.0 to 9.5 miles. About 20% of their walleyes were recovered in the Muskegon River downstream of Houghton Lake, and one was recovered 130 miles downstream. Less than 1% of their northern pike were recovered in the Muskegon River, but one was recovered 49 miles downstream. For northern pike, they concluded that most fish inhabited weed beds throughout the lake in summer, and traveled to specific streams and marshes to spawn in spring.

Discussion

Angler Survey

Historical comparisons

Previous harvest and effort estimates for Houghton Lake were reported by Christensen (1957 and 1958), Laarman (1976), and Schneider and Lockwood (1979), but one must be careful when comparing previous estimates to ours because consistent methods were not used. For example, a general creel census from 1928-64 included Houghton Lake (Loeb 1949, Laarman 1976), but this “census” was designed only to measure success of anglers who were actually interviewed and was not expanded to estimate total catch of all anglers. These general census estimates would not be directly comparable to our estimates. However, it was clear that walleye, northern pike, and panfish were the predominant species in the fishery during the 1920s and 1930s as they are today.

It also seems clear that the fishery of Houghton Lake in 1957-61 was very similar to its fishery today. Reasonable, quantitative comparisons can be made between our estimates and those done in 1957-61 (Christensen 1957 and 1958; Schneider and Lockwood 1979). They used methods fairly similar to ours, although advances in fishing gears and techniques and changes in fishing regulations complicate direct comparisons to some degree.

Statistical confidence limits were not calculated for 1957-61 estimates, so we estimated them to facilitate comparisons. To do so, we assumed the standard-error-to-estimate proportion was the same for 1957-61 as for 2001-02. In other words, we used the standard-error-to-estimate proportion from 2001-02 to calculate “approximate confidence limits” on 1957-61 estimates.

Fishing effort was significantly lower in 2001-02 than 1957-61 (Figure 10), but species composition of the harvest was similar and the harvest per hour was not substantially different for most species, including northern pike, bluegill, yellow perch, rock bass, smallmouth bass, and largemouth bass (Figure 11). Harvest per hour was significantly higher in 2001-02 for walleye, pumpkinseed, and black crappie, but was not significantly lower for any species (Figure 11).

Most notable, walleye harvest per hour was about two times higher in 2001-02 than 1957-61 (Figure 11). This was in spite of an increase in the minimum size limit on walleyes from 13 in during 1957-61 to 15 in during 2001-02. We would expect, based on a simple yield-per-recruit model, that this increase in size limit would have reduced harvest by 10% to 25% (Schneider 1978). So the increase in harvest per hour suggested walleye abundance has increased.

We think this increase in walleye abundance was the temporary result of above average year classes which were produced from 1989 through 1993. These year classes correspond to ages 8 through 12 in the all-walleyes regression in Figure 8. Fingerling stocking probably contributed to these year classes (Table 2), but success of natural reproduction was also good during this period. The 1992 year class (age 9 – Figure 8) was one of the strongest year classes observed, and no walleyes were stocked that year.

If harvest per hour related to abundance, then northern pike abundance was not significantly different between time periods (Figure 11). The minimum size limit for northern pike was increased from 20 in to 24 in between 1961 and 2001. The point estimate of harvest per hour was 40% less than the 1957-61 average, which is about what we would expect for that change in minimum size limit, although the precision on our statistics is not adequate to determine if this 40% difference is real.

Comparisons to other large lakes

In general, surveys conducted in Michigan in the past 10 years used the same methods we used on Houghton Lake, but most of them differed from our survey in seasonal time frame. For example, few other surveys were done in consecutive summer and winter periods. None-the-less, for gross comparison, we used recent angler survey results for Michigan's large inland lakes from 1993 through 1999 as compiled by Lockwood (2000a) and results for Michigan's Great Lakes waters in 2001 compiled by Rakoczy and Wesander-Russell (2002).

We estimated 499,048 angler hours occurred on Houghton Lake during the year from April 2001 through March 2002. In 2001, only Michigan waters of lakes Michigan and Huron had more recreational fishing effort than Houghton Lake. Notably, Houghton Lake had more effort than Michigan waters of lakes Erie or Superior (Table 14). Houghton Lake also had greater fishing effort than Lake Gogebic, the only other large inland lake for which recent data were available on a similar annual time frame.

Considering only the summer season, Houghton Lake had the highest harvest per hour and harvest per acre of any other large inland lake for which we have data (Table 14). It also had the second highest fishing effort (hours) per acre of large inland lakes behind Fletcher Pond.

For walleyes, our estimated annual harvest from Houghton Lake was 0.9 fish per acre. This harvest is average compared to harvests elsewhere. The average harvest of six other large Michigan lakes (> 1,000 acres) reported by Lockwood (2000a) was 0.9 walleyes per acre, ranging from 0.1 per acre in Brevoort Lake, Mackinac County to 2.4 per acre in Chicagon Lake, Iron County. These Michigan lakes all were subject to similar gears and fishing regulations, including a 15-in minimum size limit.

For northern pike, our estimated annual harvest from Houghton Lake was 0.5 fish per acre. This harvest was above average compared to harvests in Michigan and elsewhere, considering the effects of Michigan's 24-in minimum size limit on harvests. The average harvest of seven other large Michigan lakes (> 1,000 acres) reported by Lockwood (2000a) was 0.2 northern pike per acre, ranging from < 0.1 per acre in Bond Falls Flowage, Gogebic County to 0.7 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 of from 0.7 to 3.6 per acre in seven, much smaller Minnesota lakes. These lakes ranged from 136 to 628 acres in size and had no minimum size limits for northern pike.

Fish Community

Significant changes in the fish community of Houghton Lake occurred during the 1920s and 1930s. According to Laarman (1976), the harvest of northern pike "declined drastically" in the mid-1930s, while the harvest of bluegills "increased proportionally." A number of research studies were conducted during the 1930s and 1940s to determine why northern pike declined (Eschmeyer 1936; Hazzard 1936; Carbine 1942; Loeb 1949).

Many anglers at the time thought the decline of northern pike was due to excessive harvest of large, spawning-sized fish by ice fishing, especially using spears. They petitioned Michigan Department of Conservation (former MDNR) to increase restrictions on ice fishing and to eliminate spearing as a method of harvest. However, research concluded that the cause was not ice or spear fishing (Eschmeyer 1936; Hazzard 1936; Loeb 1949; Latta 1972), but a reduction in spawning success due to a loss of prime spawning habitat. Loeb (1949) wrote of Houghton Lake, "Formerly, 7 tributaries, the Muskegon River, numerous drainage ditches, and much marshland were available for pike spawning. The marshland has been almost completely filled for highway and cottage construction, and the principal drainage now enters the river below the dam instead of the lake. Studies made in the 1940s indicated that the ditches and marshland remaining then were used extensively for spawning."

Fish species and size composition was relatively stable in Houghton Lake from at least 1962 through 1993. General fish surveys were conducted 6 times during the period (Table 15), and results indicated little change (Schrouder 1993). In addition to general surveys, a number of targeted fish collections have occurred in spring to collect eggs from walleyes and northern pike for rearing operations and in fall, to evaluate walleye reproduction by targeting young-of-year fish. Results of these surveys were reported in MDNR, Fisheries Division, Fish Collection System[4].

Houghton Lake has one of the most diverse fish communities of any inland lake in Michigan. MDNR has collected 39 different species of fish in Houghton Lake in various surveys from 1935 to 1998 (Laarman 1976; Crowe and Latta 1956; Schrouder 1993). A complete list is presented in the Appendix. We collected only 20 species (Table 8), but most of the 19 we did not collect were small-bodied species captured in nets with smaller mesh than we used.

Previous investigators used seines in 5 surveys of Houghton Lake from 1935 to 1960 (Table 15). Twenty-nine species were caught (Laarman 1976), which was high compared to other inland lakes in Michigan. Lake Charlevoix was the only other lake where as many species were collected by seines. The next highest was 24 species collected from Burt Lake (Laarman 1976). Schneider (1981) reported that seine samples of 229 lakes in Michigan's Lower Peninsula from 1957 to 1964 ranged from 4 to 19 fish species. Sixteen small-bodied species (see list in Appendix) were collected with seines that we did not collect, while six species (common carp, yellow bullhead, longnose gar, longnose sucker, rainbow trout, and channel catfish) we collected were not collected by seines. These differences were most likely due to selectivity of gears rather than changes in species present.

Crowe and Latta (1956) collected 17 species with trap nets similar to ours. They collected one specie we did not: redhorse (species not reported), while we collected four species they did not: black bullhead, golden shiner, longnose sucker, and rainbow trout. None of these species were numerous in catches, so these differences probably occurred by chance and seem unimportant biologically.

Schrouder (1993) used a mix of large- and small-mesh trap and fyke nets and caught five

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[4] A computerized data system developed by MDNR, Fisheries Division, Lansing to store, analyze, and retrieve data on fish surveys collected statewide.

smaller-bodied species we did not: fathead minnow, logperch, emerald shiner, spottail shiner, and bluntnose minnow. We caught four species she did not: black bullhead, longnose sucker, rainbow trout, and channel catfish. As before, these differences in species captured seem unimportant and were probably due to chance or differences in mesh size.

Schneider (2000) gave guidance for interpreting fish population and community indices for Michigan lakes. He cautioned that biases caused by gear or season must be considered when interpreting population or community characteristics from fish samples. This means that quantitative comparisons of species and size compositions between our results and others would not be advisable until more sampling has been done using similar methods under the Large Lakes Program. Our methods targeted spring spawning fishes and were fairly unique. Our primary objective was to capture as many legal-sized walleyes and northern pike as possible. Most other surveys in Michigan were done later in the year to obtain generally representative fish samples from a lake. We showed earlier that we caught more and larger spring-spawning fish than Schrouder (1993), and we think it was due to gear/methods biases rather than fish population changes.

Walleyes and Northern Pike

Sex composition

We did not find any previous information concerning walleye sex composition from Houghton Lake. Sex of walleyes is readily determined by extruding gametes during the April spawning season, but at other times of the year sex determination would require dissection of the fish, and dissection was not part of past sampling protocols. To our knowledge, sex composition was not recorded for walleyes during previous egg-take operations in Houghton Lake.

For northern pike from Houghton Lake, sex composition was recorded a number of times in previous surveys targeting spawning fish. In each case, males outnumbered females. Carbine (1942) recorded 65% of 378 fish and 58% of 118 fish taken in 1939 and 1940, respectively, were males. Gerald Casey of MDNR reported capturing 528 males and 258 females with trap nets in a 1989 egg-take operation, that is, 67.2% males and 32.8% females (MDNR Fish Collection System analysis). The minimum size of northern pike in that survey was 17 in, and no unknown sex fish were recorded. If we exclude <17-in and unknown-sex fish from our sample, we would have 463 males and 184 females, or 71.6% males and 28.4% females, similar to Casey.

For walleyes from other lakes in Michigan and elsewhere, males consistently dominate sex composition in samples taken during spawning. 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). For example, walleyes taken with trap nets during spawning season in Lake Erie ranged from 80.2% to 93.0% males from 1994 through 1998 (Thomas and Haas 2000). The remaining fish were females. Thomas and Haas (2000) did not report any unknown-sex fish. Also, extensive data on sex composition of walleyes are available for Wisconsin lakes from spring population estimates and spear fisheries. Samples from spring population estimates in 2001 averaged 83.3% males, 6.4% females, and 10.3% unknown (Rose et al. 2002). Samples from spear fisheries averaged 82.9% males, 9.5% females, and 7.6 % unknown (Krueger 1999).

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, an eutrophic lake in southern England. Sex ratios during the February and March spawning period ranged from 6 : 1 to 8 : 1 (male to female), but the overall sex ratio for an entire year of sampling was not significantly different from 1:1.

Abundance

Crowe and Latta (1956) were the first to attempt mark-and-recapture fish abundance estimates on Houghton Lake, but they were unsuccessful. They attempted to mark and recapture fish by netting alone, and with just a two-person work crew, they could not exert enough netting effort to obtain reasonable estimates. We were successful in obtaining abundance estimates, but required a much greater investment – four 3-person crews working for 3 weeks and a companion angler harvest survey. Even with this investment, 95% confidence intervals for our abundance estimates were broad (Table 10). For example, while multiple-census estimates for both walleyes and northern pike were considerably lower than single-census estimates, 95% confidence limits for the two estimates overlapped.

A major advantage of the multiple-census estimate was that recaptures were taken during the netting operation so the estimate could be computed in May of 2001. On the other hand, it took a full year to get recaptures from the angler survey for the single-census estimate. Results of the single-census estimate were not available until May 2002. Unfortunately, there are serious disadvantages in using the multiple-census estimate. Pierce (1997) studied biases associated with population estimates of northern pike in six lakes. 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). Thus, his methods were very similar to ours, except that we collected single-census recaptures from the angler survey. Pierce's multiple-census estimates averaged 39% lower than single-census estimates. Our results were similar, multiple-census estimates were 34% lower for walleyes and 85% lower for northern pike. Pierce concluded that in general multiple-census estimates suffer from biases that make them consistently too low. He suggested the most likely sources of bias were size selectivity of the gear and unequal vulnerability of fish to near shore trap netting. We agree, and we think these biases probably affected our multiple-census estimate. Pierce also concluded that recapturing fish at a later time with a second gear type resulted in estimates that were more valid. Again we agree, so we think our single-census estimate is more accurate.

We suspect that in general these biases associated with multiple-census estimates become more severe as lake size increases. Paired multiple- and single-census abundance estimates will continue to be made on 1,000- to 20,000-acre lakes under the Large Lakes Program. So in the future, we might be able to determine if this is true.

While single-census estimates using two gear types are probably better than multiple-census estimates, they are not without problems. Mark-and-recapture estimates assume tags are not lost, so if tag loss increased with time, it would have affected the single-census method more than the multiple-census method. Tags must be retained for a full year for the single-census method and only for three weeks for the multiple-census method. Higher tag loss would lead to an overestimate of abundance, and our single-census estimates were higher than our multiple-census estimates. However, we think tag loss, even after a year, was probably minimal. We did not detect any tag loss during angler survey, that is, no fin-clipped fish > 15 in without tags were observed by survey clerks. Also, jaw tags of the type we used generally have had a good record of retention in previous studies. For example, Schneeberger and Scott (1997) used the same type of jaw tags on yellow perch and found 100% tag retention in experimental ponds.

Our single-census estimates for Houghton Lake also appeared more accurate than multiple-census estimates when judged in relation to the independently-derived harvest and mortality estimates. For example, our harvest estimate for legal-sized northern pike was 9,291. This harvest estimate matches well with similar harvest estimates made in the 1950s (Schneider and Lockwood 1979), and it produces a catch rate similar to the 1950s (Figure 11). But such a harvest would be impossible if our multiple-census population estimate of 1,575 legal-sized northern pike was accurate (Table 10).

Based on our experience in this study, we believe it would be possible but costly to improve precision of walleye abundance estimates for Houghton Lake or other lakes of comparable size. Obtaining more precise estimates would require: 1) marking more fish; 2) recapturing more marked fish; or 3) both. Confidence limits on our single-census estimate of 58,854 legal-sized walleyes were ±45% of the estimate (Table 10), which is about what would be predicted from Figure 7 given 3,087 fish or 6% of the population was marked. Each of our 10-net, 3-person work crews marked about 772 (3087/4) walleyes. So assuming each additional work crew could mark 772 walleyes, it would have required an additional 4 work crews to mark 5,900 walleyes (10% of population). This would have only improved precision to about ±38%. In order to achieve precision of about ±20%, it would be necessary to mark 17,660 walleyes (30% of the population – Figure 7). This would have taken 23 work crews with 69 people and 230 nets all working together on the lake during the three weeks after ice-out.

Improving precision by increasing the number of fish recaptured would also be costly. Based on the formula for confidence limits, a supplemental recapture effort using nets, electrofishing gear, or additional angler survey clerks would have to obtain a 3-fold increase in the number of recaptures to improve precision to about ±20%. This would require a minimum of one additional angler survey clerk or a substantial netting and/or electrofishing effort. The cost of obtaining more precise and accurate estimates is probably proportional to lake size to some degree, so, as Houghton Lake is the largest in Michigan, it could be possible to get more precise and accurate estimates on other lakes at a reasonable cost.

Our multiple- and single-census estimates of adult walleyes were reasonably close to the Wisconsin regression prediction of 59,476. Our multiple-census estimate was 16% lower at 50,109, and our single-census estimate was 16% higher at 68,495. Thus, based on this initial comparison, it seems promising that the Wisconsin regression could be useful for Michigan walleye management. More comparisons should be made on a variety of Michigan lakes in the future. Ultimately, Michigan and Wisconsin might be able to develop a joint, regional walleye regression with a much greater sample size and variety of lake types.

Population density of walleyes in Houghton Lake was average to above average compared to other lakes in Michigan and elsewhere. Lockwood (1998, unpublished data) used the single-census method to estimate abundance of ≥ 15-in walleyes on 16,630-acre Mullett Lake. He estimated walleye abundance to be 14,350 or 0.8 per acre. Our single-census estimate for ≥ 15-in walleyes in Houghton Lake was 58,854 or 2.9 per acre. A different version of the single-census method has been used for walleyes since the mid-1980s on smaller lakes in Wisconsin, Michigan, and Minnesota (Hansen 1989, Rose et al. 2002). These authors recaptured marked fish with electrofishing gear several days after the fish were marked. Results of these estimates were input to the Wisconsin regression equation, and that regression predicts Houghton Lake should have 59,576 spawning walleyes or 3.0 adult walleyes per acre. Also, Nate et al. (2000) reported an average density of 2.2 adult walleyes per acre for 131 Wisconsin lakes having natural reproduction. These lakes ranged from 100 to 10,500 acres, although most were much smaller than Houghton. Population densities from our multiple-census estimate and single-census estimates for adult walleyes were 2.5 and 3.4 per acre, respectively.

Population density of northern pike in Houghton Lake was low compared to other lakes in Michigan and elsewhere. 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 these estimates vary, but considering only estimates done for age 1 and older fish, the range in density is 1 to 29 fish per acre. Also, Pierce et al. (1995) estimated abundance and density of northern pike in seven Minnesota lakes. Their estimates of density ranged from 4.5 to 22.3 per acre of fish age 2 and older. Our estimates of numbers of adult northern pike in Houghton Lake also would essentially be for fish age 2 and older, and should be comparable, but our estimates converted to densities are only 0.3 per acre for the multiple-census method and 1.6 per acre for the single-census method.

Mean lengths at age

Our estimates of mean lengths at age for all walleyes were substantially smaller than those from past surveys (Table 16). We cannot rule out the possibility that walleye growth has slowed in Houghton Lake over the last 8 to 10 years. But on the other hand, we do know of at least three methodological biases that probably made our mean length estimates smaller than earlier ones. First, we know our spine-aged fish probably produced smaller mean lengths than scale-aged fish (Kocovsky and Carline 2000). In the 1993 and 1998 surveys, dorsal spines were used for fish ≥ 18 in and scales for fish < 18 in. Scales alone were used in surveys prior to 1993. Second, we know fish grow between April, when our survey was done, and June, when most of the earlier surveys were done (Table 15). And third, we know our spawning-season sample was dominated by slow-growing males, and while the sex compositions of past samples are unknown, they most likely contained a greater proportion of fast-growing females. Unfortunately, we do not know to what extent these biases affected our mean length estimates, but acting together they probably can account for most of the observed differences between our estimates and others.

Our estimated mean lengths for walleyes were also smaller than scale-aged state averages (Table 16). The mean growth index was -2.2. As before, we suspect this difference was due more to the three biases described above than to any real difference. In 1983, when aging in Houghton Lake was based entirely on scales, mean lengths were about equal to state averages. In 1993 and 1998, when aging was based partly on spines and partly on scales, means were only slightly below state averages (Table 16). Thus, it appears that as more scales were used in aging, the closer walleye growth in Houghton Lake was to state average growth.

Estimated mean lengths at age for northern pike from our survey were generally larger than those from past surveys of Houghton Lake (Table 17), but as with walleyes, it was not clear if these differences were biologically meaningful. The same three methodological biases mentioned for walleyes would also apply to northern pike. But while the date-sampled and sex-ratio biases mentioned earlier would have a similar effect on mean lengths of northern pike as for walleyes (producing smaller mean lengths in our samples), we do not know if mean lengths of fin ray-aged fish tend to be lower, higher, or equal to scale-aged fish. In addition, past surveys aged relatively few northern pike which makes comparisons dubious.

Estimated mean lengths of northern pike from our sample were somewhat larger than State averages (Table 17). The mean growth index was 0.82. As with walleyes, state averages for northern pike were based entirely on scale aging, so again this comparison is dubious. We need to develop new State averages for northern pike using fin rays to make more meaningful comparisons.

Mortality

For walleyes in Houghton Lake, ours was the first attempt to estimate total mortality, so we cannot compare our estimates to previous ones.

Compared to total mortality estimates for walleyes from other lakes in Michigan and elsewhere, our estimate of 46% was about average. Schneider (1978) summarized available estimates of total annual mortality for adult walleyes in Michigan. They ranged from 20% in Lake Gogebic to 65% in Bay de Noc, Lake Michigan. Schneider also presented estimates from lakes throughout Midwestern North America, other than Michigan. They ranged from 31% in Escanaba Lake, Wisconsin to 70% in Red Lakes, Minnesota. Colby et al. (1979) summarized total mortality rates for walleyes from a number of lakes across North America. They ranged from 13% to 84% for fish age 2 and older, with the majority of lakes between 35% and 65%.

The only other estimate of total mortality for northern pike from Houghton Lake was done by Diana (1983). His estimate is reasonably close to ours. He applied a catch curve to a combined-sex sample and calculated 0.85 for total instantaneous mortality rate, which corresponds to 57% total annual mortality.

Compared to total annual mortality estimates for northern pike from other lakes in Michigan and elsewhere, our estimate of 51% was average to above average. Diana (1983) estimated total annual mortality for two other lakes in Michigan, Murray Lake at 24.4% and Lac Vieux Desert at 36.2%. Pierce et al. (1995) estimated total mortality for northern pike in seven lakes in Minnesota to be 36% to 65%, although these lakes were much smaller (< 650 acres) than Houghton. Pierce et al. 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%.

Our estimates of exploitation using tag returns were likely too low. Such estimates are typically low due to tagging mortality, tag loss, and underreporting of tags (Miranda et al. 2002). We did not attempt to estimate tagging mortality, but it was probably minimal. We did attempt to estimate tag loss by double marking fish with tags and fin clips, and we did not detect any tag loss. We also attempted to measure underreporting of tags by offering a $10 reward on about half of the tags and comparing return rates of reward to non-reward tags. We found that reporting rate for reward tags was somewhat better than for non-reward tags. However, we doubt if reporting rates for reward tags was actually near 100%. Angler survey clerks saw reward tags on walleyes that were never reported, and our reward amount was relatively low compared to those used by other authors (Miranda et al. 2002). Murphy and Taylor (1991) used a variety of rewards from $5 to $50 on fish and found no significant differences in rate of return among reward values. Nichols et al. (1991) used a range of reward values on duck bands and found that reporting rate did not approach 100% until reward reached $400.

Our estimates of exploitation rates based on estimated harvest/abundance were likely too high. Instantaneous fishing rates computed from reward tags were only about 35% of harvest/abundance rates (Table 10). Thus, if the harvest/abundance estimate were actually correct, it would mean that anglers returned only 35% of reward tags. Yet our angler clerk saw only 3 of 16 reward tags on walleyes that were not returned (or about an 80% return rate) and none on northern pike that were not returned.

Compared to exploitation rates for walleyes from other lakes in Michigan and elsewhere, our estimates of 10.6 to 27.3% for Houghton Lake were about average. For example, Thomas and Haas (2000) estimated angler exploitation rates from western Lake Erie at 7.5% to 38.8% from 1989 through 1998. Serns and Kempinger (1981) reported average exploitation rates of 24.6% and 27.3% for male and female walleyes, respectively in Escanaba Lake, WI during 1958-1979. Schneider (1978) gave a range of 5% to 50% for lakes in Midwestern North America. Carlander (1997) gave a range of 5% to 59% for a sample of lakes throughout North America.

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

Recruitment

We found that fingerling stocking probably increased year-class strength of walleyes in Houghton Lake, but this should not be taken as an open endorsement of walleye stocking. Natural reproduction is clearly providing a high level of walleye recruitment in Houghton Lake, as indicated by the strong year class produced in 1992, when no fish were stocked. There also could be negative effects of walleye stocking that we did not measure in our study, and decisions about stocking should carefully weigh both positive and negative effects.

Negative effects would be primarily from density-dependent interactions, such as competition for food or cannibalism. For example, Li et al. (1996a) found that in places where walleye year-class strength was increased from stocking, the mean weight of individual fish decreased. We do not know if stocking affects growth of walleyes in Houghton Lake. Determining this would take several years of sampling to estimate mean lengths at variable stocking levels. However, we do know that growth of walleyes in Houghton Lake is currently average to below average, so increasing stocking above current levels would seem unwise and would likely reduce growth to below average. Conversely, eliminating stocking or reducing it could improve walleye growth in the lake.

Walleye stocking could also have a negative effect on survival. Li et al. (1996b) found that in places where stocking increased the abundance of a year class, it also decreased the abundance of the year class 1 year younger and 1 year older than the stocked year class. Walleye stocking could also affect the growth and survival of other predators, such as northern pike, smallmouth bass, or largemouth bass.

For northern pike, year-class strength in Houghton Lake was very consistent from 1991 through 1997, the years included in our catch-curve regression. This consistency supports the hypothesis that the northern pike abundance has stabilized at a lower level after declining in the 1920s and 1930s as reported by Carbine (1942) and Loeb (1949).

Management Implications

The predator-prey balance of Houghton Lake changed significantly during the 1930s, but the fish community and fishery has remained remarkably stable since then. Northern pike harvest per hour, and presumably abundance, decreased in the 1930s, while panfish catch per hour, and presumably abundance, increased (Loeb 1949). Further study showed that the decrease in northern pike was most likely caused by destruction of their marsh spawning habitat and that panfish probably increased in response to reduced predation from northern pike (Eschmeyer 1936; Hazzard 1936; Carbine 1942; Loeb 1949). These changes in the community structure apparently stabilized during the 1940s and 1950s and appear to have been sustained to the present. Our angler survey estimates were similar to those from the 1950s and 1960s in terms of variety and catch per hour of species harvested. Also, fish species and size compositions of fish taken in general netting surveys has changed little from at least 1962 to present.

However, this measure of stability is fairly crude, and we do not mean to suggest Houghton Lake is free of fishery management problems. To the contrary, a number of concerns have been reported recently including: 1) over abundant, slow-growing yellow perch (Schrouder 1993); 2) nutrient enrichment from human development (Schrouder 1993); 3) invasion of water-milfoil; and 4) invasion of zebra mussels (Schrouder 1993). The analyses in this report add information to help judge the seriousness of these concerns and to help measure and diagnose changes in fish populations that could occur in the future.

The walleye fishery of Houghton Lake is healthy. Harvest per hour was better in 2001-02 than it was in the 1950s and 1960s, suggesting a recent increase in abundance. This increase was probably the result of fingerling stocking and/or better-than-average natural year classes from 1989 through 1993. We think fingerling stocking did make a positive contribution to the walleye fishery, but suggest that future decisions about stocking should carefully weigh both the positive and negative affects we listed in our **Discussion** section. Harvest per acre and population density was average to above average compared to other lakes in Michigan and elsewhere. Total mortality and exploitation rates were average compared to other lakes in Michigan and elsewhere. Estimated mean lengths at age for spine-aged fish were smaller than scale-aged state averages, but this was probably due to methodological biases.

The northern pike fishery in Houghton Lake is also fairly healthy. Harvest per hour in 2001-02 was not substantially different than it was in the 1950s and 1960s, suggesting the population has been stable for the last 50 years. Harvest per acre was above average compared to other lakes in Michigan and elsewhere, but population density was below average. Total mortality and exploitation rates were average to above average compared to other lakes in Michigan and elsewhere. Mean lengths at age were above state averages, but, as with walleyes, methodological biases prevent us from knowing if this is biologically meaningful. Year class strength was consistent from year to year, suggesting natural reproduction is adequate for the present population. Although, continued protection of northern pike spawning habitat is critical for maintaining the population at current levels. We would assume that northern pike abundance would increase if natural reproduction could be restored to the level it was in the 1920s, but walleye and panfish abundance would probably decrease as a result.

Methods used for harvest, abundance, age and growth, and mortality estimates for walleyes and northern pike performed fairly well, considering the large size of Houghton Lake. Most estimates seemed reasonable when compared to those from other lakes. We were unable to determine which of the different methods for estimating abundance (multiple or single census) and fishing mortality (tag returns or harvest/abundance) were best for long-term use. Comparisons must be repeated on more lakes before conclusions can be made. Thus, the overall approach used in this study should be continued on a variety of other large lakes for at least several years before significant changes are made.

Our estimates of adult walleye abundance were fairly close to the estimate made a priori with the Wisconsin regression equation. Thus, in the short term, it seems reasonable to apply the Wisconsin regression to estimate walleye abundance in other Michigan lakes when abundance estimates are needed for management purposes. In the long term, MDNR should work towards developing an improved regression by conducting abundance estimates in other Michigan lakes.

Acknowledgements

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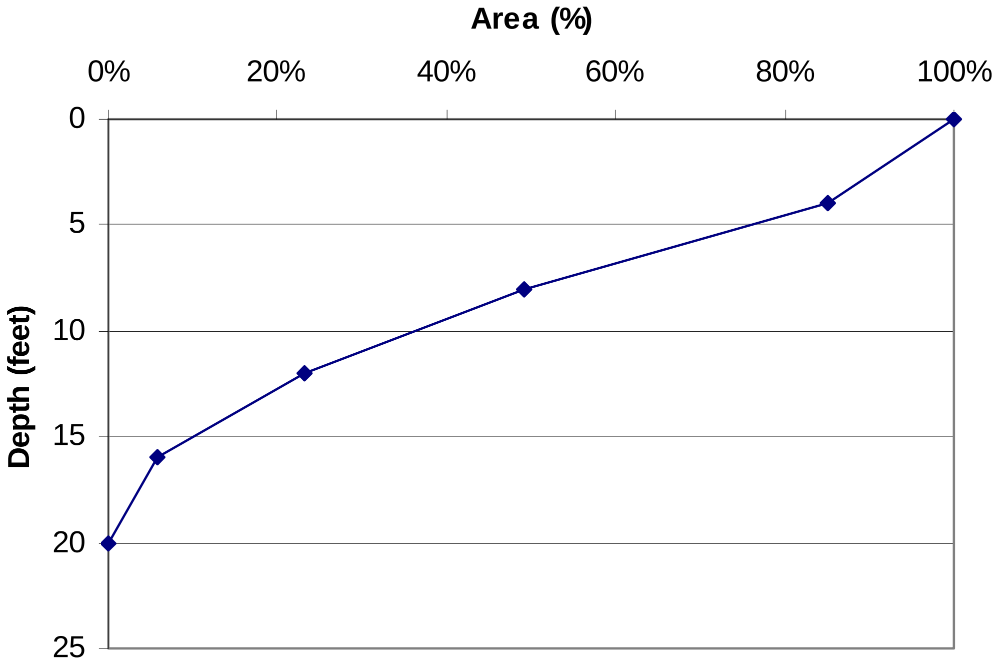


Figure 1.–Percent of area at a given depth for Houghton Lake, Michigan. Data taken from MDNR, Digital Water Atlas.

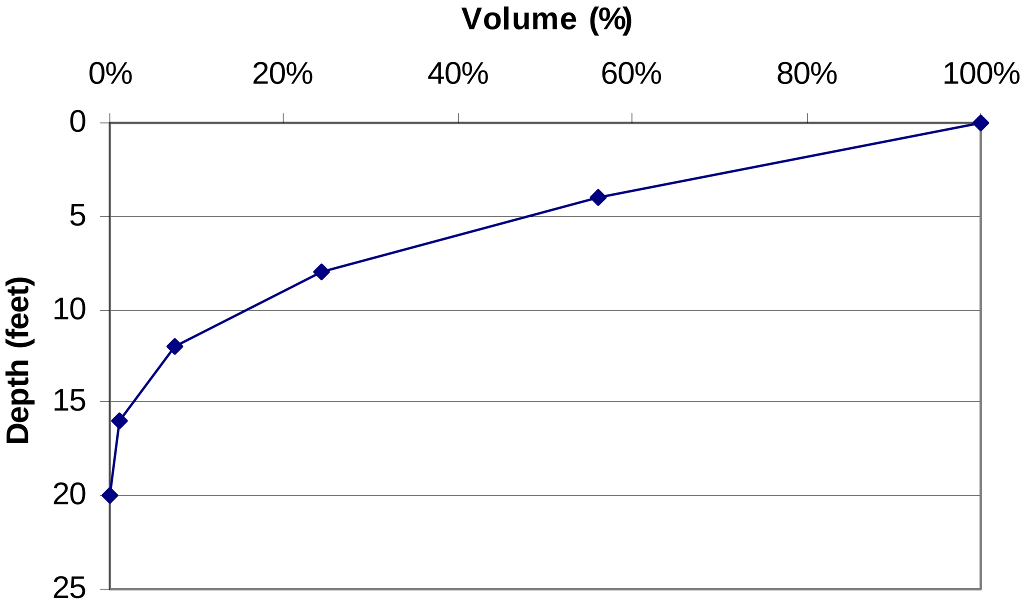


Figure 2.–Percent of volume at a given depth for Houghton Lake, Michigan. Data taken from MDNR, Digital Water Atlas.

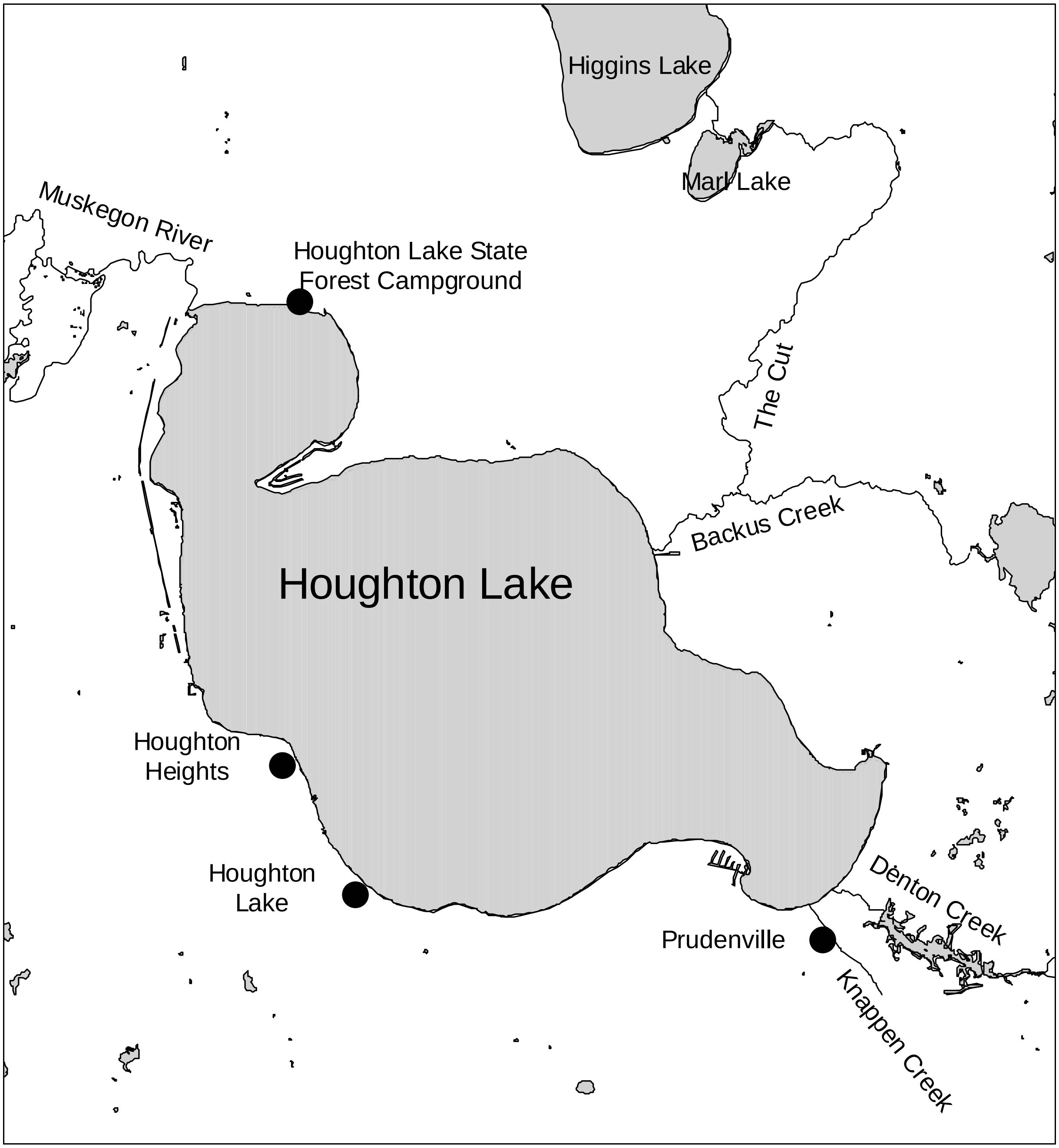
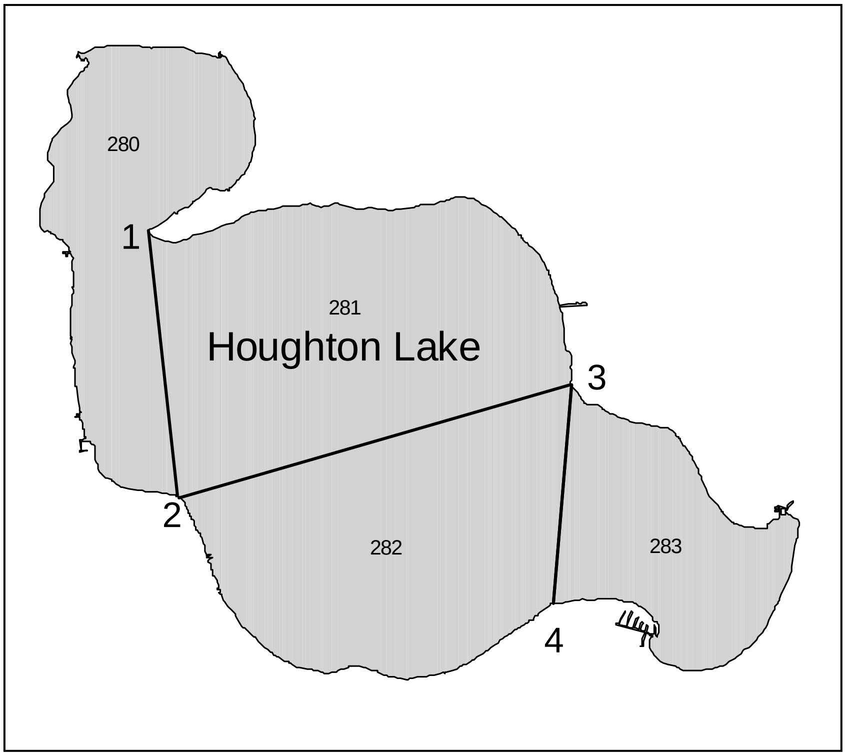


Figure 3.–Map of Houghton Lake, Roscommon County, Michigan.



Marker	Latitude	Longitude	Marker	Latitude	Longitude
1	44°22.24´N	84°46.59´W	3	44°20.74´N	84°40.99´W
2	44°19.69´N	84°46.18´W	4	44°18.53´N	84°41.50´W

Figure 4.–Houghton Lake count and interview grids used during winter 2001 and winter 2002 angler surveys. Markers indicate grid boundary line points.

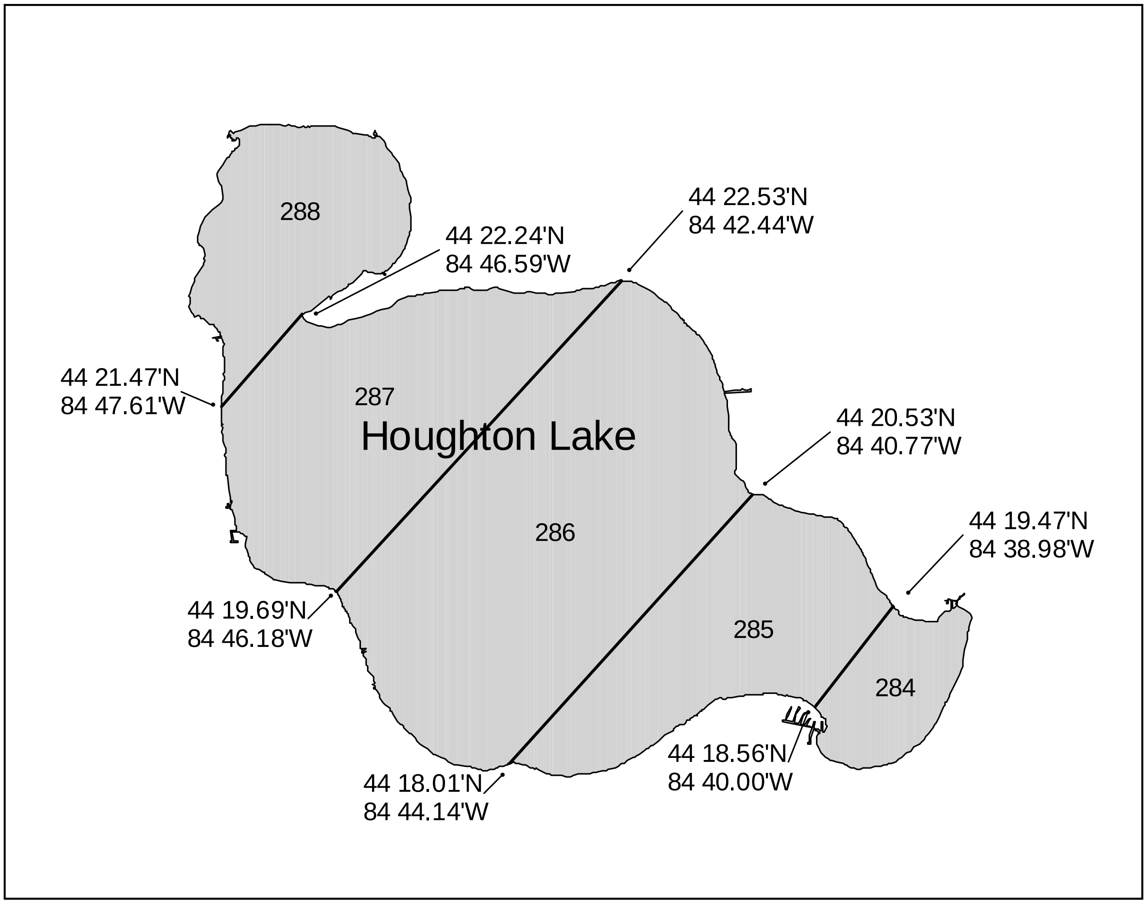
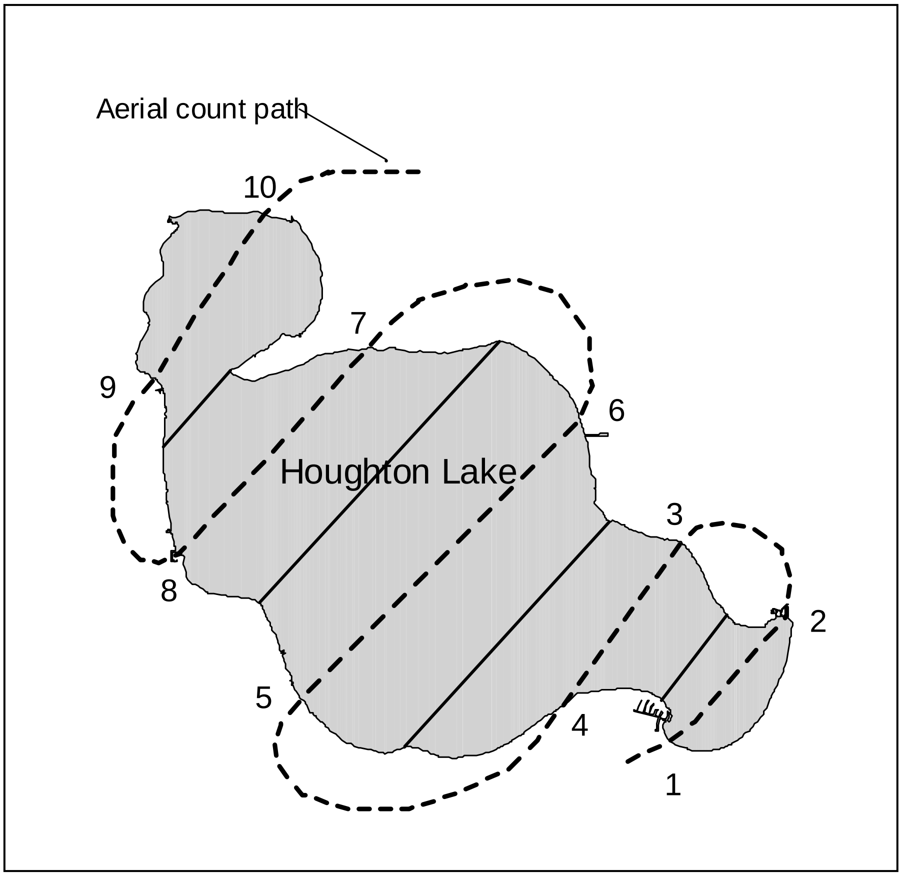


Figure 5.–Grid codes and boundary coordinates used during Houghton Lake angler creel survey, summer 2001.



Marker	Latitude	Longitude	Marker	Latitude	Longitude
1	44°18.11′ N	84°39.88′ W	6	44°21.58′ N	84°41.17′ W
2	44°19.43′ N	84°38.08′ W	7	44°22.49′ N	84°44.39′ W
3	44°20.30′ N	84°39.69′ W	8	44°20.21′ N	84°47.35′ W
4	44°18.52′ N	84°41.51′ W	9	44°22.15′ N	84°47.68′ W
5	44°18.55′ N	84°45.46′ W	10	44°24.00′ N	84°46.03′ W

Figure 6.–Aerial counting path, latitude and longitude coordinates for each of the 10 aerial counting path markers, and count and interview grids used during Houghton Lake angler creel survey, summer 2001.

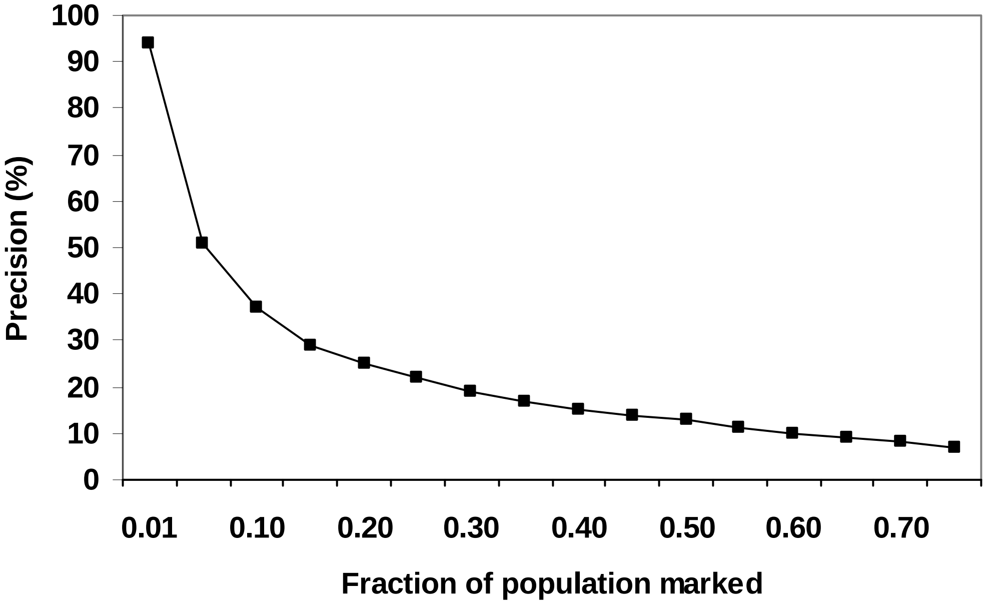
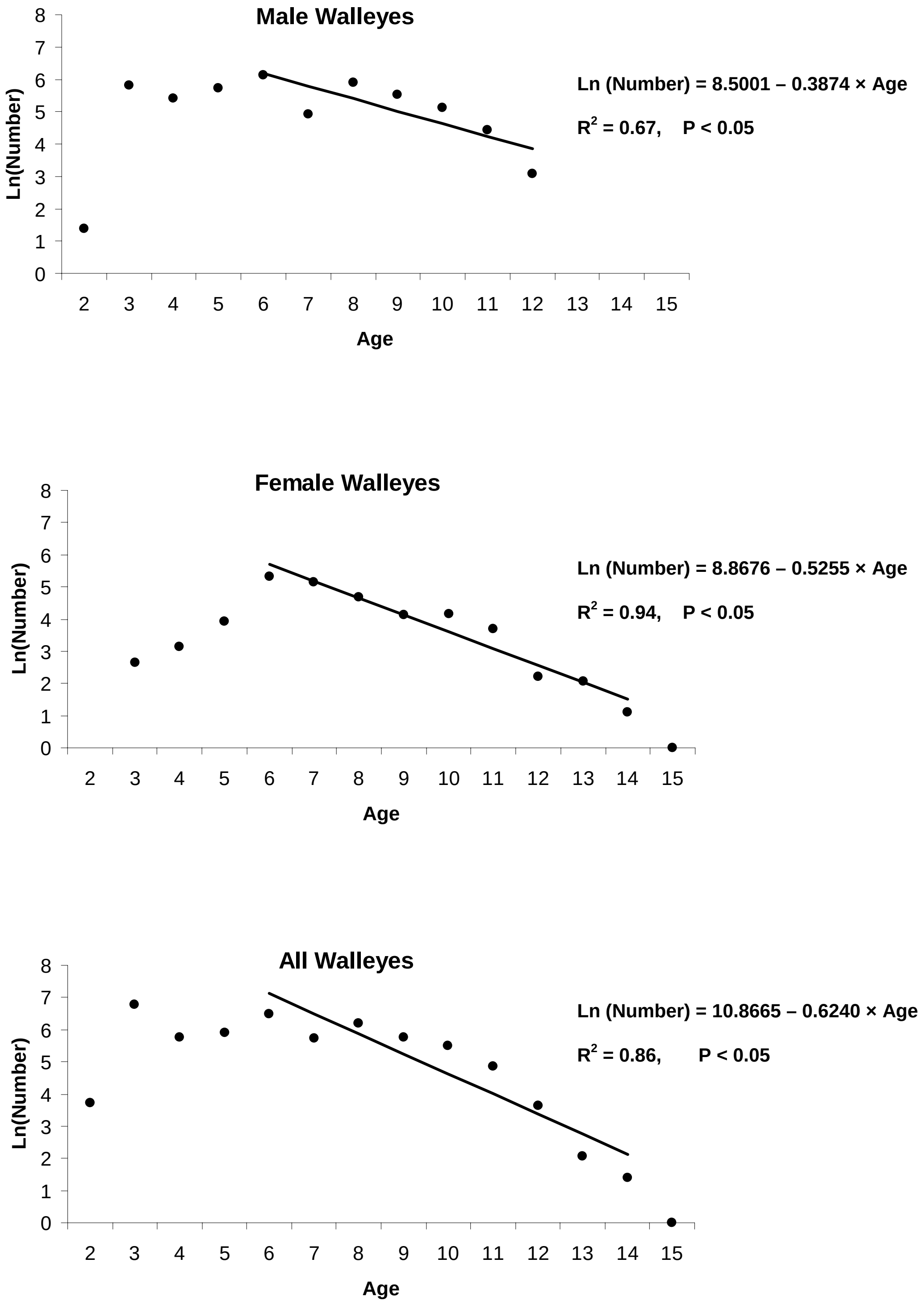


Figure 7.–Precision of walleye population estimate based on fraction of the population marked. Precision is expressed as a percentage and is the quotient of 2SE of the estimate with a given number marked and estimated population.


Male Walleyes

Ln (Number) = 8.5001 – 0.3874 × Age

$R^2 = 0.67$, $P < 0.05$

Female Walleyes

Ln (Number) = 8.8676 – 0.5255 × Age

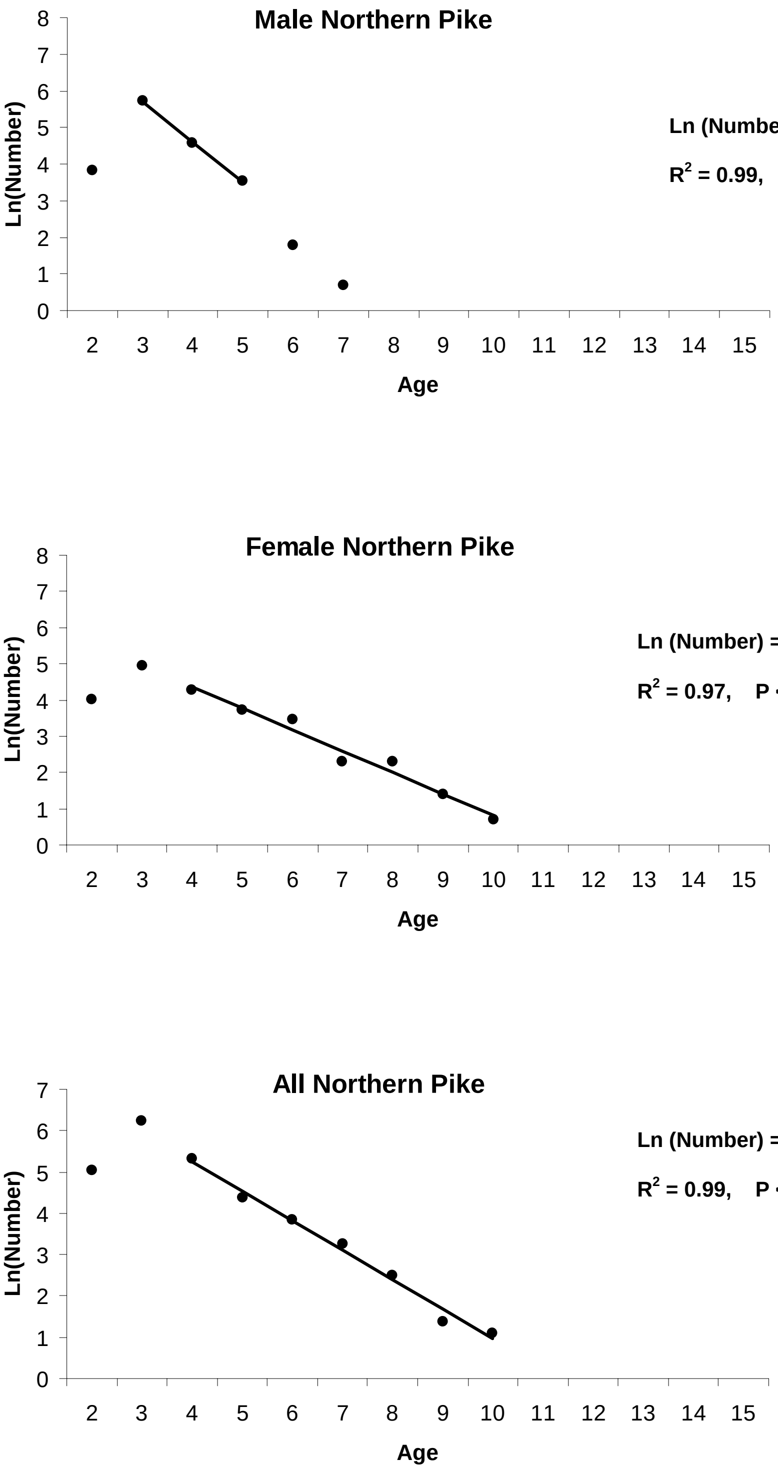
$R^2 = 0.94$, $P < 0.05$

All Walleyes

Ln (Number) = 10.8665 – 0.6240 × Age

$R^2 = 0.86$, $P < 0.05$

Figure 8.–Plots of observed ln(number) versus age for male, female, and all (including males, females, and unknown sex) walleyes. Lines are the descending limbs of catch-curve regressions with equations, coefficients of determination, and significance levels given beside each graph. Only points within ranges of lines were used in the catch-curve regression.



Ln (Number) = 8.9950 – 1.0970× Age

R^2 = 0.99, $P < 0.05$

Ln (Number) = 6.7211 – 0.5902 × Age

R^2 = 0.97, $P < 0.05$

Ln (Number) = 8.1025 – 0.7134 × Age

R^2 = 0.99, $P < 0.05$

Figure 9.–Plots of observed ln(number) versus age for male, female, and all (including males, females, and unknown sex) northern pike. Lines are the descending limbs of catch-curve regressions with equations, coefficients of determination, and significance levels given beside each graph. Only points within ranges of lines were used in the catch-curve regression.

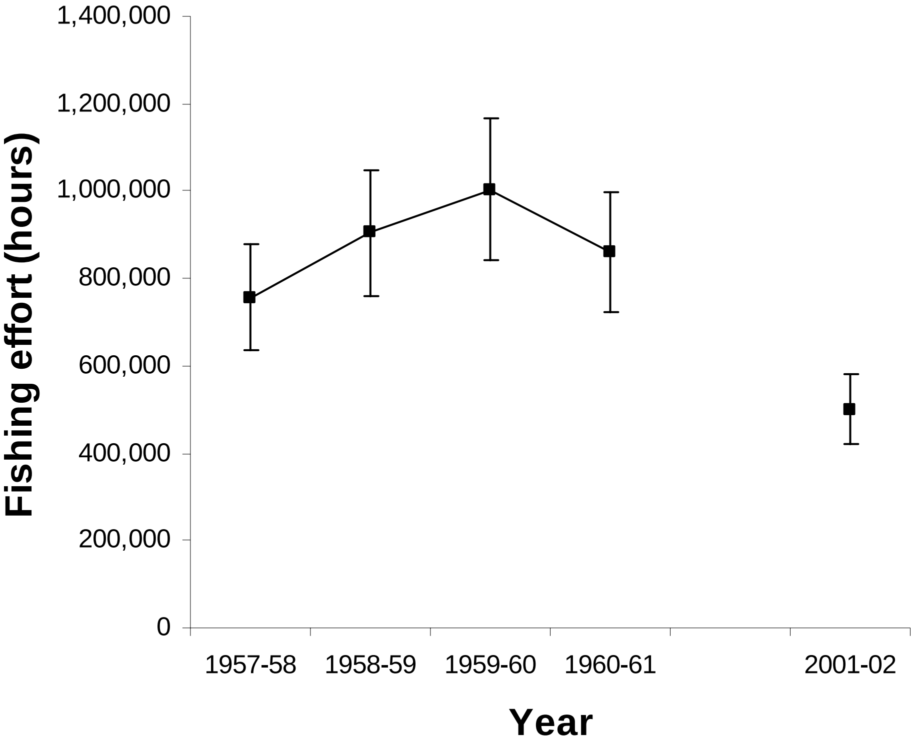
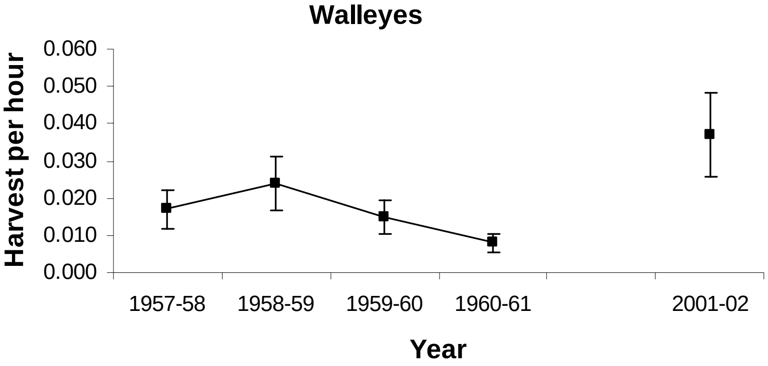
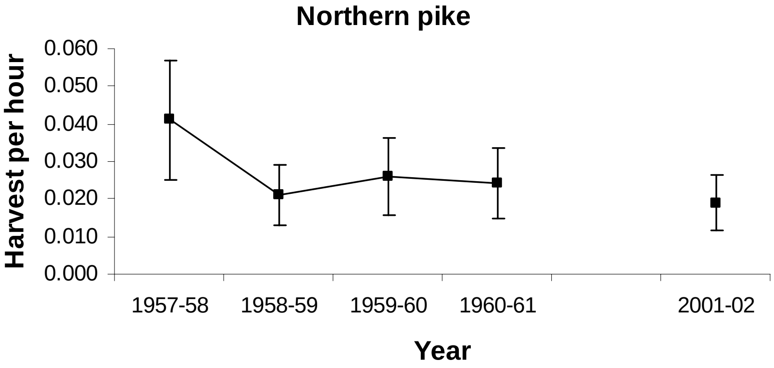


Figure 10.–Estimated fishing effort on Houghton Lake. Surveys in 1957-61 were conducted from June through September and mid-December through March of each year. Estimates for 1957-61 are those reported by Schneider and Lockwood (1979).





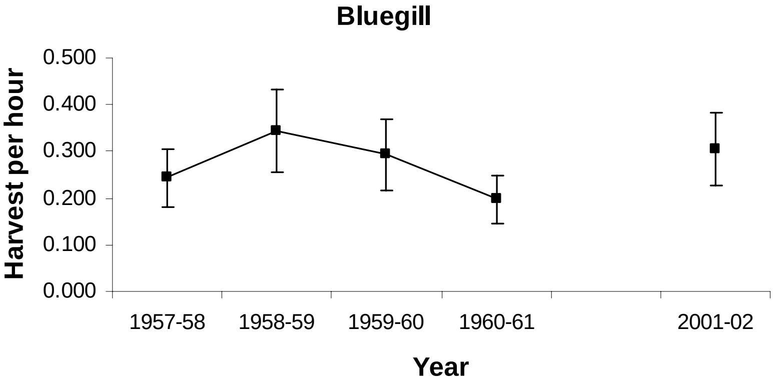


Figure 11.–Estimated catch per hour for various species on Houghton Lake. Surveys in 1957-61 were conducted from June through September and mid-December through March of each year. Estimates for 1957-61 are those reported by Schneider and Lockwood (1979). Minimum size limits in 1957-61 were 13 in, 20 in, 10 in, and 10 in for walleyes, northern pike, smallmouth bass, and largemouth bass, respectively. Minimum size limits in 2001-02 were 15 in, 24 in, 14 in, and 14 in for walleyes, northern pike, smallmouth bass, and largemouth bass, respectively. Daily bag limits were reduced for most species between 1961 and 2001.

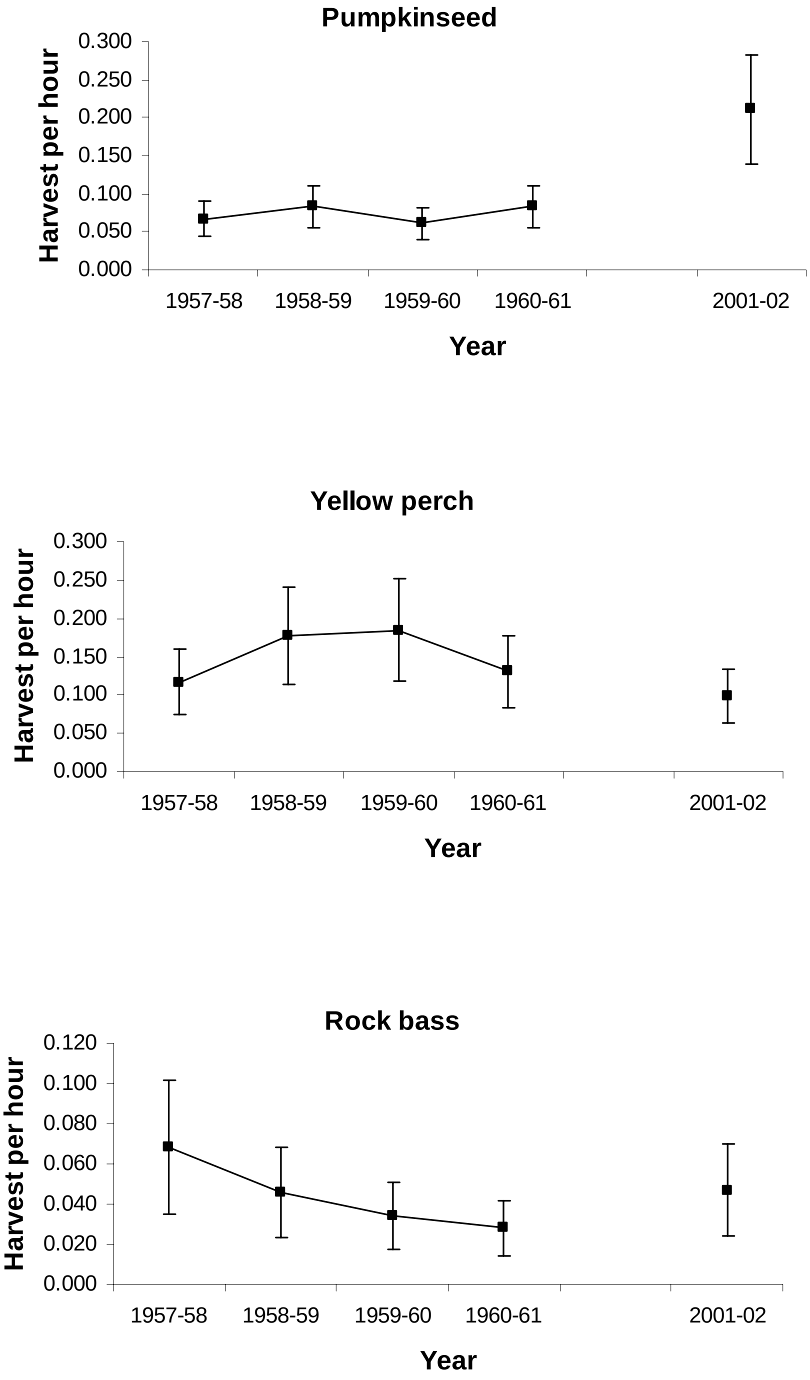
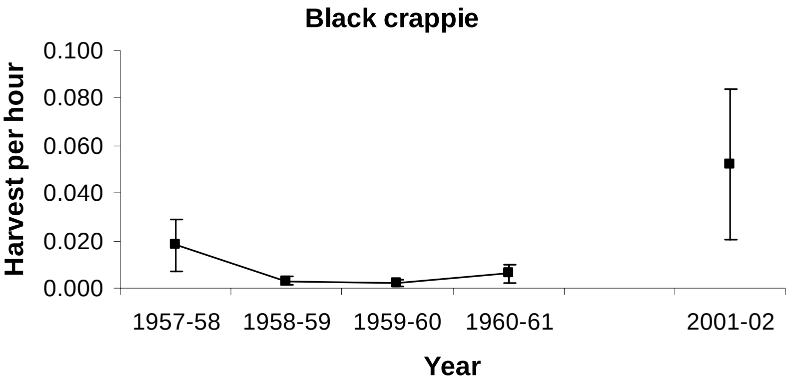
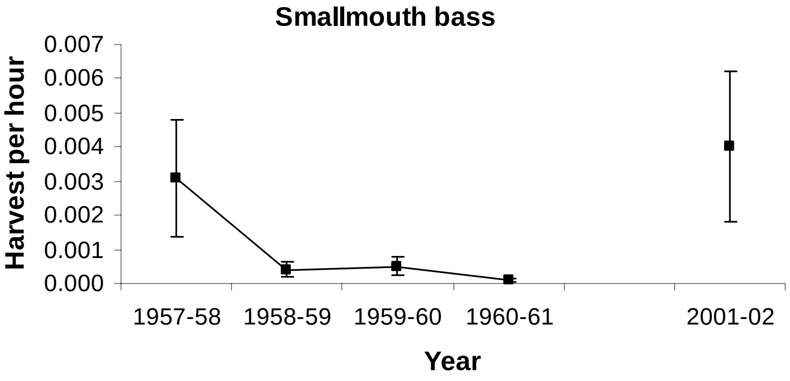


Figure 11.–Continued.





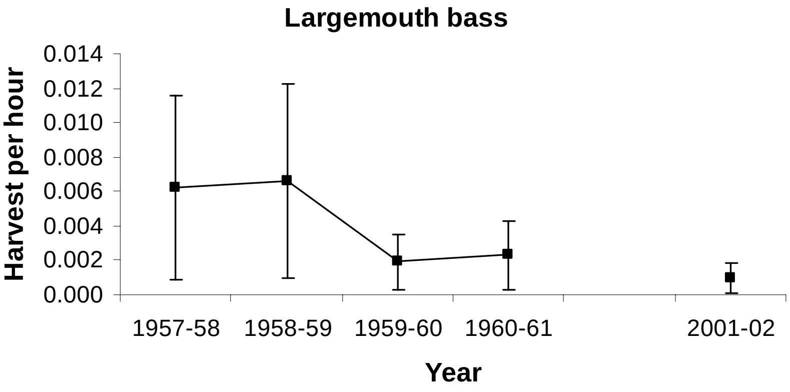


Figure 11.–Continued.

Table 1.–Lakes in Michigan that are 1,000 acres or larger. Lake size was taken from Michigan Digital Water Atlas (2003).

			Estimated annual fishing effort	
Lake/reservoir name	County	Acres	Angler hours	Year
Houghton	Roscommon	20,075	499,048	2001-02[a]
Torch	Antrim	18,722	–	–
Burt	Cheboygan	17,395	134,957	1993[b]
Charlevoix	Charlevoix	17,268	–	–
Mullett	Cheboygan	16,704	87,520	1998[b]
Gogebic	Ontonagon	13,127	121,525	1998-99[b]
Portage	Houghton	10,808	–	–
Big Manistique	Mackinac	10,346	64,691	1978-79[c]
Higgins	Roscommon	10,186	–	–
Black	Cheboygan	10,113	–	–
Crystal	Benzie	9,869	–	–
Hubbard	Alcona	8,768	–	–
Indian	Schoolcraft	8,647	–	–
Leelanau (North and South)	Leelanau	8,607	–	–
Elk	Grand Traverse	8,195	–	–
Fletcher Pond	Alpena	6,819	171,521	1997[b]
Glen	Leelanau	6,286	–	–
Grand	Presque Isle	5,822	–	–
Long	Alpena	5,342	–	–
Michigamme Reservoir	Iron	4,892	–	–
Hamlin	Mason	4,622	–	–
Walloon	Charlevoix	4,567	–	–
Brevoort	Mackinac	4,315	26,329	1996[b]
Lake Michigamme	Marquette	4,292	–	–
Muskegon	Muskegon	4,232	–	–
South Manistique	Mackinac	4,133	61,472	1978[c]
Siskiwit	Keweenaw	4,008	–	–
Douglas	Cheboygan	3,727	–	–
Long	Grand Traverse	2,911	–	–
Hardy Dam Pond	Newaygo	2,773	–	–
Skegemog	Kalkaska	2,766	–	–
Dead River Storage Basin	Marquette	2,737	–	–
Gun	Barry	2,735	–	–
Mitchell	Wexford	2,649	–	–
White	Muskegon	2,535	–	–
Platte	Benzie	2,532	–	–

Table 1.–Continued.

			Estimated annual fishing effort	
Lake/reservoir name	County	Acres	Angler hours	Year
Saint Helen	Roscommon	2,416	–	–
Torch	Houghton	2,400	–	–
Crooked	Emmet	2,352	–	–
Peavy Pond	Iron	2,347	–	–
Bond Falls Flowage	Ontonagon	2,127	7,812	1994[b]
Portage	Manistee	2,116	–	–
Gull	Kalamazoo	2,046	–	–
Independence	Marquette	2,041	–	–
Missaukee	Missaukee	2,035	46,772	1978[c]
Milakokia	Mackinac	2,031	–	–
Otsego	Otsego	2,013	33,557	1982[c]
Green	Grand Traverse	1,995	–	–
Duck	Grand Traverse	1,945	–	–
Margrethe	Crawford	1,922	–	–
Paradise	Emmet	1,912	–	–
Bear	Manistee	1,873	65,525	1964[d]
Macatawa	Ottawa	1,801	–	–
Bellaire	Antrim	1,789	–	–
North Manistique	Luce	1,709	–	–
Allegan	Allegan	1,695	–	–
Foote Dam Pond	Iosco	1,695	–	–
Cooke Dam Pond	Iosco	1,635	–	–
Tawas	Iosco	1,616	–	–
Coldwater	Branch	1,581	–	–
Intermediate	Antrim	1,571	–	–
Hodenpyl Dam Pond	Wexford	1,530	–	–
Cleveland Cliffs Basin	Alger	1,489	–	–
Gratiot	Keweenaw	1,452	–	–
McDonald	Schoolcraft	1,441	17,108	1977[c]
Betsy	Luce	1,426	–	–
Silver Lake Basin	Marquette	1,425	–	–
Van Etten	Iosco	1,409	–	–
Sanford	Midland	1,402	–	–
Devils	Lenawee	1,312	103,166	1953[d]
West Twin	Montmorency	1,306	–	–
Cass	Oakland	1,279	17,858	1982[c]
Belleville	Wayne	1,253	253,162	1978[e]

Table 1.–Continued.

			Estimated annual fishing effort	
Lake/reservoir name	County	Acres	Angler hours	Year
Lac La Belle	Keweenaw	1,205	–	–
Holloway Reservoir	Genesee	1,173	–	–
Cadillac	Wexford	1,172	–	–
Croton Dam Pond	Newaygo	1,129	–	–
Millecoquins	Mackinac	1,123	–	–
Austin	Kalamazoo	1,102	–	–
Spring	Ottawa	1,097	–	–
Tippy Dam Pond	Manistee	1,086	–	–
Chicagon	Iron	1,083	27,835	1993[b]
Pickerel	Emmet	1,082	–	–
Desor	Keweenaw	1,060	–	–
Empire Mine Tailings Basin	Marquette	1,058	–	–
Moss	Delta	1,054	–	–
Manistee	Manistee	1,051	20,884	1977-78[f]
Diamond	Cass	1,041	–	–
Perch	Iron	1,038	–	–
Kent	Livingston	1,015	191,134	1980[c]
East Unit, Crow Island	Saginaw	1,009	–	–
Thousand Island	Gogebic	1,009	35,301	1977[c]

[a] This study
[b] Lockwood (2000a)
[c] Ryckman and Lockwood (1985)
[d] Schneider and Lockwood (1979)
[e] Laarman (1979)
[f] Laarman (1980)

Table 2.–Number and size of walleye fingerlings stocked into Houghton Lake from 1987 through 2001. Mean length is the weighted mean length of lots planted for year.

Year	Number stocked	Mean length (inches)
1987	17,000	2.58
1988	75,200	2.64
1989	67,150	2.13
1990	125,469	1.85
1991	99,050	2.04
1992	0	na
1993	158,282	1.35
1994	10,000	2.56
1995	7,150	2.83
1996	0	na
1997	0	na
1998	0	na
1999	152,346	1.99
2000	0	na
2001	319,494	1.52

Table 3.–Survey periods, sampling shifts, and expansion value "F" (number of fishing hours within a sample day) for Houghton Lake angler creel survey, winter 2001 through winter 2002.

Survey period	Sample shifts		F
January 13 – February 28, 2001	0700-1530 h	0900-1730 h	12
March	0600-1430 h	1000-1830 h	12
April 28 – May 31	0600-1430 h	1330-2200 h	16
June	0600-1430 h	1330-2200 h	18
July	0600-1430 h	1300-2130 h	18
August	0630-1500 h	1230-2100 h	17
September	0630-1500 h	1200-2030 h	16
January 1 – February 14, 2002	0700-1530 h	1100-1930 h	13
February 15 – March 31	0700-1530 h	1100-1930 h	13

Table 4.–Angler survey estimates for winter 2001 from Houghton Lake. Survey period was January 13 through March 31, 2001. Two standard errors are given in parentheses.

Species	Catch/hour	Jan-Feb	Mar	Season
		Number harvested		
Walleyes	0.0454 (0.0261)	2,176 (703)	1,408 (1,809)	3,584 (1,941)
Yellow perch	0.1910 (0.0672)	10,703 (2,629)	4,367 (3,572)	15,070 (4,435)
Northern pike	0.0152 (0.0064)	1,168 (445)	32 (13)	1,200 (445)
Black crappie	0.0588 (0.0263)	1,128 (537)	3,515 (1,795)	4,643 (1,874)
Bluegill	0.2673 (0.1297)	4,008 (2,274)	17,081 (9,120)	21,089 (9,399)
Pumpkinseed	0.0507 (0.0230)	1,820 (1,017)	2,182 (1,294)	4,002 (1,646)
Rock bass	0.0046 (0.0031)	226 (206)	136 (106)	362 (231)
Total harvest	0.6330 (0.1839)	21,229 (3,759)	28,721 (10,202)	49,950 (10,872)
		Fishing effort		
Angler hours		58,211 (11,276)	20,697 (10,171)	78,908 (15,186)
Angler trips		17,403 (3,441)	6,187 (3,061)	23,590 (4,605)

Table 5.–Angler survey estimates for summer 2001 from Houghton Lake. Survey period was April 28 through September 30, 2001. Two standard errors are given in parentheses.

Species	Catch/hour	Apr-May	June	July	August	September	Season
		Number harvested					
Smallmouth bass	0.0068 (0.0037)	396 (473)	261 (283)	596 (533)	425 (491)	210 (423)	1,888 (1,004)
Walleyes	0.0485 (0.0164)	2,498 (975)	1,249 (570)	4,304 (2,902)	2,301 (1,696)	3,134 (2,556)	13,486 (4,371)
Yellow perch	0.1055 (0.0522)	1,291 (743)	4,147 (2,355)	10,476 (8,950)	11,665 (10,703)	1,759 (1,545)	29,338 (14,253)
Northern pike	0.0059 (0.0063)	191 (139)	208 (226)	807 (1,625)	365 (535)	75 (296)	1,646 (1,756)
Black crappie	0.0625 (0.0508)	2,948 (1,345)	1,562 (794)	2,473 (2,231)	7,344 (12,355)	3,049 (6,098)	17,376 (14,044)
Bluegill	0.4870 (0.1170)	3,935 (1,453)	12,645 (4,669)	67,249 (23,042)	46,311 (16,924)	5,343 (7,189)	135,483 (29,882)
Largemouth bass	0.0012 (0.0011)	0 (0)	211 (250)	56 (22)	0 (0)	73 (151)	340 (293)
Pumpkinseed	0.3709 (0.1204)	969 (565)	7,095 (2,864)	51,539 (22,310)	25,417 (13,304)	18,156 (18,507)	103,176 (32,028)
Rock bass	0.0796 (0.0397)	542 (317)	751 (759)	16,380 (10,431)	4,273 (2,829)	201 (269)	22,147 (10,842)
White sucker	0.0010 (0.0019)	0 (0)	0 (0)	0 (0)	268 (534)	0 (0)	268 (534)
Total harvest	1.1687 (0.2103)	12,770 (2,466)	28,129 (6,103)	153,880 (35,126)	98,369 (27,245)	32,000 (20,990)	325,148 (49,599)
		Number caught and released					
Smallmouth bass	0.0041 (0.0034)	30 (14)	284 (248)	289 (415)	0 (0)	543 (810)	1,146 (943)
Largemouth bass	0.0033 (0.0026)	32 (17)	226 (272)	390 (582)	84 (103)	193 (278)	925 (707)
Walleyes	0.0057 (0.0047)	0 (0)	0 (0)	0 (0)	1,585 (1,285)	0 (0)	1,585 (1,285)
Northern pike	0.0017 (0.0016)	37 (13)	0 (0)	0 (0)	433 (442)	0 (0)	470 (443)
Total catch and release	0.0148 (0.0066)	99 (25)	510 (367)	679 (713)	2,102 (1,362)	736 (856)	4,126 (1,798)
Total (harvest + release)	1.1835 (0.2112)	12,869 (2,466)	28,639 (6,115)	154,559 (35,134)	100,471 (27,278)	32,736 (21,008)	329,274 (49,631)
		Fishing effort					
Angler hours		36,135 (8,279)	50,201 (9,742)	115,886 (19,022)	53,155 (10,760)	22,837 (8,041)	278,214 (26,566)
Angler trips		10,633 (3,197)	14,990 (3,367)	54,614 (12,606)	19,417 (7,230)	7,315 (3,236)	106,969 (15,595)

Table 6.–Angler survey estimates for winter 2002 from Houghton Lake. Survey period was from January 1 through March 31, 2002. Two standard errors are given in parentheses.

Species	Catch/hour		Jan-Feb14		Feb15-Mar		Season	
			Number Harvested					
Walleyes	0.0216	(0.0099)	3,364	(1,262)	1,415	(781)	4,779	(1,484)
Yellow perch	0.0904	(0.0429)	12,972	(5,732)	6,982	(3,474)	19,954	(6,702)
Northern pike	0.0346	(0.0171)	4,729	(1,884)	2,916	(2,028)	7,645	(2,768)
Black crappie	0.0395	(0.0306)	1,704	(925)	7,028	(6,012)	8,732	(6,082)
Bluegill	0.0759	(0.0470)	1,556	(1,382)	15,198	(8,622)	16,754	(8,732)
Pumpkinseed	0.0088	(0.0066)	195	(125)	1,758	(1,293)	1,953	(1,299)
Rock bass	0.0060	(0.0040)	612	(420)	710	(625)	1,322	(753)
Total harvest	0.2769	(0.1100)	25,132	(6,398)	36,007	(11,372)	61,139	(13,048)
			Number caught and released					
Smallmouth bass	0.0001	(0.0002)	15	(41)	0	(0)	15	(41)
Northern pike	0.0101	(0.0089)	77	(46)	2,153	(1,825)	2,230	(1,826)
Total catch and release	0.0102	(0.0089)	92	(61)	2,153	(1,825)	2,245	(1,826)
Total (harvest + release)	0.2870	(0.1132)	25,224	(6,398)	38,160	(11,517)	63,384	(13,175)
			Fishing effort					
Angler hours			140,065	(53,854)	80,769	(50,763)	220,834	(74,008)
Angler trips			57,962	(22,285)	34,125	(19,820)	92,087	(29,824)

Table 7.–Angler survey estimates for summer and winter 2001-02 from Houghton Lake. Survey period was April 28 to September 30, 2001 and January 1 to March 31, 2002. Two standard errors are given in parentheses.

		2001					2002		
Species	Catch/hour	Apr-May	Jun	Jul	Aug	Sep	Jan.-Feb 14	Feb. 15-Mar	Season
		Number harvested							
Smallmouth bass	0.0038 (0.0021)	396 (473)	261 (283)	596 (533)	425 (491)	210 (423)	0 (0)	0 (0)	1,888 (1,004)
Walleyes	0.0366 (0.0109)	2,498 (975)	1,249 (570)	4,304 (2,902)	2,301 (1,696)	3,134 (2,556)	3,364 (1,262)	1,415 (781)	18,265 (4,616)
Yellow perch	0.0988 (0.0352)	1,291 (743)	4,147 (2,355)	10,476 (8,950)	11,665 (10,703)	1,759 (1,545)	12,972 (5,732)	6,982 (3,474)	49,292 (15,750)
Northern pike	0.0186 (0.0072)	191 (139)	208 (226)	807 (1,625)	365 (535)	75 (296)	4,729 (1,884)	2,916 (2,028)	9,291 (3,278)
Black crappie	0.0523 (0.0318)	2,948 (1,345)	1,562 (794)	2,473 (2,231)	7,344 (12,355)	3,049 (6,098)	1,704 (925)	7,028 (6,012)	26,108 (15,305)
Bluegill	0.3051 (0.0788)	3,935 (1,453)	12,645 (4,669)	67,249 (23,042)	46,311 (16,924)	5,343 (7,189)	1,556 (1,382)	15,198 (8,622)	152,237 (31,132)
Largemouth bass	0.0007 (0.0006)	0 (0)	211 (250)	56 (22)	0 (0)	73 (151)	0 (0)	0 (0)	340 (293)
Pumpkinseed	0.2107 (0.0723)	969 (565)	7,095 (2,864)	51,539 (22,310)	25,417 (13,304)	18,156 (18,507)	195 (125)	1,758 (1,293)	105,129 (32,054)
Rock bass	0.0470 (0.0230)	542 (317)	751 (759)	16,380 (10,431)	4,273 (2,829)	201 (269)	612 (420)	710 (625)	23,469 (10,869)
White sucker	0.0005 (0.0011)	0 (0)	0 (0)	0 (0)	268 (534)	0 (0)	0 (0)	0 (0)	268 (534)
Total harvest	0.7740 (0.1595)	12,770 (2,466)	28,129 (6,103)	153,880 (35,126)	98,369 (27,245)	32,000 (20,990)	25,132 (6,398)	36,007 (11,372)	386,287 (51,286)
		Number caught and released							
Smallmouth bass	0.0023 (0.0019)	30 (14)	284 (248)	289 (415)	0 (0)	543 (810)	15 (41)	0 (0)	1,161 (944)
Largemouth bass	0.0019 (0.0014)	32 (17)	226 (272)	390 (582)	84 (103)	193 (278)	0 (0)	0 (0)	925 (708)
Walleyes	0.0032 (0.0026)	0 (0)	0 (0)	0 (0)	1,585 (1,285)	0 (0)	0 (0)	0 (0)	1,585 (1,285)
Northern pike	0.0054 (0.0039)	37 (13)	0 (0)	0 (0)	433 (442)	0 (0)	77 (46)	2,153 (1,825)	2,700 (1,878)
Total catch and release	0.0128 (0.0055)	99 (25)	510 (367)	679 (713)	2,102 (1,362)	736 (856)	92 (61)	2,153 (1,825)	6,371 (2,562)
Total (harvest + release)	0.7868 (0.1611)	12,869 (2,466)	28,639 (6,115)	154,559 (35,134)	100,471 (27,278)	32,736 (21,008)	25,224 (6,398)	38,160 (11,517)	392,658 (51,350)
		Fishing effort							
Angler hours		36,135 (8,279)	50,201 (9,742)	115,886 (19,022)	53,155 (10,760)	22,837 (8,041)	140,065 (53,854)	80,769 (50,763)	499,048 (78,631)
Angler trips		10,633 (3,197)	14,990 (3,367)	54,614 (12,606)	19,417 (7,230)	7,315 (3,236)	57,962 (22,285)	34,125 (19,820)	199,056 (33,655)

Table 8.–Fish collected from Houghton Lake using a total sampling effort of 265 trap net lifts, 159 fyke net lifts, and 14 electrofishing runs from April 9 to May 1, 2001.

Species	Total catch[a]	Percent by number	Mean CPUE[b]		Length (in)		Number measured
			Trap-net	Fyke-net	Range	Average	
Walleyes	4,426	31.1	6.9	6.7	9.8-29.1	16.3	4,346
Northern pike	1,199	8.4	2.9	1.4	9.0-41.4	22.4	1,174
Bowfin	1,991	14.0	3.6	4.4	11.2-29.4	23.2	346
Black crappie	1,865	13.1	4.9	2.0	4.6-14.0	10.4	557
White sucker	1,072	7.5	1.6	2.4	11.4-24.2	18.7	350
Bluegill	1,011	7.1	2.2	1.8	2.3-9.7	7.2	248
Rock bass	769	5.4	1.4	1.9	3.5-12.4	7.4	420
Smallmouth bass	571	4.0	1.1	0.8	7.4-20.4	15.9	219
Largemouth bass	514	3.6	1.2	0.6	7.2-20.3	14.1	219
Pumpkinseed	432	3.0	0.7	1.2	4.2-8.8	6.9	272
Yellow perch	179	1.3	0.2	0.5	5.2-12.4	7.9	137
Brown bullhead	95	0.7	0.2	0.2	10.3-14.2	12.3	38
Yellow bullhead	60	0.4	<0.1	0.3	7.8-13.1	10.8	37
Common carp	43	0.3	0.1	<0.1	17.0-34.3	28.0	31
Black bullhead	8	0.1	<0.1	<0.1	6.3-12.0	9.3	4
Longnose gar	7	0.1	<0.1	<0.1	26.0-35.6	31.8	5
Golden shiner	7	0.1	<0.1	<0.1	5.0-7.0	6.0	2
Longnose sucker	1	<0.1	<0.1	<0.1	16.8	16.8	1
Rainbow trout	2	<0.1	<0.1	0	25.0	25.0	1
Channel catfish	1	<0.1	<0.1	0	–	–	0

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

Table 9.–Number of fish per inch group caught and measured in spring netting and electrofishing operations on Houghton Lake, April 9 to May 1, 2001.

	Species																		
Inch group	Walleyes	Northern pike	Bowfin	Black crappie	White sucker	Bluegill	Rockbass	Smallmouth bass	Largemouth bass	Pumpkin-seed	Yellow perch	Brown bullhead	Yellow bullhead	Common carp	Black bullhead	Longnose gar	Golden shiner	Longnose sucker	Rainbow trout
2	–	–	–	–	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–
3	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–
4	–	–	–	1	–	9	5	–	–	8	–	–	–	–	–	–	–	–	–
5	–	–	–	4	–	24	67	–	–	37	7	–	–	–	–	–	1	–	–
6	–	–	–	7	–	72	96	–	–	90	22	–	–	–	1	–	–	–	–
7	–	–	–	31	–	67	134	4	4	109	59	–	1	–	–	–	1	–	–
8	–	–	–	55	–	57	52	3	3	26	21	–	5	–	1	–	–	–	–
9	2	1	–	132	–	17	24	2	–	1	12	–	5	–	–	–	–	–	–
10	32	–	–	90	–	–	30	1	3	–	7	1	6	–	1	–	–	–	–
11	27	1	1	129	1	–	8	3	5	–	6	15	10	–	–	–	–	–	–
12	169	–	–	83	2	–	3	6	36	–	3	12	9	–	1	–	–	–	–
13	531	6	–	24	8	–	–	15	49	–	–	7	1	–	–	–	–	–	–
14	410	4	–	1	7	–	–	28	49	–	–	3	–	–	–	–	–	–	–
15	599	8	1	–	12	–	–	32	41	–	–	–	–	–	–	–	–	–	–
16	840	22	–	–	34	–	–	44	17	–	–	–	–	–	–	–	–	1	–
17	773	28	2	–	54	–	–	39	7	–	–	–	–	1	–	–	–	–	–
18	463	81	14	–	54	–	–	22	2	–	–	–	–	–	–	–	–	–	–
19	209	112	22	–	57	–	–	17	2	–	–	–	–	1	–	–	–	–	–
20	98	155	24	–	84	–	–	3	1	–	–	–	–	–	–	–	–	–	–
21	48	141	48	–	29	–	–	–	–	–	–	–	–	–	–	–	–	–	–
22	17	133	47	–	6	–	–	–	–	–	–	–	–	–	–	–	–	–	–
23	20	97	44	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–
24	17	88	40	–	1	–	–	–	–	–	–	–	–	1	–	–	–	–	–
25	9	50	49	–	–	–	–	–	–	–	–	–	–	4	–	–	–	–	1
26	6	33	33	–	–	–	–	–	–	–	–	–	–	1	–	1	–	–	–
27	2	32	16	–	–	–	–	–	–	–	–	–	–	7	–	–	–	–	–
28	3	26	4	–	–	–	–	–	–	–	–	–	–	4	–	–	–	–	–
29	1	18	1	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–
30	–	14	–	–	–	–	–	–	–	–	–	–	–	4	–	1	–	–	–
31	–	6	–	–	–	–	–	–	–	–	–	–	–	3	–	–	–	–	–
32	–	5	–	–	–	–	–	–	–	–	–	–	–	3	–	1	–	–	–
33	–	5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
34	–	6	–	–	–	–	–	–	–	–	–	–	–	1	–	1	–	–	–
35	–	5	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–
36	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
37	–	4	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
38	–	3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
39	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
40	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
41	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Total	4,276	1,087	346	557	350	248	420	219	219	271	137	38	37	31	4	5	2	1	1

Table 10.–Estimates of abundance, angler exploitation rates, and instantaneous fishing mortality rates for Houghton Lake walleyes and northern pike using the different methods described in text. Estimated 95% confidence intervals for estimates are given in parentheses.

	Walleyes	Northern pike
Number tagged	3,087	287
Total tag returns	294	40
Number of legal-sized[a] fish:		
Multiple census method	38,656 (31,806 - 49,265)	1,575 (975 - 4,094)
Single-census method	58,854 (32,288 – 85,419)	10,584 (1,357 – 19,811)
Number of adult[b] fish:		
Multiple census method	50,109 (41,331 – 63,619)	5,696 (2,360 – 9,032)
Single-census method	68,495 (37,693 – 99,297)	32,846 (4,450 – 61,242)
Wisconsin equation	59,576 (19,215 - 184,715)	na
Annual exploitation rates:		
Based on reward tag returns	10.6%	18.2%
Based on harvest/abundance[c]	27.3% (13.0% – 41.6%)	44.7% (1.9% – 87.4%)
Instantaneous fishing rates (F):		
Based on reward tag returns	0.1120	0.2009
Based on harvest/abundance[c]	0.3188	0.5888

[a] Walleyes ≥15 in and northern pike ≥24 in.

[b] Estimated numbers of fish, both legal size and sexually mature sublegal size, on spawning grounds in April-May 2001.

[c] Single-census estimate of abundance.

Table 11.–Weighted mean lengths and sample sizes (number aged) by age and sex for walleyes collected from Houghton Lake, April 9 to May 1, 2001. Standard errors for mean lengths are in parentheses.

	Mean length (SE)			Number aged		
Age	Males	Females	All[a]	Males	Females	All[a]
2	13.0 (–)	–	11.0 (0.8)	1	–	17
3	13.7 (0.8)	13.9 (0.6)	13.6 (0.8)	40	12	102
4	14.8 (1.2)	14.7 (1.1)	14.5 (1.2)	18	12	36
5	15.6 (0.6)	16.1 (0.6)	15.8 (0.7)	15	14	30
6	16.2 (0.7)	17.7 (1.2)	16.8 (1.1)	16	32	50
7	16.8 (0.9)	18.2 (1.2)	17.6 (1.2)	6	28	35
8	17.4 (0.8)	19.1 (1.4)	18.1 (1.3)	20	25	49
9	17.6 (0.9)	19.9 (1.6)	18.4 (1.6)	18	22	43
10	17.4 (0.6)	21.2 (2.4)	18.9 (2.3)	8	34	46
11	18.3 (0.7)	21.5 (2.2)	19.4 (1.9)	10	22	33
12	18.5 (0.1)	23.5 (2.3)	19.9 (2.4)	2	7	11
13	–	26.0 (2.1)	25.7 (2.2)	–	7	7
14	–	26.2 (2.5)	26.8 (2.4)	–	3	4
15	–	26.0 (–)	26.0 (–)	–	1	1

[a] Includes fish of unknown sex.

Table 12.–Weighted mean lengths and sample sizes (number aged) by age and sex for northern pike collected from Houghton Lake, April 9 to May 1, 2001. Standard errors for mean lengths are in parentheses.

	Mean length (SE)			Number aged		
Age	Males	Females	All[a]	Males	Females	All[a]
2	18.0 (1.0)	19.4 (2.2)	19.3 (1.8)	15	34	60
3	20.5 (1.9)	23.4 (2.3)	21.6 (2.6)	76	75	169
4	21.7 (1.3)	25.2 (3.3)	23.5 (2.9)	28	47	89
5	22.4 (2.2)	27.1 (3.3)	24.9 (3.5)	15	31	49
6	25.2 (1.5)	29.3 (3.3)	28.5 (3.6)	5	24	34
7	23.0 (–)	32.2 (3.9)	31.2 (4.3)	1	10	18
8	–	33.3 (4.3)	32.2 (4.9)	–	8	9
9	–	38.0 (4.0)	38.8 (3.8)	–	2	2
10	–	41.0 (–)	40.0 (1.4)	–	1	2

[a] Includes fish of unknown sex.

Table 13.–Catch-at-age estimates (apportioned by length-age key) for walleyes and northern pike collected with trap and fyke nets and electrofishing gear from Houghton Lake, April 9 to May 1, 2001.

	Year-	Walleyes			Northern pike		
Age	class	Males	Females	All[a]	Males	Females	All[a]
2	1999	4	–	41	46	56	155
3	1998	330	14	887	305	141	512
4	1997	224	23	314	97	71	203
5	1996	304	51	368	34	41	79
6	1995	453	207	666	6	32	47
7	1994	138	170	309	2	10	26
8	1993	364	109	486	–	10	12
9	1992	250	62	319	–	4	4
10	1991	167	64	246	–	2	3
11	1990	84	40	127	–	–	–
12	1989	22	9	38	–	–	–
13	1988	–	8	8	–	–	–
14	1987	–	3	4	–	–	–
15	1986	–	1	1	–	–	–
Totals		2,340	761	3,814	490	367	1,041

[a] Includes fish of unknown sex.

Table 14.–Comparison of recreational fishing effort and total harvest on Houghton Lake to those of selected other Michigan lakes. Lakes are listed from highest to lowest total fishing effort. Lake size was from Laarman (1976).

Lake, County	Size (acres)	Survey period	Total fishing effort (h)	Fish harvested (number)	Fish harvested per hour	Hours fished per acre	Fish harvested per acre
Michigan[a], many	–	Jan - Nov, 2001	2,684,359	677,360	0.25	–	–
Huron[a], many	–	Jan - Oct, 2001	1,807,519	1,057,819	0.59	–	–
Houghton, Roscommon (all year)	20,075	Apr 2001 - Mar 2002	499,048	386,287	0.77	24.9	19.2
Erie[a], Wayne and Monroe	–	Apr - Oct, 2001	490,807	378,700	0.77	–	–
Houghton, Roscommon (summer only)	20,075	Apr - Sep, 2001	278,214	325,148	1.17	13.9	16.2
Superior[a], many	–	Apr - Oct, 2001	180,428	60,947	0.34	–	–
Fletcher Pond, Alpena and Montmorency	8,970	May - Sep, 1997	171,521	118,101	0.69	19.1	13.2
Burt, Cheboygan	17,120	Apr - Sep, 1993	134,957	20,734	0.15	7.9	1.2
Gogebic, Ontonagon and Gogebic	13,380	May 1998 - Apr 1999	121,525	26,622	0.22	9.1	2.0
Mullett, Cheboygan	16,630	May - Aug, 1998	87,520	18,727	0.21	5.3	1.1

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

Table 15.–General fish surveys conducted on Houghton Lake by MDNR, Fisheries Division.

Time period	Gears	Reference
October 1935	Seine	Laarman (1976)
September 1938	Seine	Laarman (1976)
September 1941	Seine	Laarman (1976)
July 1948	Trap and/or fyke nets	Laarman (1976)
May 17 - June 18, 1955	Trap nets	Crowe and Latta (1956); Laarman (1976)
September - October 1956	Seine	Laarman (1976)
September 1960	Seine	Laarman (1976)
May 22 - 24, 1962	Trap and/or fyke nets; electrofishing	Laarman (1976); Schrouder (1993)
June - July 1967	Trap and/or fyke nets; electrofishing	Laarman (1976); Schrouder (1993)
June 1 - 2, 1972	Trap and fyke nets at index stations	Laarman (1976); Schrouder (1993)
June 7 - 10, 1983	Trap and fyke nets at index stations	Schrouder (1993)
June 1 - 10, 1993	Trap and fyke nets at index stations;experimental gill nets	Schrouder (1993)
June 16 - 18, 1998	Trap and fyke nets; electrofishing	MDNR, Fish Collection System
April 9 - May 1, 2001	Trap and fyke nets; electrofishing	This report

Table 16.–Mean lengths for walleyes from Houghton Lake from our survey compared to previous surveys. See Table 15 for survey references. Number aged in parentheses.

Age	State average[a]	Mean lengths from survey years						
		2001[b]	1998[c]	1993[c]	1983[d]	1972[d]	1962[d]	1955[d]
2	10.4	11.0 (17)	11.7 (1)	10.1 (33)	11.9 (5)	— (0)	10.3 (2)	10.4 (3)
3	13.9	13.6 (102)	13.5 (21)	13.6 (34)	14.1 (19)	13.5 (4)	12.7 (28)	12.4 (26)
4	15.8	14.5 (36)	15.6 (11)	15.5 (29)	15.9 (20)	16.1 (8)	16.0 (5)	14.3 (9)
5	17.6	15.8 (30)	16.9 (4)	17.3 (23)	17.9 (11)	— (0)	17.9 (6)	15.0 (6)
6	19.2	16.8 (50)	17.9 (7)	18.4 (24)	19.3 (12)	19.0 (4)	18.2 (4)	15.9 (11)
7	20.6	17.6 (35)	20.0 (4)	17.5 (2)	20.6 (2)	20.0 (2)	19.7 (6)	16.6 (4)
8	21.6	18.1 (49)	22.8 (1)	— (0)	22.2 (7)	20.3 (2)	19.7 (2)	19.7 (5)
9	22.4	18.4 (43)	24.9 (3)	21.3 (2)	22.7 (4)	21.3 (2)	23.0 (2)	19.8 (2)
10	23.1	18.9 (46)	27.1 (1)	22.8 (1)	24.2 (4)	22.0 (1)	24.7 (1)	
11		19.4 (33)		— (0)	26.5 (3)			
12		19.9 (11)		23.4 (1)				
13		25.7 (7)		— (0)				
14		26.8 (4)		28.9 (1)				
15		25.6 (1)						

[a] Jan-May averages from Schneider et al. (2000).
[b] All fish aged with spines.
[c] Fish < 18 in aged with scales. Fish ≥18 aged with spines.
[d] All fish aged with scales.

Table 17.–Mean lengths for northern pike from Houghton Lake from our survey compared to previous surveys. See Table 15 for survey references. Number aged in parentheses.

Age	State average[a]	Mean lengths from survey years					
		2001[b]	1998[c]	1993[c]	1983[c]	1972[c]	1962[c]
2	17.7	19.3 (60)	20.4 (5)	18.7 (13)	17.4 (7)	18.8 (6)	17.6 (13)
3	20.8	21.6 (169)	21.8 (5)	20.5 (23)	19.6 (28)	19.9 (8)	20.4 (16)
4	23.4	23.5 (89)	24.0 (2)	21.2 (13)	22.4 (14)	21.4 (2)	
5	25.5	24.9 (49)	23.3 (5)	21.9 (7)	— (0)	29.7 (1)	
6	27.3	28.5 (34)	24.2 (3)	29.2 (1)	31.8 (1)		
7	29.3	31.2 (18)		— (0)			
8	31.2	32.2 (9)		— (0)			
9		38.8 (2)		38.7 (1)			
10		40.0 (2)					

[a] Jan-May averages from Schneider et al. (2000).
[b] All fish aged with dorsal fin rays.
[c] All fish aged with scales.

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Approved by Paul W. Seelbach

Appendix–Fish species captured in Houghton Lake from 1935 through 2001 by MDNR crews using various gear types.

Common name	Scientific name
Species we collected in 2001 with trap nets, fyke nets, and electrofishing gear	
Walleye	*Sander vitreus*
Northern pike	*Esox lucius*
Bowfin	*Amia calva*
Black crappie	*Pomoxis nigromaculatus*
White sucker	*Catostomus commersonii*
Bluegill	*Lepomis macrochirus*
Rock bass	*Ambloplites rupestris*
Smallmouth bass	*Micropterus dolomieu*
Largemouth bass	*Micropterus salmoides*
Pumpkinseed	*Lepomis gibbosus*
Yellow perch	*Perca flavescens*
Common carp	*Cyprinus carpio*
Brown bullhead	*Ameiurus nebulosus*
Yellow bullhead	*Ameiurus natalis*
Black bullhead	*Ameiurus melas*
Longnose gar	*Lepisosteus osseus*
Golden shiner	*Notemigonus crysoleucas*
Longnose sucker	*Catostomus catostomus*
Rainbow trout	*Oncorhynchus mykiss*
Channel catfish	*Ictalurus punctatus*
Additional species collected with seine (Laarman 1976)	
Longear sunfish	*Lepomis peltastes*
Mimic shiner	*Notropis volucellus*
Common shiner	*Luxilus cornutus*
Sand shiner	*Notropis stramineus*
Spottail shiner	*Notropis hudsonius*
Blacknose shiner	*Notropis heterolepis*
Blackchin shiner	*Notropis heterodon*
Rosyface shiner	*Notropis rubellus*
Spotfin shiner	*Cyprinella spiloptera*
Bluntnose minnow	*Pimephales notatus*
Johnny darter	*Etheostoma nigrum*
Blackside darter	*Percina maculata*
Iowa darter	*Etheostoma exile*
Logperch	*Percina caprodes semifasciata*
Killifish	*Fundulus* sp.
Mudminnow	*Umbra* sp.
Additional specie collected with trap nets (Crowe and Latta 1956)	
Redhorse	*Moxostoma* sp.
Additional species collected with trap and fyke nets (Schrouder 1993)	
Fathead minnow	*Pimephales promelas*
Emerald shiner	*Notropis atherinoides*