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A Summary and Analysis of the Large Lakes Survey Program in Michigan in 2001–2010

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Michigan Department of Natural Resources
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A Summary and Analysis of the Large Lakes Survey Program in Michigan in 2001–2010

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Introduction

The Large Lakes Survey Program was initiated by the Michigan Department of Natural Resources (DNR), Fisheries Division in 2001 with the primary goal of developing and refining an assessment and monitoring program for highly-valued game fish species in Michigan's largest inland lakes (Clark et al. 2004). In particular, survey efforts during 2001–2010 targeted 4 focal species, Walleye (*Sander vitreus*), Northern Pike (*Esox lucius*), Smallmouth Bass (*Micropterus dolomieu*), and Muskellunge (*Esox masquinongy*), in large northern Michigan lakes (>1,000 acres) where management decisions regarding the allocation of fishery resources were particularly pressing. The main objectives of the program were to estimate abundance, growth, mortality and harvest of these species in each of these lakes, and to compare various methods for estimating abundance and exploitation. Individual reports were published for each lake or in some cases lake system (interconnected lakes) as part of the DNR Special Report series. This report synthesizes results from the first 10 years of study and addresses these objectives: (a) compare and contrast the utility of various analytical methods, (b) document the amount of variation in population and fishery metrics among focal fish populations, (c) determine if variation in key population metrics can be explained by particular lake features or characteristics of fish communities, and (d) explore if there is evidence for density-dependent mechanisms affecting the population dynamics of focal fish species. Not all metrics/analyses could be calculated/conducted for all species.

Study Area

From 2001 through 2010, the DNR conducted fish and angler surveys on 22 of Michigan's largest lake systems in its Upper Peninsula and northern Lower Peninsula (Table 1). Lakes ranged in size from 1,709 to 20,075 acres, with an average size of 8,644 acres. Southern Michigan lake systems were essentially excluded from the first 10 years of the Large Lakes Program because we selected lakes within the 1836 Treaty-ceded territory and the 1842 Treaty-ceded territory of Michigan (Figure 1). The impetus only to sample in treaty-ceded territories was impending or ongoing negotiations with Native American Tribes regarding the allocation of fishery resources. These negotiations prompted the DNR to prioritize the collection of biological data necessary for making informed decisions about fishery resources within the Treaty-ceded territories.

Table 1.–Lake systems surveyed in the Large Lakes Program from 2001–2010, with comparison of recreational fishing effort and total harvest.

ID	Lake	County	Survey period	Size (acres)	Fishing effort (hrs)	Fish harvested (number)	Fish harvested per hr	Hrs fished per acre	Fish harvested per acre
1	Houghton Lake	Roscommon	Apr 2001–Mar 2002	20,075	499,048	386,287	0.77	24.86	19.24
2	Michigamme Reservoir	Iron	May 2001–Feb 2002	6,400	93,543	21,623	0.23	14.62	3.38
3	Crooked- Pickerel lakes	Emmet	Apr 2001–Mar 2002	3,434	55,894	13,665	0.24	16.28	3.98
4	Burt Lake	Cheboygan	Apr 2001–Mar 2002	17,120	134,205	68,473	0.51	7.84	4.00
5	Muskegon River system	Muskegon	Apr 2002–Mar 2003	4,232	180,064	184,161	1.02	42.55	43.52
6	Lake Leelanau	Leelanau	Apr 2002–Mar 2003	8,320	112,113	15,463	0.14	13.48	1.86
7	Cisco Lake Chain	Gogebic, Vilas	May 2002–Feb 2003	3,987	180,262	120,412	0.67	45.21	30.20
8	South Manistique Lake	Mackinac	May 2003–Mar 2004	4,133	142,686	43,654	0.31	34.52	10.56
9	Big Manistique Lake	Luce, Mackinac	May 2003–Mar 2004	10,346	88,373	71,652	0.81	8.54	6.93
10	North Manistique Lake	Luce	May 2003–Mar 2004	1,709	10,614	7,603	0.72	6.21	4.45
11	Bond Falls Flowage	Ontonagon	May 2003–Oct 2003	2,127	21,182	3,193	0.15	9.96	1.50
12	Grand Lake	Presque Isle	Apr 2004–Mar 2005	5,822	33,037	10,623	0.32	5.67	1.82
13	Long Lake	Presque Isle, Alpena	Apr 2004–Mar 2005	5,342	34,894	7,004	0.20	6.53	1.31
14	Peavy Pond	Iron	May 2004–Feb 2005	2,794	26,447	6,299	0.24	9.47	2.25
15	Black Lake	Cheboygan, Presque Isle	Apr 2005–Mar 2006	10,113	59,874	18,762	0.31	5.92	1.86

Table 1.–Continued.

ID	Lake	County	Survey period	Size (acres)	Fishing effort (hrs)	Fish harvested (number)	Fish harvested per hr	Hrs fished per acre	Fish harvested per acre
16	Lake Gogebic	Gogebic, Ontonagon	Apr 2005–Mar 2006	13,127	116,857	17,568	0.15	8.90	1.34
17	Lake Michigamme	Baraga, Marquette	May–Sep 2006	4,292	26,574	4,307	0.16	6.19	1.00
18	Lake Charlevoix	Charlevoix	Apr 2006 Mar 2007	17,268	57,126	19,671	0.34	3.31	1.14
19	Portage-Torch lakes	Houghton	Apr 2007–Feb 2008	13,208	42,725	6,339	0.15	3.23	0.48
20	Elk-Skegemog lakes	Antrim, Kalkaska, Grand Traverse	Apr 2008–Mar 2009	10,961	53,916	12,647	0.23	4.92	1.15
21	Mullett Lake	Cheboygan	Apr 2009–Mar 2010	16,704	71,240	63,136	0.89	4.26	3.78
22	Indian Lake	Schoolcraft	Apr 2010–Mar 2011	8,647	20,521	14,372	0.70	2.37	1.66
	Average			8,644	93,691	50,769	0.42	12.95	6.70
	Median			7,360	58,500	16,516	0.31	8.19	2.06

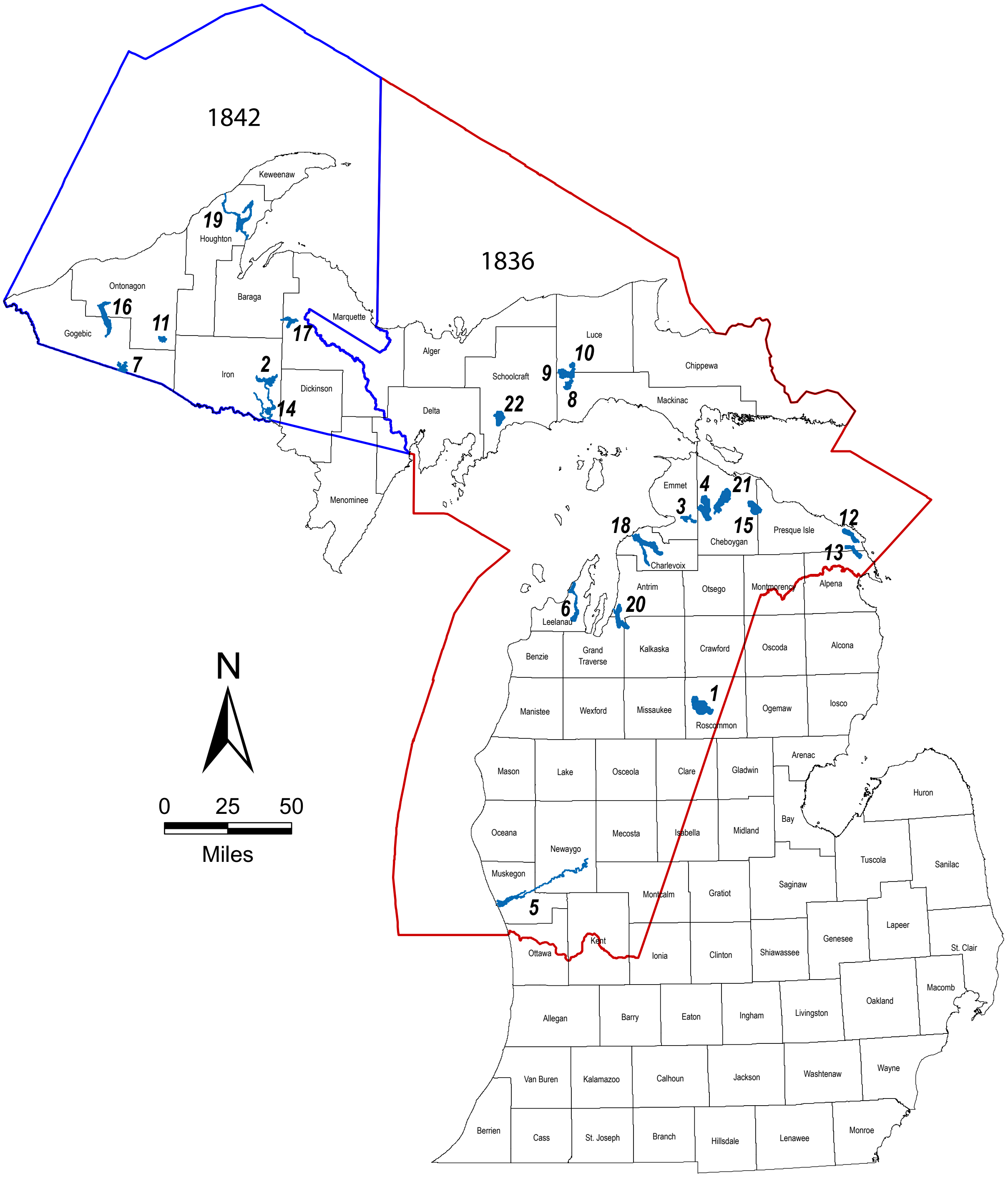


Figure 1.–Map of the lake systems surveyed as part of the Large Lakes Program in 2001–2010. The 1836 Treaty-ceded territory and 1842 Treaty-ceded territory are outlined in red and blue, respectively.

Methods

Although species composition of all fish captured in the surveys was recorded, the protocol was designed to prioritize catch of particular game species. Therefore, fish populations were sampled with trap nets, fyke nets, and electrofishing boats from the time of ice-out through the Walleye and Northern Pike spawning periods. For most lakes ice-out occurred in early to mid-April, though a few surveys began in late March. Surveys were completed prior to the opening day of the fishing season for Walleye, Northern Pike, and Muskellunge (last Saturday in April in the Lower Peninsula and May 15 in the Upper Peninsula). Trap nets were 8 x 6 x 3 feet with 2-inch stretch mesh and 70- to 100-foot leads, and fyke nets were 6 x 4 feet with 3/4- to 2-inch stretch mesh and 70- to 100-foot leads. Nets were primarily located to target Walleyes and Northern Pike (i.e., nonrandomly), though nets were also set to ensure broad coverage of the shoreline of each lake. Duration of net sets ranged from 1–3 nights, but most were 1 night. A typical survey lasted 2–3 weeks. Latitude and longitude were recorded for all net locations using global positioning systems (GPS). Smith-Root® boats equipped with boom-mounted electrodes (DC) were also used for electrofishing in order to increase the number of fish marked in some lakes. Electrofishing transects were approximately 1 mile in length. On some lakes, a standardized survey (Wehrly et al. 2015) was also conducted in early summer using fyke nets, trap nets, experimental gill nets, seines, and electrofishing and these data were used for comparison. Summary statistics, described below, were not estimated for every metric for a water body and/or species because of low sample size, low levels of precision, or some other factor that resulted in estimates in which we had little confidence. Thus, sample sizes vary by species and lake throughout the report. Species present were described in terms of catch per unit effort (CPUE), proportion of total catch, and length frequency. Mean CPUEs in trap and fyke nets were calculated 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).

Size Structure and Sex Ratio

Total lengths of all Walleyes, Northern Pike, Smallmouth Bass, and Muskellunge were measured to the nearest 0.1 inch. For other fish, lengths were measured to the nearest 0.1 inch for subsamples of up to 200 fish per survey crew. Lengths were taken over the course of the survey to account for any temporal changes in size structure of fish collected. Individuals were recaptured multiple times over the course of each survey. However, size-structure data for target species was based only on the length of individuals measured the first time they were captured. Walleye and Northern Pike with flowing gametes were identified as male or female; fish with no flowing gametes were identified as unknown sex. Muskellunge were identified using flowing gametes or from external characteristics as recommended by Lebeau and Pageau (1989). Sex of Smallmouth Bass could not be accurately determined because Smallmouth Bass spawn later in the spring than the other focal species and flowing gametes were never evident during surveys.

Abundance

For each lake system we attempted to estimate abundance of legal-sized and adult Walleyes, Northern Pike, Smallmouth Bass, and Muskellunge using mark-and-recapture methods; however, our primary species of interest were Walleye and Northern Pike. Thus, for several lake systems we terminated spring surveys before sufficient Smallmouth Bass or Muskellunge were collected to produce satisfactory estimates of abundance. Legal-sized Walleyes (≥15 in), Northern Pike (≥24 in), Smallmouth Bass (≥14 in), and Muskellunge (≥42 in) were fitted with monel-metal jaw tags. For most surveys, crews tagged as many fish as possible until the Walleye spawning season was nearing completion. To assess tag loss, tagged fish were double-marked by clipping either the left pelvic fin or the anterior 3 spines/fin rays of the dorsal fin. Reward ($10) and nonreward tags were applied in an approximate 1:1 ratio. Large tags (size 16) used on large (≥36 in) Northern Pike and Muskellunge were all nonreward. Two lake systems (Cisco Lake Chain and Peavy Pond) were managed without a minimum size limit for Northern Pike at the time of our survey. On those lake systems we tagged all Northern Pike 18 inches and larger.

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

Netting and electrofishing catch data were pooled to generate estimates of Walleye and Northern Pike abundances. Two different methods for estimating abundance from these mark-and-recapture data were used, one derived from marked-unmarked ratios during the spring survey (multiple census) and the other derived from marked-unmarked ratios from the angler survey (single census; see below). For the multiple-census estimate, the Schumacher-Eschmeyer formula for daily recaptures during the tagging operation was used (Ricker 1975):

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

N_1 = multiple-census population estimate (number of legal-sized fish; or number of adult fish)

C_d = total number of 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

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.

The minimum number of recaptures necessary for an unbiased estimate was set a priori at four (Ricker 1975). Asymmetrical 95% confidence intervals were computed as:

$$\frac{1}{\frac{1}{N_1} \pm t(\sigma)}$$

where t = Student's T value for m -1 degrees of freedom; σ = standard error of $1/N_1$ (calculated as the square root of the variance of $1/N_1$), and Variance of $1/N_1$ was calculated as:

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

The multiple-census method was used to estimate abundance of both legal-sized and adult Walleyes and Northern Pike. Individuals having flowing gametes were considered adults regardless of length. Thus, some adults were above or below the legal size limit. To account for unequal effort in different parts of lake systems (Ricker 1975), multiple-census estimates were occasionally made for areas/lakes within a lake system, when minimum sample sizes were met, which were then summed to provide estimates for the entire lake system. In these instances, the assumption was made that movement between areas/lakes was negligible.

For single-census estimates, data from all locations within lake systems were pooled because we used the subsequent angler survey to assess recaptures, and there was evidence of extensive fish movement among most locations during the angling seasons. The minimum number of recaptures necessary for an unbiased estimate was set a priori at three, and the Chapman modification of the Petersen method was used to generate population estimates (with variance) using the following formulas from Ricker (1975):

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

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)

R = number of recaptures in second sample

Asymmetrical 95% confidence limits were calculated using values from the Poisson distribution for the 95% confidence limits on the number of recaptured fish (R), which were substituted into the equation for N above (Ricker 1975). The numbers of adult Walleyes and Northern Pike (with variance) were estimated from the single-census estimates by dividing the estimates for legal-sized fish by the proportion of legal-sized fish on the spawning grounds, using the formulas:

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

N_a = estimated number of adult Walleyes or Northern Pike

N_{sub} = number of sublegal and mature fish (<15 in for Walleye, or <24 in for Northern Pike) caught

N_{leg} = number of legal-sized fish caught

N_2 = single-census estimate of legal-sized Walleyes or Northern Pike

For single-census estimates, it was assumed that some fraction of sublegal (i.e., unmarked) fish would grow to legal size during the recapture period and would inflate population estimates by increasing the count of unmarked fish in the fishery. To account for this effect, the number of unmarked fish observed in the angler survey was reduced by the estimated number that recruited to legal size during the recapture period. This adjustment would be especially important if fin-clipping had a negative effect on growth, whereby unclipped fish would recruit to legal size faster than clipped ones. The number of fish that recruited to legal size during the angler survey was estimated using the weighted average monthly growth for fish of slightly sublegal size. For example, to make this adjustment for Walleye the annual growth of slightly sublegal fish (i.e., 14.0–14.9 in fish) was determined from mean length-at-age data. This value was then divided by the length of the growing season in months (6) and rounded to the nearest 0.1 inch. This average monthly growth was used as the criteria to remove from the estimate of C unmarked and fin-clipped fish that were observed in the angler survey. The largest size of a sublegal Walleye at tagging was 14.9 inches; thus, an average monthly growth of 0.2 inches would result in all fish 15.1 inches or smaller, caught during the first full month (June) after tagging, to be subtracted from the total number of fish caught in the sample (C). Tagged fish were not adjusted since they were known to be of legal size at the time of tagging. Adjustments were made for each month of the creel surveys resulting in final recapture rates (R/C) that were used to make the single-census population estimates. The coefficient of variation (CV) was calculated for each abundance estimate (single- and multiple-census) as the standard deviation divided by the point estimate. We considered estimates with a CV less than or equal to 0.40 to be reliable (Hansen et al. 2000). For the Cisco Lake Chain (Hanchin et al. 2008) and Peavy Pond (Hanchin 2011), estimates were initially made for Northern Pike 18 inches and larger because there were no minimum size limits on Northern Pike in those systems. For proper comparison with other estimates, the abundance of 24-inch and larger Northern Pike in the Cisco Chain and Peavy Pond was estimated for this report. Additionally, the single-census estimates for adult Northern Pike in those systems were recalculated based on the estimates for 24-inch and larger Northern Pike, rather than being based on the estimates for 18-inch and larger Northern Pike as was done initially.

Density (number of fish per acre) was calculated using the best abundance estimates considering all potential biases and sources of error. Criteria included number marked, whether the minimum number of recaptures was obtained, and coefficient of variation. When a population estimate was not possible due to low sample size or low precision, but density was understood to be low, the minimum density was calculated as the number of unique individuals marked divided by the water body surface area in acres. These minimum density values were used in statistical analyses that explored evidence of density-dependent mechanisms, but were not used to compare and contrast the utility of various analytical methods. Population estimates that did not meet the minimum number of recaptures, or the minimum CV were not included and were not used in any statistical analysis.

Growth

Accurate ages for older fish were important since one goal of the large lakes survey program was to estimate annual mortality. Dorsal spines were used to age Walleyes and Smallmouth Bass and dorsal fin rays were used to age Northern Pike and Muskellunge because they provided a good combination of ease of collection in the field and accuracy and precision of age estimates. Although the most accurate and precise ageing structures are otoliths for older Walleyes (Heidinger and Clodfelter 1987; Kocovsky and Carline 2000; Isermann et al. 2003) and otoliths or cleithra for Northern Pike (Casselman 1974; Harrison and Hadley 1979), collecting these structures would have required killing the fish, which would greatly reduce the number of marked fish at large. Additionally, although there is no consensus on the accuracy and precision of spines versus scales (Belanger and Hogler 1982; Campbell and Babaluk 1979; Erickson 1983; Kocovsky and Carline 2000; Isermann et al. 2003; Donabauer 2010), spines were chosen because they likely provide more accurate ages for the oldest fish in the populations. 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 size goals for each lake system were 20 male and 20 female fish per inch group for Walleyes and Northern Pike, and 20 Smallmouth Bass per inch group. All muskellunge encountered were aged.

Dorsal spines and fin rays were prepared by sectioning samples using a table-mounted high-speed rotary cutting tool. Sections approximately 0.02 inches thick were cut as close to the proximal end of the spine or ray as possible. Sections were examined at 40x–80x magnification with transmitted light and were photographed with a digital camera. The digital image was archived for multiple readers. Two technicians independently aged samples, and ages were considered final when independent estimates were in agreement. Samples in dispute were aged by a third technician. Disputed ages were considered final when the third technician agreed with one of the first two. Samples were discarded if three technicians disagreed on age, though occasionally an average age was used when ages assigned to older fish (≥ age 10) were within ±10% of each other.

After a final age was identified for all samples, age-length keys (Devries and Frie 1996) were constructed and weighted mean lengths-at-age were calculated. Mean growth indices were calculated by comparing the data to Michigan state averages derived using spines/fin rays (Michigan Department of Natural Resources, unpublished data). The mean growth index is the average of deviations (by age group) between the observed mean lengths and statewide seasonal average lengths. Mean growth indices in the individual lake reports were largely calculated using the statewide average derived from scales (Schneider et al. 2000). Since then, new statewide averages have been created using dorsal spines for Walleyes and Smallmouth Bass, and fin rays for Northern Pike. For this report, new growth indices were calculated for all populations using the new statewide averages.

Angler Survey

Direct contact angler surveys were conducted on each lake system during the open-water period and the ice-cover period, and used to estimate several population and fishery metrics. The open-water period surveys generally started in late April and continued through the end of September or the end of October, with November and the first part of December rarely being surveyed. The ice-cover periods generally started in late December or early January and continued through March. The ice-cover periods on Bond Falls Flowage and Lake Michigamme were not surveyed since it was known that very little angling effort occurred at that time of year. Survey designs varied somewhat according to the size of the lake systems. Generally creel clerks worked from a boat or snowmobile to collect angler interviews in a roving design. Roving-type interviews were generally incomplete-trip interviews. Complete-trip interviews were also made occasionally at access sites. Counts of anglers were either made from a clerk progressing along a predetermined path via a boat, snowmobile, or airplane. Counts were made once per day. Both weekend days and three randomly-determined weekdays were selected for counting and interviewing; no holidays were sampled. One of two shifts was selected for each sample day. Starting location and direction of travel were randomized for both counting and interviewing. Minimum fishing time prior to interviewing (incomplete-trip interview) was 1 h (Lockwood 2004; Clark et al. 2004). All roving interview data were collected by individual angler to avoid party size bias (Lockwood 1997), though the number of anglers in each party was recorded on one interview form for each party. Interview information collected included: date, fishing mode, start time of fishing trip, interview time, species targeted, bait used, number of fish harvested by species, number of fish caught and released by species, length of harvested Walleyes, Northern Pike, Smallmouth Bass, and Muskellunge and applicable tag numbers.

Catch and effort estimates were made using a multiple-day method (Lockwood et al. 1999). Effort was the product of mean counts for a given period day type, days within the period, and the expansion value (the number of hours within sample days) for that period. Thus, the angling effort and catch reported are for those periods sampled, no expansions were made to include periods not sampled (e.g., 0100 to 0400 hours).

Most interviews (>80%) collected were of a single type (generally roving). However, during some shorter periods (i.e., day type within a month for some lakes) fewer than 80% of interviews may have been of a single type. When 80% or more of interviews within a time period (weekday or weekend day within a month) were of an interview type, the appropriate catch-rate estimator for that interview type (Lockwood et al. 1999) was used on all interviews. When less than 80% were of a single interview type, a weighted average R_w was used:

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

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

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

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

From the angler interview data collected, catch and harvest by species were estimated along with angling effort (expressed as both angler hours and angler trips). An angler trip was defined as the period an angler was at a lake (fishing site) and actively fishing. When an angler left the lake or stopped fishing for a significant period of time (e.g., an angler leaving the lake to eat lunch), the trip was considered over. All estimates are given with ± 2 SE, which provided statistical significance of 75 to 95% assuming a normal distribution and $N \geq 10$ (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. For Walleyes, Northern Pike, and Smallmouth Bass the initial harvest estimates were expanded by adjusting for the nonsurveyed period based on the percentage of tag returns from the nonsurveyed period. Additionally, and for proper comparison with the abundance estimates, the harvest for these species was further adjusted for the percentage of sublegal fish that grew over the minimum size limit during the fishing season. If a harvest estimate was not possible for a given species, but tagged fish were caught and returned, I used the number of tagged fish known to be harvested divided by the water body surface area as a minimum estimate of harvest per acre. For lakes with no minimum size limit on Northern Pike, harvest estimates for all fish were converted to harvest estimates of 24-inch and larger Northern Pike by multiplying by the percentage of 24-inch and larger Northern Pike measured during the creel survey.

Mortality

Catch-at-age was calculated for males, females, and all fish (including males, females, and those of unknown sex) by apportioning total catch by inch group to total catch by age group using an age-length key. Total annual mortality rates were estimated using weighted catch curve regressions based on the recommendation of Smith et al. (2012) and with assumptions described by Ricker (1975). The goal was to estimate total mortality for fish of legal size for comparison with mortality attributable to fishing. Following the recommendations of Smith et al. (2012) I used the age of maximum catch as the youngest age group included in analysis.

Angler exploitation rates were estimated using three methods: 1) the percent of reward tags returned by anglers; 2) the estimated harvest divided by the multiple-census estimate of abundance; and 3) the estimated harvest divided by the single-census estimate of abundance. Probability of tag loss was calculated as the number of fish in the recapture sample that had lost tags (fin clip and no tag) divided by all fish in the recapture sample that had been tagged, including fish that had lost their tag. Standard errors were calculated assuming a binomial distribution (Zar 1999).

Using the first method, exploitation rate was estimated as the fraction of available reward tags returned by anglers, adjusted for tag loss. The tag loss adjustment was made by reducing the number of available reward tags by the percentage of tags lost over the course of the creel survey. Exploitation was also calculated by sex for each lake. For some populations (especially Northern Pike) estimates were made using returned reward and nonreward tags in order to increase the sample size. Additionally, for this report, data from all lakes were pooled to determine exploitation by inch group. Tagging mortality was assumed to be negligible. Although actual nonreporting was not assessed (for all tags, reward and nonreward), the actual number of tag returns was compared to the expected number (X) based on the ratio:

$$\frac{R}{C} = \frac{X}{H_a}$$

where R = the number of tags observed in creel, C = the number of fish observed in creel (adjusted for those that recruited to legal size over the course of the fishing season, and H_a = the total expanded harvest adjusted first for nonsurveyed period (based on percentage of tag returns from nonsurveyed period) and second for the percentage of fish that recruited to legal size over the course of the fishing season. Additionally, individual tags observed by the creel clerks were verified to see if they were subsequently reported by anglers. This is not a true estimate of nonreporting because there is the possibility that anglers believed the necessary information was obtained by the creel clerks, and further reporting to the DNR was unnecessary. Tags observed by the creel clerks that were not voluntarily reported by the angler were added to the voluntary tag returns for exploitation estimates.

Voluntary tag returns were encouraged with a monetary reward ($10) denoted on approximately 50% of the tags. Tag return forms were made available at boater access sites, at DNR offices, and from creel clerks. Additionally, tag-return information could be submitted online at the DNR website. Return rates were calculated separately for reward and nonreward tags, unadjusted for tag loss. The reporting rate of nonreward tags relative to reward tags (λ *in* Pollock et al. 1991) was calculated as the fraction of nonreward tags harvested and reported divided by the fraction of reward tags harvested and reported (with available tags adjusted for short-term tag loss and mortality during tagging). In addition to data on harvested fish, starting in 2004 the release rate for legal fish was estimated from responses to a question on the tag return form asking if the fish was released. The release rate was calculated as the total number of tag returns reported as released divided by all of the tagged fish known to have been caught (voluntary returns and unreported tags observed in the creel survey).

In the second and third methods (see above), exploitation was calculated as the adjusted harvest estimate from the angler survey (H_a from above) divided by the multiple- and single-census abundance estimates for legal-sized fish. The estimated annual harvest was adjusted for the nonsurveyed period based on the fraction of tag returns from the nonsurveyed period. Also, for proper comparison with the abundance estimates of legal fish as existed in the spring, the harvest estimate was reduced to account for fish that grew to legal size over the course of the creel survey. The reduction of harvest was based on the percentage of fish observed in the creel survey that were determined to have been sublegal at the time of the spring survey (See *Abundance* subsection of the *Methods* section). These methods for calculating exploitation are essentially the same as used by Beard et al. (2003), though described using different terms. Confidence limits (95%) were calculated for these exploitation estimates assuming a normal distribution, and summing the variances of the abundance and harvest estimates.

For two lakes (Houghton Lake and Michigamme Reservoir) the exploitation estimates derived by dividing harvest by abundance differ from those values in the initial reports (Clark et al. 2004, Hanchin et al. 2005) because harvest estimates were adjusted for nonsurveyed months in the current evaluation. Additionally, the Michigamme Reservoir creel estimates (and estimates derived from the creel survey estimates) in this report were corrected for errors and differ from those initially reported by Hanchin et al. 2005.

Recruitment

Because population data for each fish population were only obtained during a single year, year-class strength could not be rigorously evaluated. However, we evaluated the residuals from catch-curve regressions as indices of year-class strength (Maceina 2003) as well as the coefficient of determination from catch curve regressions (RCD; Isermann et al. 2002) as a quantitative index of recruitment variability. For some populations, sublegal adults were included in a second catch curve regression to estimate recruitment variability (as opposed to the one used to estimate total mortality of legal-sized fish). This second catch curve better represented the variability in catch-at-age observed in the population.

Movement

Short-term movement of Walleyes and Northern Pike was evaluated by comparing the distance between points of initial capture and recapture during the spring survey (netting locations or midpoint of electrofishing transects). Longer-term movement for three Walleye populations (Muskegon River system, Lake Charlevoix, and the Portage-Torch system) with Great Lakes connectivity was evaluated by comparing the distance between points of initial survey capture and recapture by anglers. Due to the large sample sizes and the complexity of irregular shorelines, distances between capture locations for both analyses were calculated as the most direct line using the Haversine formula (Sinnott 1984). Analysis of variance was used to determine differences in minimum distance moved between sexes and among sizes at initial capture. Deviation in latitude between capture locations was used to determine north-south movement. Analysis of latitude was primarily related to the Muskegon River population, where we wanted to know if fish moved to rivers north or south of the Muskegon; east-west movement (longitude) was not of interest.

Analysis

The objectives of this report all related to knowledge that could be gained from synthesis of the individual large lake surveys that had previously be analyzed on a lake-specific basis. These objectives included determining if variation among lakes in key fish population metrics could be explained by particular lake features (e.g., connectivity to a Great Lake) or characteristics of fish communities (e.g., indicators of prey abundance) or density-dependent factors for the focal species. To address these objectives, my statistical methods included correlation, regression, and stepwise multiple regression analysis. I used a Pearson correlation when both variables were normally distributed and a Spearman rank correlation when at least one variable was not normally distributed. Some variables were natural log-transformed to achieve increased normality. When numerous variables were tested simultaneously, I used Bonferroni corrections of alpha to account for spurious correlations.

Another objective of this report was to compare and evaluate analytical methods used for estimating Walleye and Northern Pike abundance. Comparisons were completed independently for legal-sized Walleyes and Northern Pike. I did not compare abundance estimates for adult fishes since the single-census estimates for adult fishes were not true mark-recapture estimates, because they were essentially estimates for legal-sized Walleyes and Northern Pike that were adjusted to account for sublegal mature fish that were on the spawning grounds. I used the Wilcoxon Signed Rank test for comparison of abundance estimates because the data lacked normality as determined using the Wilks-Shapiro procedure. Abundance estimates were also compared to the independently-derived harvest and exploitation estimates (from angler survey data) as a way to evaluate their apparent accuracy. For these comparisons, constant catchability was assumed across water bodies.

Additional analyses were conducted to explore the reliability of the mark-recapture abundance estimates. Specifically, in order to evaluate potential violations of assumptions of a mark-recapture study using jaw tags and a creel survey for the recapture sample, I pooled all creel survey data (interviews) and calculated the recapture rate (R/C) for each month of the angling season both with and without adjustment (see *Abundance* section) of R and C, to determine if recapture rates remained constant, as assumed by the analysis. For this analysis, some lakes were removed because clerks did not record fish lengths for some portion of the year (Houghton, Burt, Crooked-Pickerel, Mullett), there was improper recording of marked versus unmarked fish (Leelanau and Muskegon), or the ice-cover period was not surveyed (Lake Michigamme and Bond Falls Flowage). Additionally, I combined months that were only partially surveyed with an adjacent month (e.g. April–May, December–January, and February–March). In order to assess the likelihood that tag loss, lack of tag detection, or higher mortality of tagged fish contributed to error in population abundance estimates, I assessed trends in R/C over the angling season. As explained by Deroba et al. (2005), the R/C ratio would decline over the year if marks/tags were lost, or if marked/tagged fish were growing slower than unmarked ones. To assess this latter problem, the R/C trend was also evaluated for different length classes of Walleyes (15–18 in and ≥18 in). Length classes were selected for approximately equal sample sizes in each group. Although the differential treatment of sublegal (clipped) and legal-sized (clipped and tagged) Walleyes had the potential to obscure results, if marks/tags were affecting growth the 15–18 inch group would be both gaining (from sublegal fish) and losing (to the 18 inch and larger group) unmarked fish, while the 18 inch and larger group would only be gaining unmarked fish. Thus, the 18 inch and larger group would potentially show an increasing trend in the R/C ratio for some portion of the year. To ascertain whether the R/C ratio declined over the months following tagging, a negative exponential equation was fit to the data using the following formula from Deroba et al. (2005):

$$R / C = \alpha X^{-\beta}$$

where X is the month, α is the R/C ratio in April/May, and β is the rate that the R/C ratio decreases by month. I estimated the parameters with a linear regression of the $\log_e$ transformed equation:

$$\log_e (R / C) = \log_e \alpha - \beta X + \varepsilon \,.$$

Additionally, I was concerned that the growth increments used to adjust for unmarked fish that recruited to legal size over the course of the year may have been overestimated if the true growing season of Walleyes was longer than six months. In order to test this potential source of error, I examined the difference between the unadjusted R/C and the adjusted R/C across all months. If marked and unmarked fish were being removed from analysis in the same proportion, then there should be no difference between the two R/C ratios over time.

In order to test for differences in angler selectivity between sexes and among inch groups (Seber 1982; Pierce 1997), I used a Chi-square analysis comparing the length-frequencies from tag returns to the known population tagged, pooling all lakes. This was done primarily to test the assumption of equal vulnerability of fish of different sizes (Ricker 1975), but also to explore how angler exploitation varies with sex and size. For this analysis, I compared the lengths and sexes of fish recaptured by anglers in the angling year following tagging (both harvested and released) to those tagged during the spawning run that were not recaptured by anglers. For Walleyes, I used inch groups from 15 to 30 inches, since the minimum size limit for Walleye is 15 inches and including Walleye greater than 30 inches resulted in cells with expected frequencies lower than 5. For Northern Pike, I used inch groups from 24 to 36 inches. The residuals (observed minus expected) from these analyses were used to assess whether angler catch (harvest + release) indicated a selection for various inch groups. Angler catch was further analyzed for selectivity by calculating exploitation and the percentage of legal-sized fish that were reported as being released by inch group. For both of these analyses I used reward and nonreward tag returns in order to increase sample size, and for the exploitation estimates I only used tag returns from the angling year following tagging. For analysis of released fish, I used populations surveyed starting in 2004 when a question was first added to the tag return form about released fish and also used all angler tag returns collected at the time of report writing in order to improve sample sizes. Since I used tag returns gathered across several years, I used the angler-reported lengths for the analysis of released fish. Statistical significance was set at $\alpha = 0.05$ for all analyses.

Results and Discussion

Walleyes comprised, on average, 35.2% (median = 24.2%) of the total catch by number, which ranged from 0.6% to 97.8% (Table 2). In some systems (e.g. Muskegon River system and Indian Lake) the percentage contribution from Walleyes was high as a result of targeted electrofishing for Walleyes. Northern Pike were less abundant than Walleyes making up, on average, 8.3% (median = 5.2%) of the total catch by number, and ranging from 0.9% to 26.3% (Table 3). Smallmouth Bass accounted for even less of the total catch making up, on average, 3.1% (median = 2.3%) of the total catch by number, and ranging from 0.1% to 14.0% (Table 4). Often, our ice-out surveys occurred too early in the year to capture many Smallmouth Bass; thus, the percent compositions of each species are not necessarily indicative of the true assemblage structure. Muskellunge were collected in 7 of the 22 lakes surveyed and never comprised more than 0.1% of the total catch by number.

Size Structure, Growth, and Sex Ratio

Walleyes exhibited evidence of density-dependence in terms of both size structure and growth. The percentage of legal-sized Walleyes was negatively related ($F = 11.68$, $P = 0.003$, $df = 19$) to the density of adult Walleyes (Figure 2). Additionally, the mean growth index was negatively related ($F = 25.23$, $P < 0.001$, $df = 21$) to the density of adult Walleyes and was best described using a natural logarithmic function (Figure 3). For both of these relationships, the populations with documented migration to the Great Lakes (Muskegon River system, Lake Charlevoix, and Portage-Torch system) were excluded. Because densities were calculated for the inland lakes proper, these populations would not be valid for evaluations of density dependence. There appears to be a threshold density of 3 adult Walleyes per acre, above which all populations exhibited low mean growth indices relative to the state average. At lower densities, the mean growth indices had a broader range, indicating that factors other than density influence growth.

Table 2.–Walleye metrics from spring netting/electrofishing surveys of lakes surveyed in the Large Lakes Program from 2001–2010.

Lake	Number caught[a]	Percentage of total catch	Mean trap-net CPUE[a,b]	Mean fyke-net CPUE[a,b]	Length range (in)	Average length (in)[c]	Percentage ≥15 inch	Adult sex ratio[d]	Legal-sized sex ratio[e]
Houghton Lake	4,426	31.1	6.9	6.7	9.8–29.1	16.3	72.6	3.1	2.5
Michigamme Reservoir	2,471	25.7	NA	3.7	7.7–26.6	15.3	52.9	9.0	5.6
Crooked-Pickerel lakes	997	14.7	11.7	3.4	5.9–22.6	15.1	52.6	4.4	2.8
Burt Lake	2,899	16.8	5.6	2.5	6.3–29.0	16.5	69.9	6.0	4.3
Muskegon River system	5,573	97.8	0.5	0.2	13.2–31.6	24.1	99.8	1.6	1.6
South Lake Leelanau	3,519	44.1	15.1	27.9	6.7–29.2	16.2	68.7	6.3	4.7
North Lake Leelanau	161	4.7	0.7	0.4	6.1–28.4	16.3	68.2	2.0	1.7
Cisco Lake chain	11,010	17.0	NA	11.4	4.8–29.8	14.4	29.4	4.0	1.0
South Manistique Lake	4,855	66.6	44.5	11.5	6.7–29.1	17.1	74.4	2.6	1.9
Big Manistique Lake	4,689	40.7	39.9	9.2	7.0–26.5	19.2	92.4	2.0	1.8
North Manistique Lake	447	24.2	6.7	4.2	9.2–28.5	20.4	99.8	1.5	1.5
Bond Falls Flowage	5,618	75.0	NA	15.9	4.3–26.8	15.4	54.1	4.4	2.0
Grand Lake	3,295	15.8	11.2	4.7	4.9–28.0	14.0	43.0	2.8	1.8
Long Lake	837	10.9	1.9	1.0	7.3–27.1	17.1	85.9	2.6	2.6
Peavy Pond	2,509	19.5	NA	0.9	4.7–29.4	14.9	53.1	1.5	1.6
Black Lake	1,057	21.1	2.6	1.0	14.7–25.5	17.6	99.4	7.9	7.9
Lake Gogebic	18,229	73.5	NA	38.8	5.2–30.2	14.9	39.5	12.4	4.6
Lake Michigamme	2,326	59.1	NA	1.3	5.8–30.7	16.4	75.9	8.4	6.6
Lake Charlevoix	2,703	19.7	6.5	1.6	7.9–32.8	21.6	93.1	1.3	1.3
Portage-Torch lakes	5,699	15.1	26.6	8.9	9.5–30.7	20.9	97.2	3.5	3.4
Elk-Skegemog lakes	82	0.6	0.4	<0.1	9.5–30.1	25.1	96.1	1.6	1.6
Mullett Lake	1,079	26.0	1.9	NA	10.6–28.5	19.6	99.3	4.2	4.2
Indian Lake	4,264	90.6	18.0	16.3	5.2–29.4	15.8	58.7	6.0	3.5
Mean	3,858	35.2	11.8	7.8	7.5–28.7	17.6	72.9	4.3	3.1
Median	2,899	24.2	6.7	4.0	6.7–29.1	16.4	72.6	3.5	2.5

[a] Includes recaptures.

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

[c] Does not include recaptures.

[d] Adult Walleye were defined as those of legal size and sexually-mature fish of sub-legal size on spawning grounds.

[e] Number of 15-in and larger males divided by number of 15-in and larger females.

Table 3.–Northern Pike metrics from spring netting/electrofishing surveys of lakes surveyed in the Large Lakes Program from 2001–2010. Dash (–) indicates no estimate.

Lake	Number caught [a]	Percentage of total catch	Mean trap-net CPUE [a,b]	Mean fyke-net CPUE [a,b]	Length range (in)	Average length (in)[c]	Percentage legal size	Adult sex ratio [d]	Legal-sized sex ratio [d]
Houghton Lake	1,199	8.4	2.9	1.4	9.0–41.4	22.4	27.6	1.3	0.1
Michigamme Reservoir	1,861	19.3	–	6.0	9.6–39.9	19.4	6.3	1.5	0.3
Crooked-Pickerel lakes	285	4.2	2.5	2.3	9.6–31.8	18.8	4.0	1.2	0.0
Burt Lake	203	1.2	0.4	0.1	9.8–38.1	23.9	35.0	0.9	0.3
Lake Leelanau	992	8.7	3.1	0.5	9.6–42.0	20.2	13.0	0.8	0.1
Cisco Lake chain	3,979	6.2	–	5.0	6.4–34.7	18.2	6.2	1.1	0.2
South Manistique Lake	277	3.8	2.3	1.0	7.8–31.1	19.9	13.5	0.8	0.6
Big Manistique Lake	214	1.9	1.1	1.1	12.2–49.4	24.7	49.8	1.3	1.0
North Manistique Lake	17	0.9	0.6	0.0	16.3–40.0	29.7	88.2	1.0	1.0
Bond Falls Flowage	967	12.9	–	3.9	10.1–48.1	20.8	13.5	1.8	0.7
Grand Lake	232	1.1	1.1	0.2	10.9–42.0	23.3	49.3	1.9	0.9
Long Lake	397	5.2	0.8	0.7	9.9–40.5	22.1	34.7	0.9	0.3
Peavy Pond	3,310	25.8	–	6.3	5.6–38.5	18.1	4.2	1.0	0.6
Black Lake	1,312	26.3	3.5	1.6	9.6–42.0	22.7	32.3	2.3	0.7
Lake Gogebic	1,294	5.2	–	2.7	7.5–42.0	21.3	18.4	1.2	0.4
Lake Michigamme	653	16.6	–	1.8	9.8–43.7	22.5	30.5	2.4	1.1
Lake Charlevoix	876	6.4	2.5	0.2	11.2–44.0	24.4	52.8	1.3	0.5
Portage-Torch lakes	1,965	5.2	5.4	3.6	8.2–44.1	23.7	21.3	1.4	1.3
Elk-Skegemog lakes	335	2.4	1.6	0.4	9.4–39.0	21.5	40.0	0.8	0.2
Mullett Lake	440	10.6	3.2	–	7.4–36.2	21.7	28.0	2.1	1.0
Indian Lake	50	1.1	1.2	0.0	8.9–37.2	21.3	22.4	4.6	1.2
Mean	993	8.3	2.1	1.9	9.5–40.3	21.9	28.1	1.5	0.6
Median	653	5.2	2.3	1.3	9.6–40.5	21.7	27.6	1.3	0.6

[a] Includes recaptures.
[b] Number per trap-net or fyke-net night.
[c] Does not include recaptures.
[d] Number of 24-in and larger males divided by number of 24-in and larger females.

Table 4.–Smallmouth Bass metrics from spring netting/electrofishing surveys of lakes surveyed in the Large Lakes Program from 2001–2010.

Lake	Number caught[a]	Percentage of total catch	Mean trap-net CPUE[a,b]	Mean fyke-net CPUE[a,b]	Length range (in)	Average length (in)[c]	Percentage ≥14 inch
Houghton Lake	571	4.0	1.1	0.8	7.4–20.4	15.9	84.5
Michigamme Reservoir	127	1.3	NA	0.3	10.6–20.8	14.7	58.3
Crooked-Pickerel lakes	264	3.9	1.4	2.8	8.1–20.9	15.8	76.8
Burt Lake	1,383	8.0	3.1	4.7	8.4–21.8	16.3	80.0
Lake Leelanau	318	2.8	1.4	0.1	9.9–20.1	15.9	79.4
Cisco Lake chain	97	0.1	NA	0.1	2.7–17.4	12.5	13.4
South Manistique Lake	60	0.8	0.3	0.3	6.6–20.0	16.0	87.3
Big Manistique Lake	221	1.9	1.3	1.0	7.9–19.9	14.5	65.9
North Manistique Lake	9	0.5	0.0	0.2	3.7–12.1	8.2	0.0
Bond Falls Flowage	36	0.5	NA	0.1	8.6–18.3	14.1	47.2
Grand Lake	2,125	10.2	5.5	3.7	3.0–20.2	12.8	39.8
Long Lake	1,076	14.0	2.3	1.5	8.1–20.5	15.1	65.8
Peavy Pond	60	0.5	NA	0.1	3.0–20.4	15.4	87.9
Black Lake	116	2.3	0.3	0.2	11.4–21.1	17.1	95.5
Lake Gogebic	130	0.5	NA	0.3	8.1–19.1	14.2	47.3
Lake Michigamme	117	3.0	NA	0.1	9.6–18.2	13.8	18.4
Lake Charlevoix	522	3.8	1.4	0.2	10.7–21.1	15.7	69.4
Portage-Torch lakes	115	0.2	0.6	0.1	2.5–21.1	16.0	86.6
Elk-Skegemog lakes	512	3.7	2.7	0.4	7.0–21.7	15.6	75.0
Mullett Lake	106	2.6	0.6	NA	12.7–21.5	16.6	91.7
Indian Lake	41	0.9	0.1	0.2	8.8–19.5	14.9	68.3
Mean	381	3.1	1.5	0.9	7.6–19.8	14.8	63.7
Median	127	2.3	1.3	0.3	8.1–20.4	15.4	69.4

[a] Includes recaptures

[b] Number per trap-net or fyke-net night

[c] Does not include recaptures

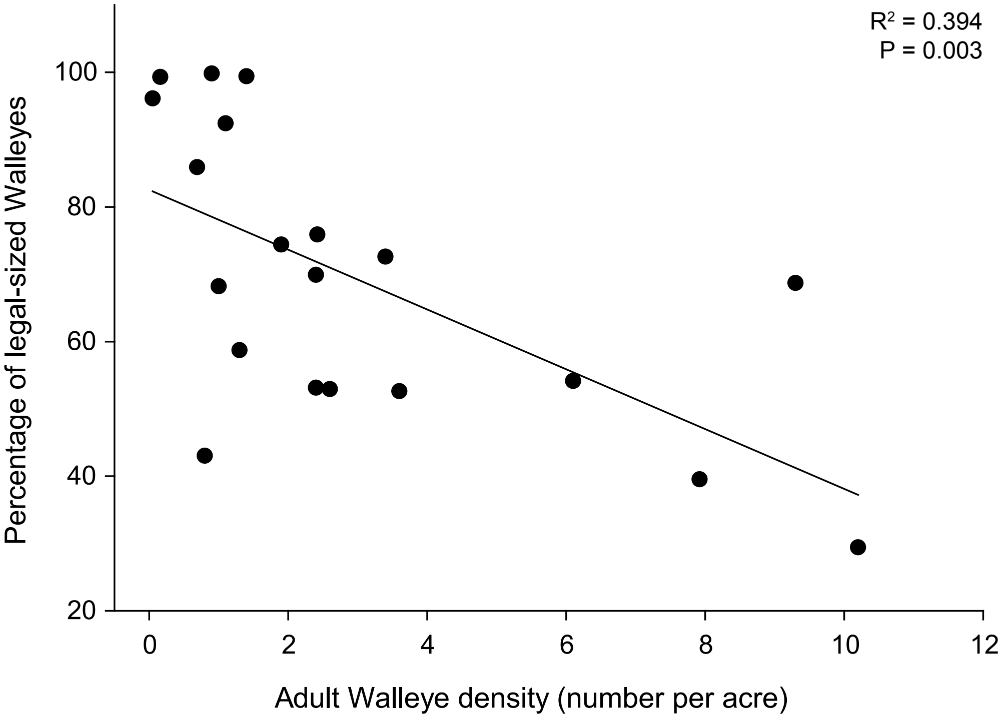


Figure 2.–Relationship between adult Walleye density (number per acre) and the percentage of legal-sized Walleyes observed in Large Lakes Program surveys in 2001 to 2010. The regression equation is: y = -4.445(x) + 82.55.

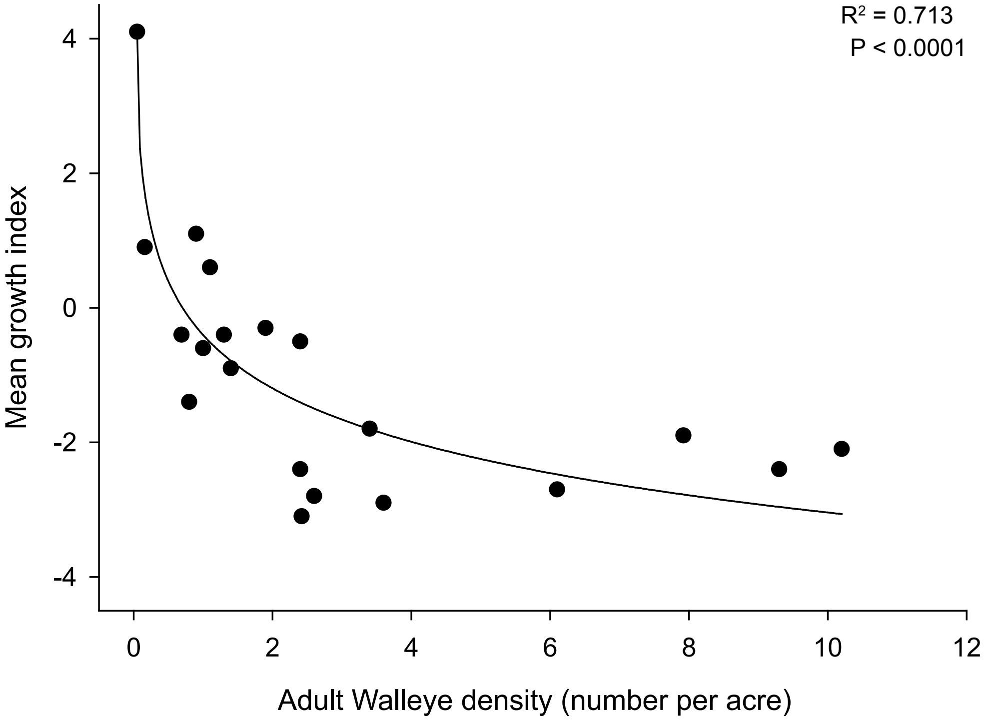


Figure 3.–Relationship between adult Walleye density (number per acre) and the mean growth index for Walleyes observed in Large Lakes Program surveys in 2001 to 2010. The regression equation is: y = -1.146Ln(x) - 0.403.

Overall, the average and median percentages of captured Walleye that were of legal size were 72.9 and 72.6, respectively, and values ranged from 29.4% to 99.8% (Tables 2 and 5). Populations with a high percentage of legal-sized Walleyes were generally those with relatively low density or with connection to the Great Lakes. High Walleye size structure observed in large lakes connected to the Great Lakes was attributed to movement of large Walleyes to the relatively forage-rich nearshore habitat of the large lakes (Hanchin et al. 2007; Hanchin 2015; Hanchin 2016). Populations with a low percentage of legal-sized Walleyes generally had relatively high density and demonstrated consistent recruitment. The ratio of male to female Walleyes averaged 4.3 (median = 3.5) and values ranged from 1.3 to 12.4. When only legal-sized Walleyes were considered, the average was 3.1 (median = 2.5) and the range was much smaller (1.0 to 7.9).

Northern Pike also exhibited evidence of density-dependence in terms of both size structure and growth. The average and median percentages of legal-sized Northern Pike were 28.1 and 27.6, respectively, and values ranged from 4.0% to 88.2% (Table 3). Few populations had a percentage of legal-sized Northern Pike greater than 50%, which is likely a result of the statewide minimum size limit being high relative to the growth potential of most Northern Pike populations. The percentage of legal-sized Northern Pike was negatively related ($F = 8.87$, $P = 0.008$, $df = 18$) to the density of adult Northern Pike (Figure 4). Additionally, the mean growth index was negatively related ($F = 11.63$, $P = 0.003$, $df = 18$) to the density of adult Northern Pike and was best described using a natural logarithmic function (Figure 5). As was done for Walleyes, the populations with documented migration to the Great Lakes were excluded from analysis. There appeared to be a threshold density of 2 adult Northern Pike per acre, above which all populations exhibited low mean growth indices. At lower densities, the mean growth indices had a broader range, indicating that factors other than density influence growth.

The processes and conditions that affect Northern Pike growth and size structure appear to affect Walleyes similarly across lakes. Both mean growth indices ($F = 10.73$, $P = 0.004$, $df = 20$) and percentages of legal-sized fish ($F = 9.68$, $P = 0.006$, $df = 20$) were positively related when Northern Pike were compared to Walleyes. From this simple comparison alone, it does not appear that Walleye and Northern Pike compete with each other enough to have significant negative effects on one another.

In addition to density-dependence, there is some evidence that Northern Pike growth and size structure were related to the abundance of White Suckers across lakes. The mean growth index for Northern Pike was positively related to both the percentage composition of White Suckers ($F = 8.96$, $P = 0.007$, $df = 20$; Figure 6) and the CPUE of White Suckers in fyke nets ($F = 5.09$, $P = 0.037$, $df = 19$). Additionally, the percentage of legal-sized Northern Pike was positively related to the percentage composition of White Suckers ($F = 17.51$, $P < 0.001$, $df = 20$). Similar relationships between Northern Pike and White Suckers have been documented by others (Jacobson 1992; Bertolo and Magnan 2005); however, I caution that these correlations could simply be spurious given that larger lakes tend to have lower density Northern Pike populations as well as larger tributaries that support White Sucker spawning. It is mentioned here given the occasional practice of sucker removals sometimes justified by the possible negative effect that they may have on Northern Pike. Rather, this analysis suggests the possibility of just the opposite; White Suckers may provide valuable forage to Northern Pike. More research on the relationship between Northern Pike and White Suckers is warranted.

Contrary to Walleyes, the sex ratio for adult Northern Pike did not always favor males. The ratio of male to female Northern Pike averaged 1.5 (median = 1.3) and values ranged from 0.8 to 2.4. When only legal-sized Northern Pike were considered, the average and median were both 0.6 and the range was 0.1 to 1.3. The lower male to female ratio in legal-sized Northern Pike is a result of the growth differences between males and females. In general, female Northern Pike had higher mean length at age as well as higher growth potential. On average, the asymptotic length (L_∞) for females was 9.9 inches greater than for males (37.8 in versus 27.9 in), where both could be estimated (N = 17). Because female Northern Pike made up, on average, 67% of the legal-sized Northern Pike in Large Lake Program surveys, in populations managed with the 24-inch minimum size limit (MSL), angler harvest will likely

Table 5.–Percentage of Walleyes per inch group collected from lakes surveyed in the Large Lakes Program from 2001–2010.

	Lakes surveyed																					
Inch group	Houghton Lake	Michigamme Reservoir	Crooked-Pickerel lakes	Burt Lake	Muskegon River system	South Lake Leelanau	North Lake Leelanau	Cisco Lake chain	S. Manistique Lake	Big Manistique Lake	N. Manistique Lake	Bond Falls Flowage	Grand Lake	Long Lake	Peavy Pond	Black Lake	Lake Gogebic	Lake Michigamme	Lake Charlevoix	Portage-Torch lakes	Elk-Skegemog lakes	Mullett Lake	Indian Lake
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.2
6	0.0	0.0	0.3	0.1	0.0	0.0	8.3	0.0	0.1	0.0	0.0	0.0	1.8	0.0	0.5	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.7
7	0.0	0.1	0.1	0.1	0.0	0.0	4.5	0.0	1.9	0.6	0.0	0.1	4.6	1.6	0.7	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
8	0.0	0.4	0.1	0.0	0.0	0.0	1.3	0.1	1.8	1.0	0.0	0.0	1.6	4.1	2.0	0.0	0.0	0.1	0.5	0.0	0.0	0.0	1.0
9	0.0	0.4	1.2	0.0	0.0	0.2	0.0	0.2	0.1	0.0	0.2	0.1	0.2	0.0	3.1	0.0	0.0	0.1	4.4	0.0	1.3	0.0	2.9
10	0.7	1.2	0.9	0.7	0.0	0.2	1.9	4.6	0.4	0.0	0.0	1.5	3.8	0.0	2.8	0.0	0.2	0.1	1.6	0.1	1.3	0.1	0.8
11	0.6	2.2	1.9	0.6	0.0	0.4	0.6	12.1	1.2	0.1	0.0	7.1	16.3	0.4	3.4	0.0	6.3	0.5	0.0	0.2	1.3	0.0	0.3
12	4.0	3.7	7.9	1.6	0.0	2.2	1.9	16.6	2.9	0.7	0.0	15.9	13.5	2.4	6.3	0.0	12.0	1.3	0.0	0.6	0.0	0.1	6.2
13	12.4	14.5	13.8	12.1	0.0	8.4	6.4	20.8	9.0	3.1	0.0	21.2	4.7	4.9	9.5	0.0	24.2	5.3	0.0	0.6	0.0	0.5	22.6
14	9.6	24.5	21.1	14.9	0.2	19.7	5.1	16.3	8.3	2.0	0.0	19.9	10.2	0.7	18.6	0.5	17.8	15.3	0.2	1.1	0.0	0.0	6.6
15	14.0	23.5	21.1	12.6	0.2	22.1	12.8	10.8	9.5	4.9	0.0	15.1	12.0	5.5	21.1	7.8	9.9	24.9	0.9	4.1	0.0	0.7	8.5
16	19.6	11.6	14.6	13.4	0.8	17.3	11.5	5.4	9.4	3.4	1.0	8.8	13.3	11.1	15.1	26.1	8.8	22.3	5.6	4.0	0.0	5.9	17.7
17	18.1	7.2	9.5	15.6	1.0	11.6	8.3	3.2	10.8	5.1	4.0	4.4	8.5	24.9	7.2	31.2	10.2	13.9	7.3	5.8	0.0	12.9	11.4
18	10.8	6.1	3.9	12.9	1.0	6.6	7.7	1.7	16.0	14.9	14.6	3.0	4.8	24.1	4.6	18.9	5.5	6.6	8.4	5.9	1.3	18.9	5.7
19	4.9	2.2	2.1	7.3	1.9	4.0	8.3	1.4	11.1	26.3	25.2	1.6	1.9	11.7	2.2	9.9	2.0	3.6	10.3	11.6	0.0	18.1	5.1
20	2.3	0.9	1.1	4.2	5.9	2.5	5.8	1.3	6.0	14.3	16.8	0.8	0.9	5.2	1.5	4.0	1.3	2.1	7.5	14.0	1.3	19.1	4.8
21	1.1	0.4	0.2	1.9	11.0	1.7	3.8	1.1	4.2	9.7	18.3	0.3	0.6	2.0	0.3	1.3	1.0	1.2	7.5	14.8	0.0	13.3	2.0
22	0.4	0.4	0.1	0.8	15.3	1.0	2.6	0.9	3.9	7.0	12.4	0.0	0.4	0.9	0.2	0.0	0.5	0.8	6.7	12.8	7.8	5.5	1.0
23	0.5	0.1	0.0	0.5	13.3	0.8	4.5	0.7	1.9	4.2	4.7	0.0	0.3	0.1	0.1	0.1	0.2	0.3	3.9	10.1	15.6	2.7	0.9
24	0.4	0.0	0.0	0.4	12.2	0.3	0.6	0.7	0.9	1.9	2.2	0.1	0.2	0.0	0.1	0.0	0.1	0.5	3.8	6.2	16.9	0.6	0.7
25	0.2	0.1	0.0	0.1	11.0	0.2	0.6	0.7	0.5	0.4	0.2	0.0	0.1	0.1	0.1	0.1	0.0	0.3	5.0	3.0	11.7	0.8	0.6
26	0.1	0.1	0.0	0.1	9.4	0.1	1.3	0.6	0.1	0.2	0.0	0.0	0.1	0.0	0.2	0.0	0.0	0.4	6.6	2.4	6.5	0.5	0.1
27	0.0	0.0	0.0	0.0	6.6	0.2	1.3	0.3	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.2	6.3	1.2	11.7	0.1	0.0
28	0.1	0.0	0.0	0.0	5.2	0.1	0.6	0.3	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.3	5.8	1.0	14.3	0.1	0.0
29	0.0	0.0	0.0	0.0	3.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	4.5	0.3	7.8	0.0	0.0
30	0.0	0.0	0.0	0.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	2.3	0.1	1.3	0.0	0.0
31	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0
32	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N	4,276	2,039	951	2,745	4,635	3,344	156	9,744	3,836	3,693	404	4,286	2,660	750	2,095	995	14,502	1,986	2,107	4,925	77	847	3,498

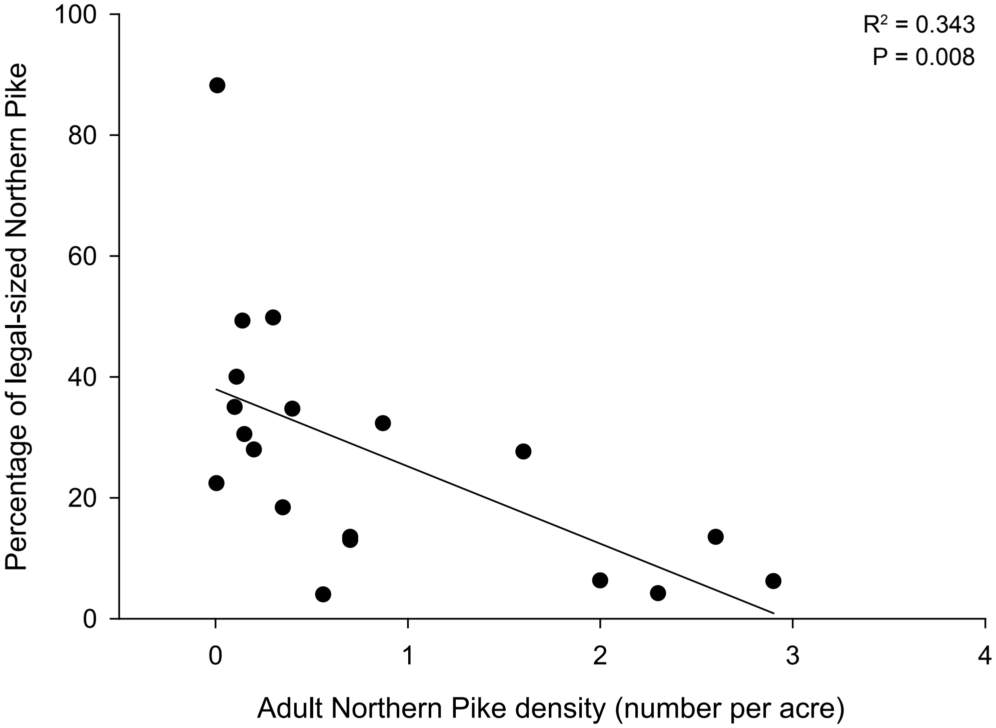


Figure 4.–Relationship between adult Northern Pike density (number per acre) and the percentage of legal-sized Northern Pike observed in Large Lakes Program surveys in 2001 to 2010. The regression equation is: y = -12.778(x) + 37.96.

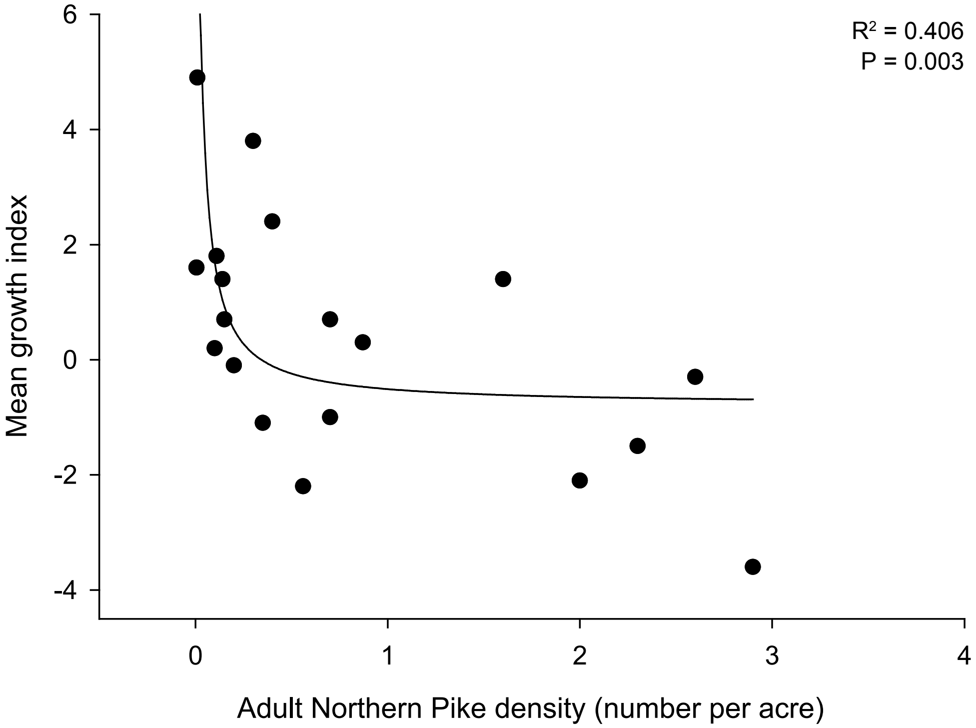


Figure 5.–Relationship between adult Northern Pike density (number per acre) and the mean growth index for Northern Pike observed in Large Lakes Program surveys in 2001 to 2010. The regression equation is: y = -0.765Ln(x) - 0.440.

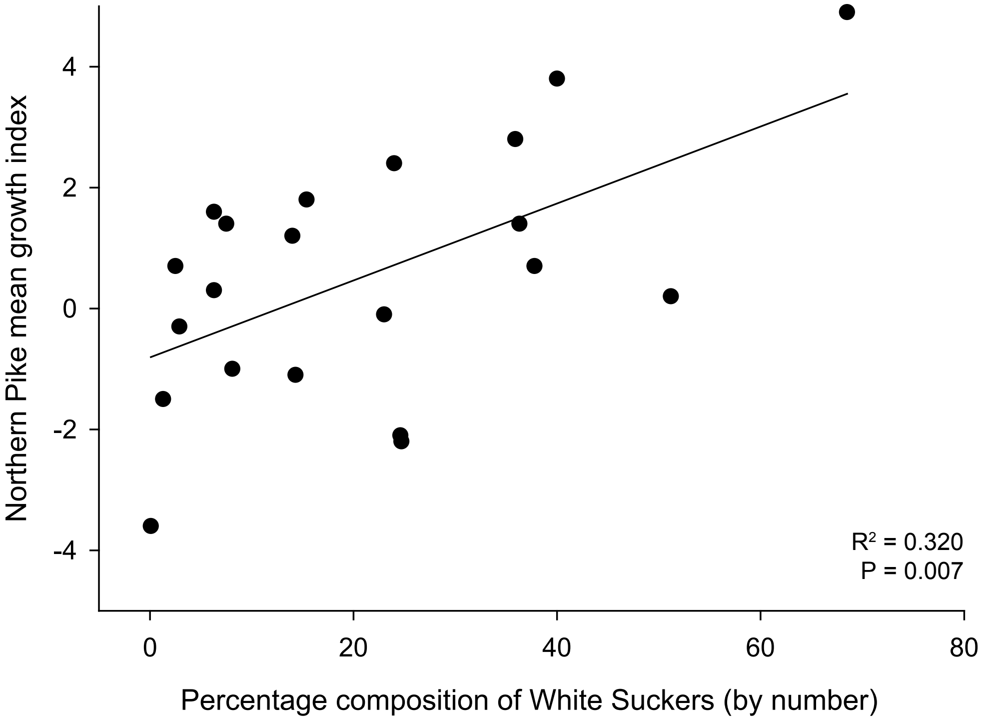


Figure 6.–Relationship between the percentage composition of White Suckers (by number) from spring surveys and the mean growth index for Northern Pike observed in Large Lakes Program surveys from 2001 to 2010.

remove a greater proportion of female Northern Pike. In populations where females make up such a high percentage of the legal-sized population, size regulations should consider the potential effects on both size structure and spawning potential. For example, in Houghton Lake and Lake Leelanau, where 91% and 95%, respectively of the legal-sized Northern Pike were females, there is relatively little harvest of male Northern Pike. While this potential for skewed harvest may not be a problem if angler exploitation is low, it should at least be taken into consideration by managers.

Most Smallmouth Bass populations had a relatively high proportion of large individuals (typically 50% of fish > legal size), especially the larger lakes in the northern Lower Peninsula. The average and median percentages of legal-sized Smallmouth Bass were 63.7 and 69.4, respectively, and values ranged from 13.4% to 95.5% (Table 4). Populations in the western Upper Peninsula tended to have lower size structure. It is unknown whether that may be due to higher abundance and density-dependent growth or simply lower lake productivity causing slower bass growth. No relationships between density and growth or size structure were evident (all p values > 0.25). It is possible that data from more populations are needed to detect a relationship, or alternatively, perhaps lower size-structure in western Upper Peninsula lakes results from generally lower lake productivity in that region.

Abundance

Multiple-census and single-census abundance estimates differed significantly for legal-sized Walleyes ($Z = -3.680$, $df = 17$, $P < 0.001$). For all analyses of Walleye population estimates, I removed populations for which one or both estimates did not meet minimum recapture or CV requirements. Populations removed were the Muskegon River system, South and North Lake Leelanau, Elk-Skegemog lakes, and Mullett Lake. Although multiple- and single-census estimates were positively correlated ($r = 0.879$, $N = 18$, $P < 0.001$), multiple-census estimates were lower than single-census estimates in 17 of 18 lakes used in the analysis (Table 6); in fact, multiple-census estimates were on average 41% lower than single-census estimates.

Table 6.–Walleye population estimates based on multiple-census (Schumacher-Eschmeyer) and single-census (Chapman-Petersen) methods from lakes surveyed in the Large Lakes Program from 2001–2010. Dash (–) indicates no estimate. Coefficient of variation (CV) = SD/mean.

	Adult Walleye[a] (Schumacher-Eschmeyer)		Adult Walleye[a] (Chapman-Petersen)		Legal-sized[b] Walleye (Schumacher-Eschmeyer)		Legal-sized[b] Walleye (Chapman-Petersen)	
Lake	Estimates	CV	Estimates	CV	Estimates	CV	Estimates	CV
Houghton Lake	50,109	0.10	68,495	0.23	38,656	0.10	58,854	0.23
Michigamme Reservoir	5,384	0.17	16,859	0.14	2,371	0.15	9,540	0.14
Crooked-Pickerel lakes	9,552	0.13	12,346	0.27	4,825	0.15	7,049	0.27
Burt Lake	21,832	0.10	42,032	0.18	13,622	0.10	32,295	0.18
Muskegon River system	17,372	0.28	99,678[c]	0.49	14,532	0.31	99,506[c]	0.49
South Lake Leelanau	40,760	0.18	–	–	20,971	0.18	–	–
North Lake Leelanau	1,868[c]	0.66	–	–	1,514[c]	0.86	–	–
Cisco Lake chain	40,239	0.07	40,823	0.11	7,236	0.06	12,558	0.12
South Manistique Lake	7,558	0.05	7,898	0.08	5,505	0.05	6,473	0.08
Big Manistique Lake	8,070	0.04	11,856	0.13	7,384	0.04	11,350	0.13
North Manistique Lake	1,827	0.11	1,576	0.29	1,827	0.11	1,576	0.29
Bond Falls Flowage	12,501	0.08	12,906	0.13	4,631	0.09	7,015	0.13
Grand Lake	3,634	0.05	4,641	0.23	2,308	0.05	3,308	0.23
Long Lake	2,842	0.11	3,695	0.34	2,760	0.11	3,649	0.34
Peavy Pond	6,011	0.09	6,753	0.12	2,614	0.07	4,082	0.12
Black Lake	8,252	0.10	14,013	0.27	7,442	0.11	13,943	0.27
Lake Gogebic	32,190	0.05	103,916	0.16	7,789	0.08	41,402	0.16
Lake Michigamme	5,965	0.09	10,392	0.14	4,615	0.10	8,241	0.14
Lake Charlevoix	4,318	0.06	9,859	0.14	4,335	0.06	9,844	0.14
Portage-Torch lakes	17,147	0.06	42,231	0.09	16,911	0.06	41,795	0.09
Elk-Skegemog lakes	600	0.31	–	–	600	0.31	–	–
Mullett Lake	2,374	0.24	7,494[c]	0.55	2,364	0.24	7,476[c]	0.55
Indian Lake	7,176	0.09	14,102	0.20	3,782	0.08	8,995	0.20
Mean	13,373	0.14	26,578	0.21	7,765	0.15	19,448	0.22
Median	7,558	0.10	12,626	0.17	4,631	0.10	9,268	0.17

[a] Adult Walleye were defined as those of legal size and sexually-mature fish of sub-legal size on spawning grounds.

[b] Legal-sized Walleye were defined as those ≥ 15 in.

[c] Estimate did not meet minimum requirement for recaptures or coefficient of variation (CV)

While single-census estimates were consistently higher than multiple-census estimates, the difference increased with lake size (Figure 7; $r = 0.703$, $N = 18$, $P = 0.001$). However, the differences between methods were still substantial in lakes less than 5,000 acres, averaging 27%.

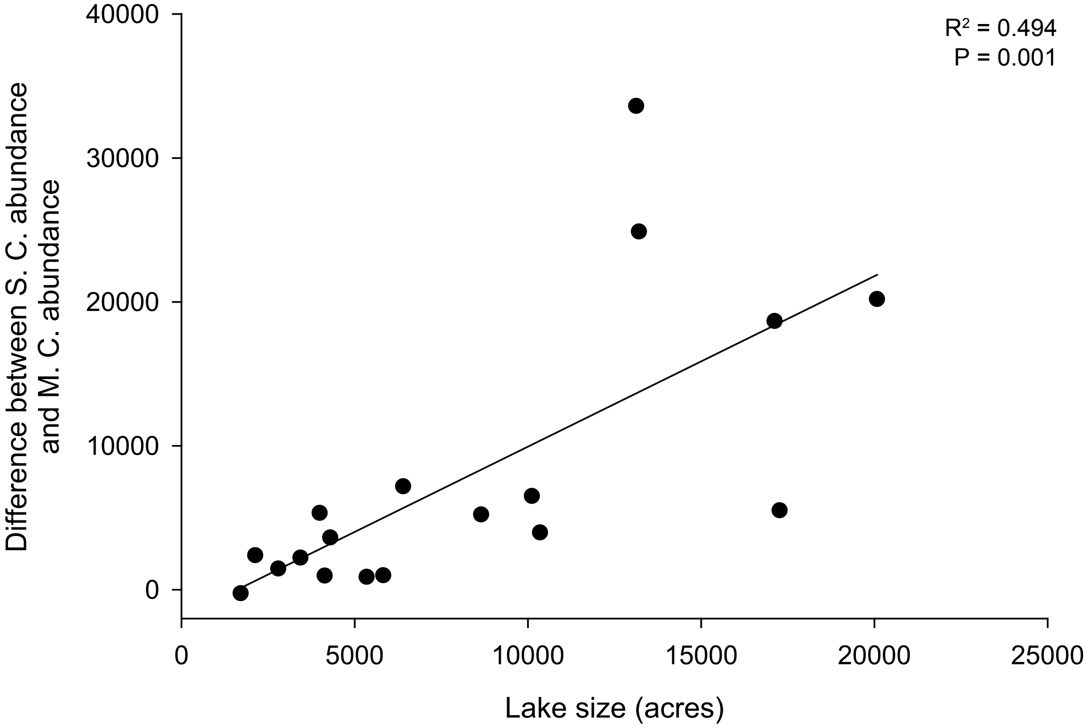


Figure 7.–Relationship between lake size (acres) and the difference between the single- and multiple-census estimates for legal-sized Walleyes in Large Lakes Program surveys from 2001 to 2010.

Adult Walleye abundance estimates were more similar to each other than estimates for legal-sized Walleyes were, especially in smaller lakes. The difference between multiple- and single-census estimates of adult Walleye abundance was again positively correlated with lake size ($r = 0.515$, $N = 18$, $P = 0.029$); however, the differences between methods were less, and in lakes less than 5,000 acres they averaged 10%. Thus, perhaps multiple-census methods are more suitable for use in smaller lakes. Pierce (1997) found the best agreement between multiple- and single-census estimates of spawning Northern Pike abundance in the smallest (62 acres) of six lakes, and thought that it was due to more effective sampling of the population given the size of the lake. While our lakes were much larger, it appears that in lakes less than around 2,000 acres (Figure 8) the difference between multiple- and single-census estimates of adult Walleye abundance would be negligible. However, more information from smaller lakes would help to corroborate this speculation.

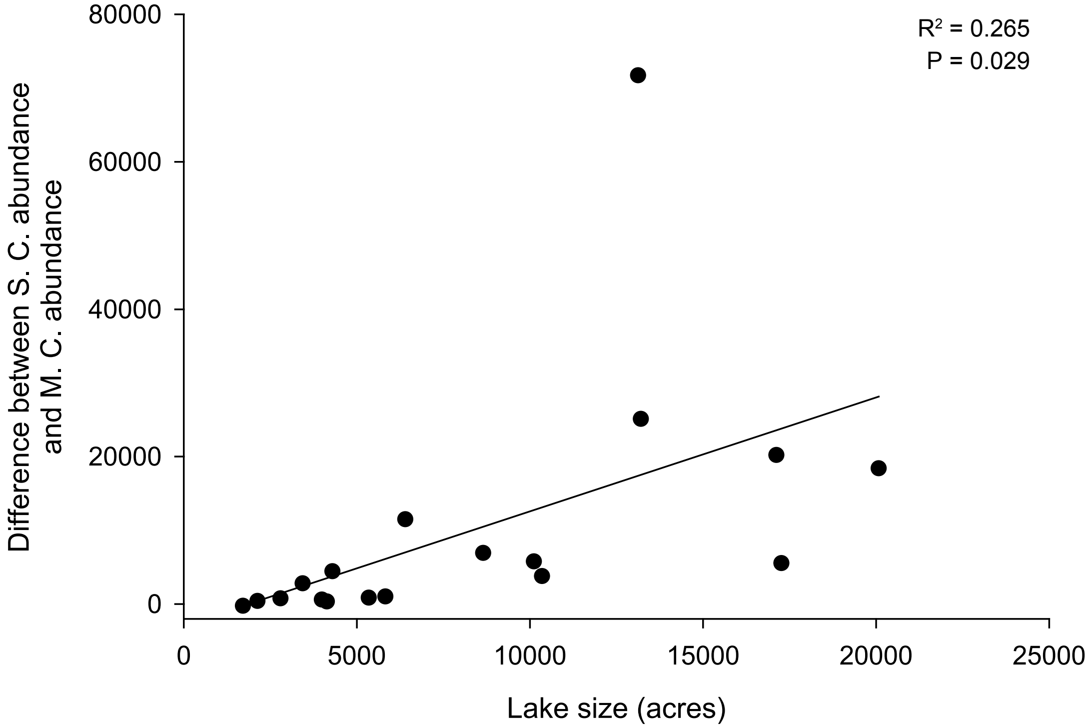


Figure 8.–Relationship between lake size (acres) and the difference between the single- and multiple-census estimates for adult Walleyes in Large Lakes Program surveys from 2001 to 2010.

Given the disparity between the multiple- and single-census estimates, I compared the census estimates to the independently-derived harvest and exploitation estimates in order to gauge their apparent accuracy. For example, the Walleye exploitation estimates made by dividing the harvest estimates by the multiple-census abundance estimates were on average 158% higher than the tag-return exploitation estimates (independent of abundance estimates), while the exploitation estimates made by dividing the harvest estimates by the single-census abundance estimates were only 44% higher. I consider the tag-return estimates to be minimum values; thus, the positive biases of the other exploitation estimates are both reasonable. However, I do not believe that nonreporting was significant enough to suggest that the true Walleye exploitation rates were, on average, 2.6 times higher than the tag-return estimates, which would have been the case if the multiple-census abundance estimates were accurate. Obviously there are other factors to consider such as the validity of the actual harvest estimate; however, all things being held equal, the single-census abundance estimates for legal-sized Walleyes seem to be more comparable to the other independently-derived estimates. Pierce (1997) suggested that multiple-census estimates made during the onshore spawning migration of Northern Pike are likely biased low due to size selectivity and unequal vulnerability of fish to nearshore netting. Additionally, multiple-census methods have the potential problem of incomplete mixing, which is not a problem with the single-census method given that it allows sufficient time for marked fish to fully mix with unmarked fish. In comparing surveys conducted similarly to ours, Pierce (1997) concluded that recapturing fish at a later time with a second gear type resulted in estimates that were more valid. One disadvantage of the single-census estimates, however, is lower precision. The average CV values for the single-census estimates were 0.21 (adult) and 0.22 (legal-sized) while the average CV values for the multiple-census estimates were 0.14 (adult) and 0.15 (legal-sized). Thus, our single-census methods may be more accurate, but less precise than the multiple-census methods.

In addition to comparing methods for estimating abundance, another goal of the study was to evaluate the adjustment of the recapture sample for fish that recruited to legal size over the course of the creel surveys. While there was initially some concern that fin-clipped fish may have recruited at a different rate to legal size than unclipped fish, there was little evidence for this difference. The difference between the adjusted and unadjusted R/C ratio was positively related to the month following tagging ($F = 19.018$, $df = 7$, $P = 0.005$). This likely resulted from the removal of unmarked fish at a higher proportion than marked fish, especially as the year progressed. In fact, it was occasionally noted that the length used to distinguish fish that had recruited to legal size in a given month would have resulted in the removal of tagged fish, which were known to be of legal size at the time of marking. Thus, either the growth increment was too large, resulting in the removal of too many unmarked fish or the tags were having a negative effect on growth. While it is possible that tags could have a negative effect on growth, it is more likely that the process for removal of marked and unmarked fish from analysis was flawed as evidenced by the large increase in the proportion of unmarked fish removed across months (Figure 9). Additionally, unmarked fish measured in the creel surveys were actually about 1.0 inches smaller ($F = 39.620$, $df = 1$, $P < 0.001$) than marked fish; thus, we expected more of them to be removed than marked fish. If tags were having a negative effect on growth, one would expect to remove a higher proportion of marked fish. For example, a 15-inch Walleye tagged in April might only grow to 15.2 inches by June, while an unmarked Walleye might grow to 15.4 inches. If the length criteria used in June to remove fish from analysis was 15.3 inches, the marked fish would be removed, but the unmarked one would not. Overall it appears likely that the assumption of a six-month growing season (Schneider et al. 2000) is inaccurate for the populations surveyed in this study. In hindsight, the removal of any fish from analysis was likely unnecessary and the assumption could have been made that both clipped and unclipped fish of sublegal size would recruit to legal size at the same rate. The only situation in which unmarked fish would have to be removed from analysis is one in which a minimum size was used for marking and the recapture period was extensive. In that case, the only fish recruiting to the size of interest would be unmarked fish.

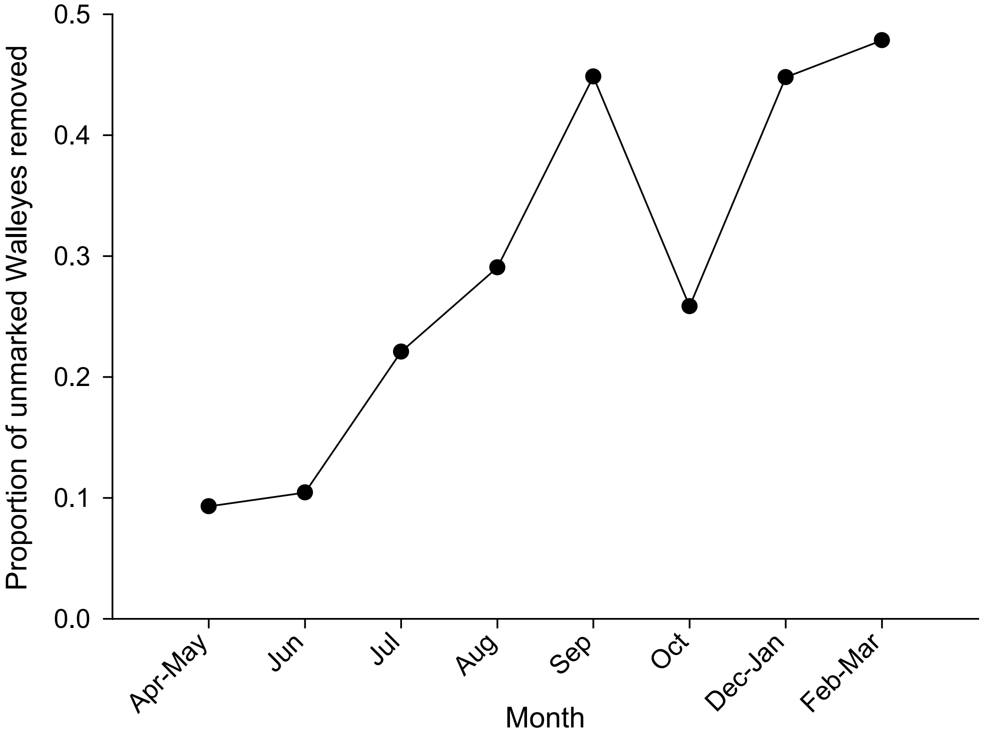


Figure 9.–Proportion of unmarked Walleyes removed from recapture samples obtained during creel surveys conducted as part of Large Lakes Program surveys from 2001 to 2010.

Despite the problems associated with the adjustment of the R/C ratio, I was able to evaluate seasonal trends in the unadjusted R/C ratio to assess potential tag loss, poor mark recognition, or marked/tagged fish growing slower than unmarked ones. Neither the unadjusted R/C (F = 1.829, df = 7, P = 0.225) nor the adjusted R/C (F = 0.116, df = 7, P = 0.745) significantly declined when the entire angling season was evaluated (Figures 10 and 11). In fact, there appeared to be a general decline in the R/C ratio from April/May to September and a subsequent incline from October to February/March. When only the open-water period was evaluated the unadjusted R/C declined significantly (F = 19.394, df = 5, P = 0.012), from a value of $\alpha = 0.210$ in Apr/May at a rate of $\beta = -0.241$, and the adjusted R/C ratio declined significantly (F = 20.561, df = 5, P = 0.011), from a value of $\alpha = 0.221$ in Apr/May at a rate of $\beta = -0.170$. The lack of a consistent trend throughout the angling season obscured interpretation; however, Deroba et al. (2005) also found a slight increase in the R/C ratio of Walleyes in the latter portion of the angling season. Overall, Deroba at al. (2005) concluded that fin regeneration, lack of mark recognition, or mortality resulting from marking were problematic, while recruitment of unmarked fish and slowed growth resulting from fin-clipping were not. Similarly, the decline in the R/C ratios we observed during the open-water period could have been the result of tag loss, poor mark recognition, or marked/tagged fish growing slower than unmarked ones. In order to test for a negative effect of jaw tags on growth, I compared the trends in the R/C ratio between the two length groups (15–18 in and >18 in). If marks/tags were affecting growth, the 15–18 inch group would be both gaining (from sublegal fish) and losing (to the 18 in and larger group) unmarked fish, while the 18 inch and larger group would only be gaining unmarked fish. Thus, 18-inch and larger Walleyes would potentially show a decreasing trend in the R/C ratio. Neither the R/C ratio for 15- to 18-inch Walleyes (F = 3.894, df = 7, P = 0.096), nor the R/C ratio for 18-inch and larger Walleyes (F = 0.017, df = 7, P = 0.900) significantly decreased or increased over the course of the angling season following tagging. In fact, the length class (>18 in) expected to have a decreasing trend in R/C if tags were affecting growth actually had a steeper increase in R/C from September to March. Thus, it appears likely that loss or poor recognition of marks was affecting the R/C ratio more than a potential negative effect of tags on growth.

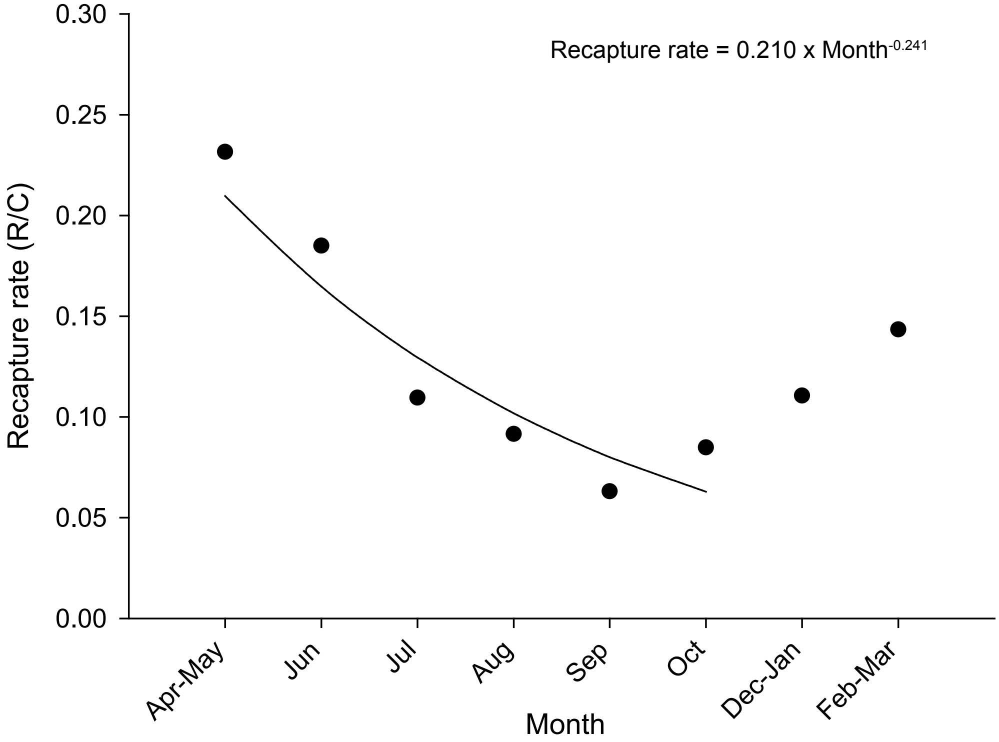


Figure 10.–Unadjusted recapture rate (R/C) of Walleyes observed during creel surveys conducted as part of Large Lakes Program surveys from 2001 to 2010. Equation represents recapture rate from April-May through October.

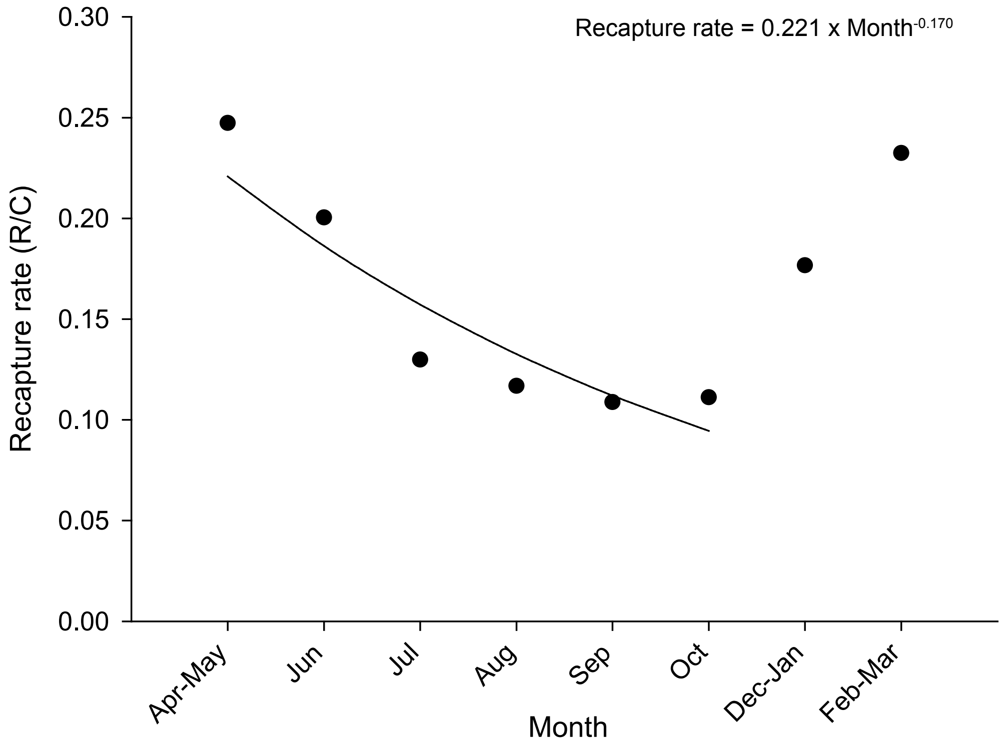


Figure 11.–Adjusted recapture rate (R/C) of Walleyes observed during creel surveys conducted as part of Large Lakes Program surveys from 2001 to 2010. Equation represents recapture rate from April-May through October.

The results of our analysis were not conclusive, but it appeared that both nondetection of marks or mortality due to marking were more likely to affect the R/C ratio than tag loss. Since Walleyes were double-marked, the likelihood of a fish losing its tag and regenerating its fin, resulting in nondetection as a marked individual, was low. Moreover, first-year jaw tag retention for Walleyes averaged 96.8% ($N = 20$ lakes) over the course of the study. It is possible that the R/C ratio declined during the open-water portion of the creel survey when clerks had more difficulty observing fish while they were interviewing from boats, and then increased during the ice-cover portion of the creel survey when the clerks were interviewing anglers on the ice. Another explanation for the decreasing and then increasing trend observed in the R/C ratio is a possible seasonal segregation of mature and immature Walleyes. Early in the season mature Walleyes are somewhat segregated from immature ones, and anglers often fish in relatively shallow water where the mature fish are still residing. The R/C ratio is relatively high during this time. From late spring through the fall, mature fish move to deeper water and gradually become mixed with immature fish. This mixing correlates with the decline in the R/C ratio. The increase in the R/C ratio observed from October through mid-March may suggest that mature and immature Walleyes are again becoming segregated.

The evaluation of Northern Pike abundance estimates did not result in many meaningful results. Multiple-census and single-census abundance estimates were not significantly different for legal-sized Northern Pike ($Z = -0.314$, $df = 5$, $P = 0.753$) though only 6 populations had valid estimates for comparison (Table 7). Although they were positively correlated ($r = 0.977$, $N = 6$, $P < 0.001$) the significant relationship was largely the result of the outlying data point for the Portage-Torch lake system where Northern Pike abundance was an order of magnitude higher than the other five lakes. Similar to Walleyes, the R/C ratio did not significantly decline ($F = 1.468$, $df = 7$, $P = 0.271$) when the entire angling season was evaluated, but it was nearly significant ($F = 6.219$, $df = 7$, $P = 0.067$) when only the open-water portion was considered. The Northern Pike data had lower sample sizes and more variation

Table 7.–Northern Pike population estimates based on multiple-census (Schumacher-Eschmeyer) and single-census (Chapman-Petersen) methods from lakes surveyed in the Large Lakes Program from 2001–2010. Dash (–) indicates no estimate. Coefficient of variation (CV) = SD/mean.

	Adult Northern Pike[a] (Schumacher-Eschmeyer)		Adult Northern Pike[a] (Chapman-Petersen)		Legal-sized[b] Northern Pike (Schumacher-Eschmeyer)		Legal-sized[b] Northern Pike (Chapman-Petersen)	
Lake	Estimates	CV	Estimates	CV	Estimates	CV	Estimates	CV
Houghton Lake	5,696	0.25	32,846[c]	0.44	1,575	0.29	10,584[c]	0.44
Michigamme Reservoir	4,299	0.14	13,052[c]	0.42	234	0.20	842[c]	0.42
Crooked-Pickerel lakes	1,921	0.29	628[c]	0.61	–	–	48[c]	0.61
Burt Lake	703	0.27	1,779[c]	0.68	332[c]	0.46	910[c]	0.68
Lake Leelanau	6,349	0.20	–	–	282	0.16	–	–
Cisco Lake chain	11,404	0.13	18,425[c]	0.65	584	0.16	1,182[c]	0.65
South Manistique Lake	1,907[c]	0.59	2,881[c]	0.57	164[c]	0.52	846[c]	0.57
Big Manistique Lake	2,901	0.39	3,642[c]	0.56	6,195[c]	1.21	2,156[c]	0.56
North Manistique Lake	–	–	36[c]	0.41	–	–	32[c]	0.41
Bond Falls Flowage	5,538	0.15	6,510[c]	0.54	164	0.21	918[c]	0.54
Grand Lake	808	0.19	280	0.20	331	0.23	124	0.20
Long Lake	1,887	0.16	1,348[c]	0.45	599	0.16	600[c]	0.45
Peavy Pond	4,740	0.06	5,937	0.30	172	0.14	267	0.30
Black Lake	2,879	0.04	8,826[c]	0.42	883	0.11	3,136[c]	0.42
Lake Gogebic	4,538	0.29	3,271	0.34	813	0.36	659	0.34
Lake Michigamme	671	0.15	2,448[c]	0.52	272	0.19	858[c]	0.52
Lake Charlevoix	690	0.09	903	0.19	264	0.09	546	0.19
Portage-Torch lakes	7,370	0.24	16,006	0.26	2,740	0.23	7,269	0.26
Elk-Skegemog lakes	1,187	0.17	680	0.27	629	0.21	416	0.27
Mullett Lake	3,157	0.26	6,052[c]	0.69	815	0.23	2,023[c]	0.69
Indian Lake	510	0.81	1,404[c]	0.70	49[c]	0.71	396[c]	0.70
Mean	3,458	0.24	6,348	0.46	900	0.31	1,691	0.46
Median	2,890	0.20	3,076	0.45	332	0.21	844	0.45

[a] Adult Northern Pike were defined as those of legal size and sexually-mature fish of sub-legal size on spawning grounds.

[b] Legal-sized Northern Pike were defined as those ≥ 24 in.

[c] Estimate did not meet minimum requirement for recaptures or coefficient of variation (CV)

than Walleye data, but it appears that they may be similarly affected by nondetection of marks/tags or a seasonal segregation between mature and immature fish. As mentioned previously for Walleyes, multiple-census methods have the potential problem of incomplete mixing and being biased low due to size selectivity and unequal vulnerability of fish to nearshore netting (Pierce 1997). Although these are not problems with the single-census method we used, for Northern Pike the use of a creel survey for the recapture samples was ineffective in most lakes. Given Pierce's (1997) recommendation to recapture Northern Pike at a later time with a second gear type, additional recapture methods such as gill nets should be considered to improve the sample size for Northern Pike abundance estimates.

Using the best estimates of Walleye abundance, density of legal-sized Walleyes averaged 1.9 fish per acre (range = 0.1 to 4.6 fish/acre), though the median (1.5 fish per acre) was a better measure of central tendency for these skewed data (Table 8; Figure 12). The most frequently occurring density observed during the course of the study was from 0 to 1 legal-sized Walleye per acre and 74% of populations had less than 3 legal-sized Walleyes per acre. Adult Walleye density averaged 3.0 fish per acre (range = 0.1 to 10.2 fish per acre) with a median value of 2.4 fish/acre. The most frequently occurring density for adult Walleyes was from 0 to 1 fish per acre (Figure 13) and only 35% of populations exceeded the recommendation for "good" Walleye populations of 3 adult Walleyes per acre (Schneider et al. 2007). Adult Walleye density in this study was higher than the average density reported by Nate et al. (2000) for 131 Wisconsin lakes having natural reproduction. The lakes reported by Nate et al. (2000) ranged in size from 100 to over 10,000 acres and were randomly selected from Walleye lakes subject to state-licensed angling and tribe-licensed spearing. It is possible that the higher average density observed in our lakes is due to the fact that we purposely selected lakes known to have abundant Walleye populations rather than using a random selection. It is worth reiterating that the single-census estimates of adult Walleye abundance were not true mark-recapture estimates since they were essentially the estimates for legal-sized Walleyes that were adjusted to account for sublegal mature Walleyes that were on the spawning grounds. It is uncertain how this would compare to a true mark-recapture estimate of adults if anglers had been allowed to harvest Walleyes less than 15 inches. Trap nets are selective for larger Walleyes (Laarman and Ryckman 1982) while angling is selective for smaller Walleyes (Myers et al. 2014).

Adult Walleye density was positively related to fyke-net CPUE ($r = 0.678$, $N = 22$, $P = 0.001$), but it was not related to trap-net CPUE ($r = 0.108$, $N = 17$, $P = 0.679$) during the spring surveys. Although trap nets were not used in several of the western U.P. lakes, it appears that fyke-net CPUE is the preferred index of relative abundance for surveys of spawning Walleyes. Rogers et al. (2003) also found that fyke-net CPUE was positively related to adult Walleye density in northern Wisconsin lakes. Although sample size was low, adult Walleye density was not related ($r = 0.021$, $N = 10$, $P = 0.953$) to the CPUE in 125-foot, graded-mesh experimental gill nets used in the summer Status and Trends surveys. Adult Walleye density was not significantly related to measures of productivity such as total phosphorous or Chlorophyll-α, though there was some weak indication ($r = 0.409$, $N = 20$, $P = 0.074$) that adult Walleye density was positively related to total phosphorous when the nonparametric test was used. Adult Walleye abundance was positively related to lake surface area ($r = 0.423$, $N = 22$, $P = 0.050$), but it was not related to area of the littoral zone calculated as the area of the lake equal to or less than 15 feet deep.

For lakes surveyed under the Large Lakes Program from 2000 to 2010 the density of legal-sized Northern Pike averaged 0.12 fish per acre (range = 0.01 to 0.60 fish/acre; Table 9), though the median (0.06 fish per acre) was a better measure of central tendency for these skewed data (Figure 14). The most frequently occurring density observed during the course of the study was from 0 to 0.1 legal-sized Northern Pike per acre and no populations exceeded 0.6 legal-sized Northern Pike per acre. Adult Northern Pike density averaged 0.8 fish per acre (range = 0.1 to 2.9 fish per acre; Table 9) with a median value of 0.4 fish/acre. The most frequently occurring density for adult Northern Pike was from 0 to 0.2 fish per acre (Figure 15). Adult Northern Pike density was lower than the average (9.3 fish ≥ 14 in per acre) reported for Minnesota lakes (Pierce and Tomcko 2005), but the lakes were much

Table 8.–Walleye population parameters from lakes surveyed in the Large Lakes Program from 2001–2010. Dash (–) indicates no estimate.

Lake	Estimated number Adult Walleyes	Estimated number Legal-sized Walleyes	Adult density (number/acre)	Legal-sized[a] density (number/acre)	Total annual mortality (%)	Mean growth index[b]	Asymptotic total length (in)	Recruitment coefficient of determination
Houghton Lake	68,495	58,854	3.4	2.9	46.4	-1.8	26.6	0.86
Michigamme Reservoir	16,859	9,540	2.6	1.5	37.1	-2.8	20.1	0.87
Crooked-Pickerel lakes	12,346	7,049	3.6	2.1	50.6	-2.9	18.6	0.94
Burt Lake	42,032	32,295	2.4	1.9	37.5	-0.5	22.2	0.93
Muskegon River system	37,890	37,851	4.6	4.6	37.9	4.0	27.0	0.67
South Lake Leelanau	51,930	34,154	9.3	6.0	38.5	-2.4	21.2	0.98
North Lake Leelanau	3,735	1,798	1.0	0.6	23.9	-0.6	24.6	0.68
Cisco Lake chain	40,823	12,558	10.2	3.0	30.2	-2.1	29.4	0.86
South Manistique Lake	7,898	6,473	1.9	1.6	29.0	-0.3	23.1	0.78
Big Manistique Lake	11,856	11,350	1.1	1.1	31.0	0.6	23.3	0.90
North Manistique Lake	1,576	1,576	0.9	0.9	35.8	1.1	24.0	0.80
Bond Falls Flowage	12,906	7,015	6.1	3.3	45.3	-2.7	20.1	0.79
Grand Lake	4,641	3,308	0.8	0.6	43.4	-1.4	24.8	0.82
Long Lake	3,695	3,649	0.7	0.7	56.6	-0.4	22.4	0.91
Peavy Pond	6,753	4,082	2.4	1.5	44.2	-2.4	21.2	0.91
Black Lake	14,013	13,943	1.4	1.4	48.8	-0.9	20.6	0.80
Lake Gogebic	103,916	41,402	7.9	3.2	47.6	-1.9	23.8	0.88
Lake Michigamme	10,392	8,241	2.4	1.9	40.9	-3.1	25.5	0.96
Lake Charlevoix	9,859	9,844	0.6	0.6	–	3.0	27.5	0.06
Portage-Torch lakes	42,231	41,795	3.2	3.2	51.7	1.9	29.6	0.64
Elk-Skegemog lakes	600	600	0.1	0.1	–	4.1	27.6	–
Mullett Lake	2,648	2,640	0.2	0.2	26.4	0.9	22.2	0.60
Indian Lake	11086	6,033	1.3	0.7	25.3	-0.4	23.0	0.66
Mean	22,530	15,480	3.0	1.9	39.4	-0.5	23.8	0.79
Median	11,856	8,241	2.4	1.5	38.5	-0.6	23.3	0.84

[a] Greater than or equal to 15 inches.

[b] The mean deviation from the statewide quarterly average calculated using dorsal spines. Only age groups where N ≥ 5 were used.

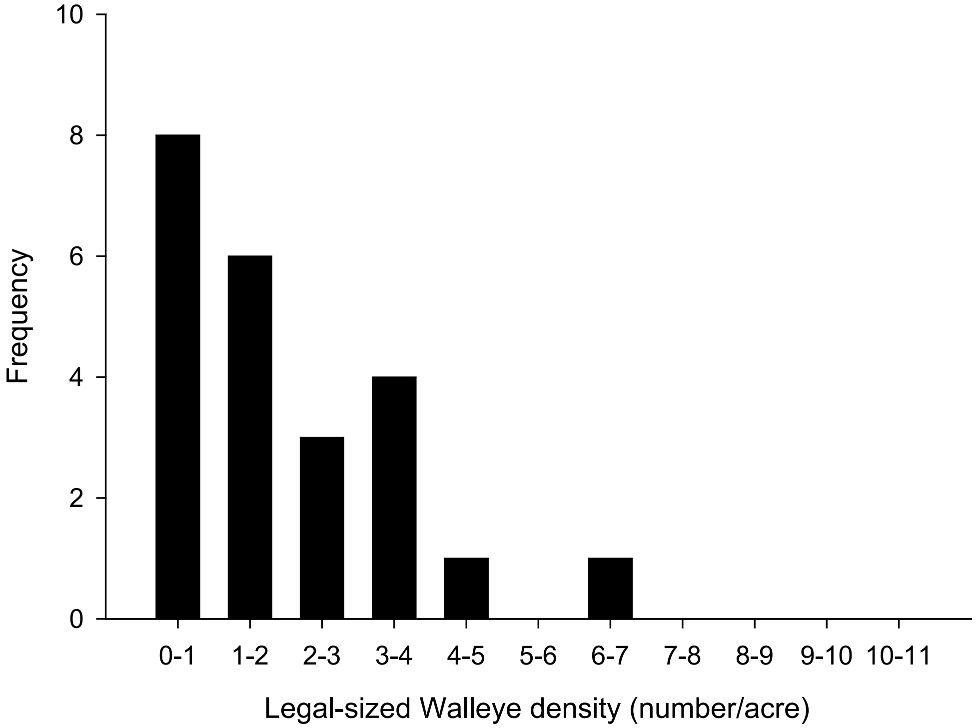


Figure 12.–Distribution of legal-sized (≥ 15 in) Walleye densities from Large Lakes Program surveys from 2001 to 2010.

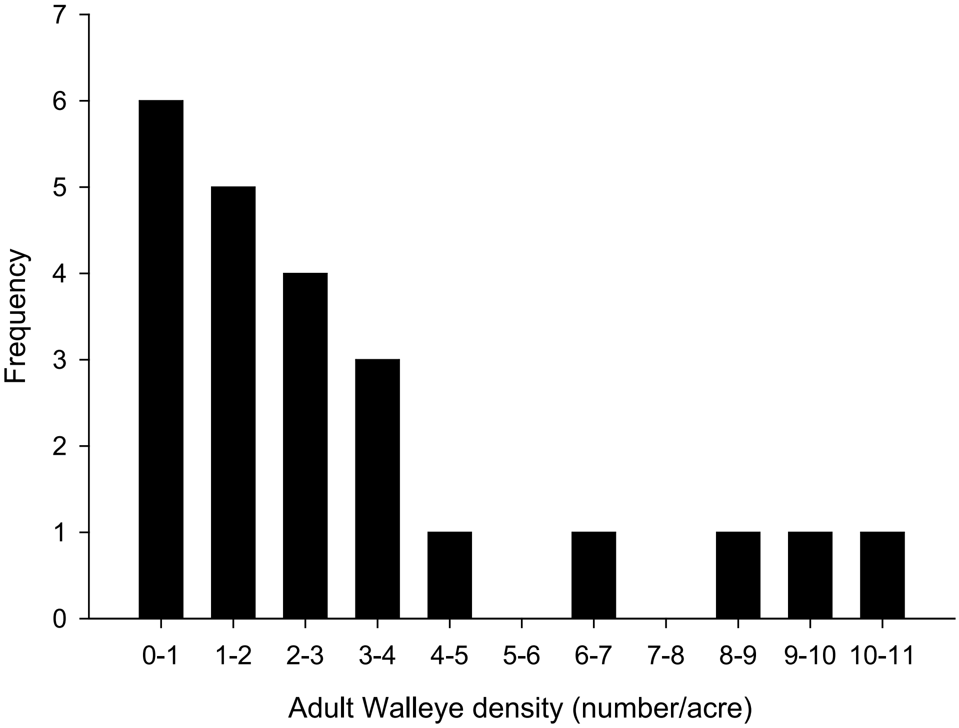


Figure 13.–Distribution of adult Walleye densities from Large Lakes Program surveys from 2001 to 2010.

Table 9.–Northern Pike population parameters from lakes surveyed in the Large Lakes Program from 2001–2010. Dash (–) indicates no estimate.

Lake	Estimated number: Adult Northern Pike	Estimated number: Legal-sized Northern Pike	Adult density (number/acre)	Legal-sized[a] density (number/acre)	Total annual mortality (%)	Mean growth index[b]	Asymptotic total length (in)	Recruitment coefficient of determination
Houghton Lake	32,846	10,584	1.6	0.53	51.0	1.4	45.0	0.99
Michigamme Reservoir	13,052	842	2.0	0.13	63.0	-2.1	40.2	0.85
Crooked-Pickerel lakes	1,921	–	0.6	0.01	63.1	-2.2	29.2	1.00
Burt Lake	1,779	910	0.1	0.05	35.7	0.2	35.9	0.80
Lake Leelanau	6,349	282	0.7	0.03	55.5	0.7	37.5	0.93
Cisco Lake chain	11,404	584	2.9	0.15	64.0	-3.6	25.6	0.98
South Manistique Lake	2,881	846	0.7	0.20	47.8	-1.0	27.3	0.87
Big Manistique Lake	2,901	–	0.3	0.01	31.4	3.8	49.0	0.79
North Manistique Lake	–	–	0.0	0.01	35.8	4.9	33.3	0.79
Bond Falls Flowage	5,538	164	2.6	0.05	57.0	-0.3	43.9	0.97
Grand Lake	808	331	0.1	0.06	49.5	1.4	34.8	0.86
Long Lake	1,887	599	0.4	0.11	47.6	2.4	37.1	0.90
Peavy Pond	6,336	267	2.3	0.11	51.2	-1.5	44.2	0.98
Black Lake	8,826	3,136	0.9	0.31	61.8	0.3	34.8	0.96
Lake Gogebic	4,538	813	0.4	0.06	54.4	-1.1	50.9	0.85
Lake Michigamme	671	272	0.2	0.06	47.5	0.7	39.7	0.95
Lake Charlevoix	903	546	0.1	0.03	29.3	2.8	33.3	0.58
Portage-Torch lakes	16,006	7,269	1.2	0.60	43.2	1.2	39.7	0.90
Elk-Skegemog lakes	1,187	629	0.1	0.06	33.8	1.8	35.2	0.92
Mullett Lake	3,157	815	0.2	0.05	48.4	-0.1	30.3	0.92
Indian Lake	–	–	0.0	0.00	43.6	1.6	35.1	0.94
Mean	6,473	2,058	0.8	0.12	48.3	0.5	37.2	0.89
Median	3,157	815	0.4	0.06	48.4	0.7	35.9	0.92

[a] Greater than or equal to 24 inches.

[b] The mean deviation from the statewide quarterly average calculated using dorsal fin rays. Only age groups where N ≥ 5 were used.

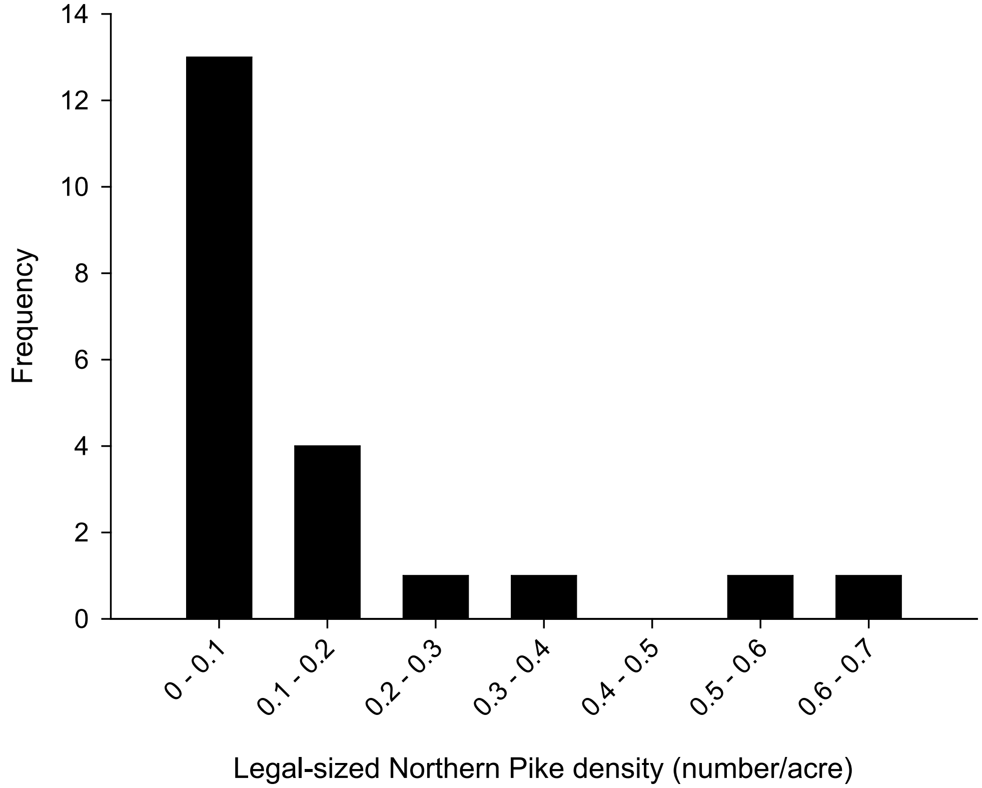


Figure 14.–Distribution of legal-sized (≥24 in) Northern Pike densities from Large Lakes Program surveys from 2001 to 2010.

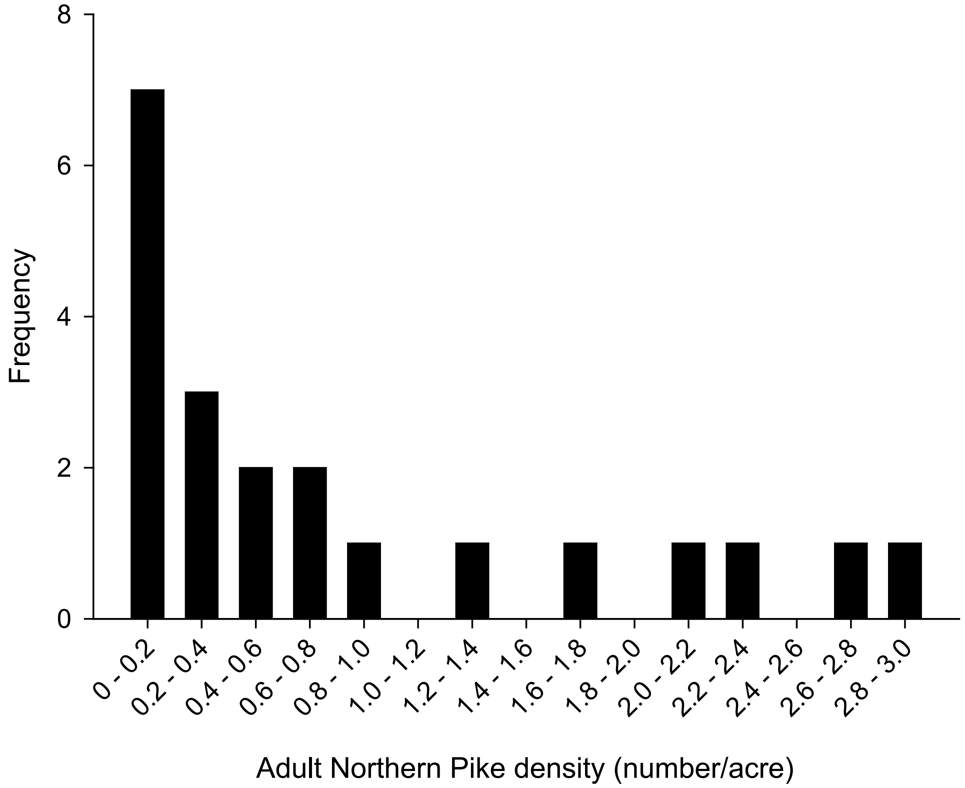


Figure 15.–Distribution of adult Northern Pike densities from Large Lakes Program surveys from 2001 to 2010.

smaller than the ones surveyed in our program. Adult Northern Pike density was positively related to both fyke-net CPUE ($r = 0.855$, $N = 20$, $P < 0.001$) and trap-net CPUE ($r = 0.698$, $N = 15$, $P = 0.004$); thus, either should be suitable indices of relative abundance for surveys of spawning Northern Pike. Although not statistically significant ($r = 0.583$, $N = 10$, $P = 0.077$), the nonparametric relationship between adult Northern Pike density and CPUE in 125-foot, graded-mesh experimental gill nets used in the summer Status and Trends surveys shows some promise that it could be used as an index of relative abundance. Density of legal-sized Northern Pike was positively related ($r = 0.754$, $N = 18$, $P < 0.001$) to Chlorophyll-α, but density of adult Northern Pike was not. Adult Northern Pike density was, however, positively related to total phosphorous ($r = 0.632$, $N = 19$, $P = 0.004$) when the nonparametric test was used. It is peculiar that the density of one size group would be related to a measure of productivity and not the other; thus, little can be said about these relationships given that they may be spurious. Adult Northern Pike abundance was not related to total lake area, and although it was related to littoral acreage ($r = 0.783$, $N = 17$, $P < 0.001$), it was largely due to a single outlying data point. When the data point for Houghton Lake was removed, the relationship was not significant.

Although our spring surveys often took place prior to smallmouth bass moving onshore, we were able to estimate abundance for 10 lakes (Table 10). Smallmouth Bass were not as abundant as Walleyes in the large lakes surveyed, though there were often more legal-sized Smallmouth Bass than legal-sized Northern Pike. Using the best estimates of Smallmouth Bass abundance, density averaged 0.38 fish per acre (range = 0.07 to 1.96 fish/acre; Table 10).

Angler Survey Data

Overall, anglers fished on average 12.9 hours per acre in 22 large Michigan lakes over the entire angling season (Table 1). For comparison, anglers fished about double that amount (26.7 hours per acre) in large (> 500 acres) lakes within the 1842 Treaty-ceded territory of Wisconsin from 1995 to 2010 (Cichosz 2012). Cichosz (2012) reported a significant difference between overall angler effort between large and small lakes, so perhaps the higher effort in Wisconsin is due to the smaller size of the lakes. Our lakes ranged in size from 1,709 to 20,075 acres; thus, they were all “large” by the standard used in Cichosz (2012). When I compared the hours fished per acre between lakes less than and greater than the arbitrary value of 5,000 acres, there was no significant difference ($t = 2.070$ $df = 9.5$, $P = 0.067$) at the $\alpha = 0.05$ level, though there would have been a significant difference ($t = 2.459$ $df = 21$, $P = 0.023$) if equal variances could have been assumed which would possibly occur with a larger sample size. Lakes less than 5,000 acres had 20.0 angler hours per acres, while those greater than 5,000 acres had 8.3 hours per acre.

The targeted catch rates observed for Walleyes and Northern Pike were rather similar (Tables 11 and 12), averaging 0.231 and 0.218 fish per hour, respectively. For comparison, targeted Walleye catch rates in 20 lakes (199 – 3,816 acres) within the 1842 Treaty-ceded territory of Wisconsin averaged 0.17 fish per hour in 2010 (Cichosz 2012) and targeted Walleye catch rates in Mille Lacs, MN averaged 0.39 fish per hour in 2011 (Jensen 2012). Perhaps reflecting their vulnerability during spawning, or their overall aggressive nature, Smallmouth Bass targeted catch rates were 1.7 times higher than those for Walleyes, averaging 0.382 fish per hour (Table 13). Targeted and nontargeted catch rates were highly correlated for Walleyes ($r = 0.803$, $N = 22$, $P < 0.001$) and Smallmouth Bass ($r = 0.649$, $N = 19$, $P = 0.003$), but not for Northern Pike ($r = 0.244$, $N = 18$, $P = 0.330$) likely due to the fact that in many lakes relatively few anglers targeted Northern Pike. Although both targeted and nontargeted catch rates may provide useful indices of relative abundance, the targeted catch rates provide a more practical number when communicating with anglers; thus, all future inland angler surveys should estimate catch rates for species that are frequently targeted.

Table 10.–Smallmouth Bass population parameters from lakes surveyed in the Large Lakes Program from 2001–2010. Dash (–) indicates no estimate.

Lake	Legal-sized[a] density (number/acre)	Total annual mortality (%)	Mean growth index[b]	Asymptotic total length (in)	Recruitment coefficient of determination
Lake Leelanau	0.30	39.1	0.6	19.5	0.91
South Manistique Lake	0.07	25.1	1.1	18.9	0.61
Big Manistique Lake	0.10	45.1	0.8	19.1	0.90
Grand Lake	0.49	36.3	0.2	19.3	0.89
Long Lake	1.96	24.4	-0.7	18.9	0.85
Peavy Pond	–	–	0.3	20.4	–
Black Lake	0.12	37.1	1.7	19.6	0.72
Lake Gogebic	0.13	22	0.1	18.7	0.59
Lake Michigamme	0.01	43.3	-2.2	18.5	0.86
Lake Charlevoix	0.40	24.7	1.7	19.8	0.59
Portage-Torch lakes	–	22.7	0.7	19.7	0.90
Elk-Skegemog lakes	0.24	36.2	1.4	20.7	0.97
Indian Lake	–	–	1.3	19.1	–
Mean	0.38	32.4	0.5	19.4	0.80
Median	0.19	36.2	0.7	19.3	0.86

[a] Greater than or equal to 14 inches.

[b] The mean deviation from the statewide quarterly average calculated using dorsal spines. Only age groups where N ≥ 5 were used.

Table 11.–Walleye catch and harvest statistics from lakes surveyed in the Large Lakes Program from 2001–2010. Dash (–) indicates no estimate.

	Exploitation			Catch per hr[c]		Harvest		Percentage
Lake	(reward tags)	(harvest/abundance[a])	(harvest/abundance[b])	(targeted)	(non-targeted)	per hr	per acre	released
Houghton Lake	10.6	47.1	30.9	–	0.040	0.037	1.03	8.0
Michigamme Reservoir	29.3	90.7	22.5	0.449	0.248	0.059	0.49	76.2
Crooked-Pickerel lakes	16.3	42.8	29.3	0.740	0.202	0.041	0.72	79.8
Burt Lake	9.0	54.6	23.0	0.181	0.073	0.060	0.55	18.1
Muskegon River system	3.5	12.5	4.8	0.244	0.015	0.012	0.49	23.9
South Lake Leelanau	16.1	30.5	–	0.523	0.371	0.093	1.50	74.9
North Lake Leelanau	14.6	–	–	0.126	0.059	0.055	0.52	6.8
Cisco Lake chain	17.3	30.7	17.7	0.392	0.109	0.016	0.77	84.9
South Manistique Lake	27.5	94.5	80.4	0.269	0.114	0.047	1.61	59.2
Big Manistique Lake	9.4	22.8	14.8	0.102	0.038	0.019	0.16	48.9
North Manistique Lake	7.9	18.3	21.3	0.083	0.032	0.032	0.20	0.0
Bond Falls Flowage	36.8	16.4	10.9	0.245	0.149	0.046	0.46	69.0
Grand Lake	6.7	11.5	8.0	0.064	0.015	0.010	0.06	31.9
Long Lake	8.6	10.4	7.8	0.070	0.013	0.009	0.06	32.1
Peavy Pond	18.7	24.2	15.5	0.304	0.109	0.030	0.28	72.6
Black Lake	11.6	25.8	13.8	0.075	0.038	0.032	0.20	17.0
Lake Gogebic	9.3	41.8	7.9	0.273	0.177	0.046	0.43	74.0
Lake Michigamme	20.0	45.2	25.3	0.342	0.238	0.088	0.54	56.9
Lake Charlevoix	8.8	21.1	9.3	0.113	0.034	0.018	0.06	48.1
Portage-Torch lakes	12.3	19.9	8.1	0.161	0.124	0.090	0.30	26.1
Elk-Skegemog lakes	3.3	7.6	–	0.073	0.001	0.001	0.01	0.0
Mullett Lake	–	34.1	–	0.084	0.015	0.012	0.05	22.0
Indian Lake	–	9.4	4.0	0.167	0.061	0.022	0.05	64.7
Mean	14.2	32.4	18.7	0.231	0.099	0.038	0.46	43.3
Median	11.6	25.0	14.8	0.174	0.061	0.032	0.43	48.1

[a] Estimated harvest divided by multiple-census abundance estimate.

[b] Estimated harvest divided by single-census abundance estimate.

[c] Catch per hr of all sizes of Walleyes, both harvested and released.

Table 12.–Northern Pike catch and harvest statistics from lakes surveyed in the Large Lakes Program from 2001–2010. Dash (–) indicates no estimate.

Lake	Exploitation			Catch per hr[c]		Harvest		Percentage
	(reward tags)	(harvest/abundance[a])	(harvest/abundance[b])	(targeted)	(non-targeted)	per hr	per acre	released
Houghton Lake	18.2	322.6	48.0	–	0.024	0.019	0.498	22.5
Michigamme Reservoir	11.1	166.5	46.3	0.281	0.161	0.007	0.096	95.9
Crooked-Pickerel lakes	–	–	20.3	–	0.036	0.000	0.004	99.4
Burt Lake	7.8	92.7	33.8	0.284	0.007	0.002	0.020	66.9
Lake Leelanau	25.9	57.4	–	–	0.022	0.001	0.019	93.3
Cisco Lake chain	22.0	26.8	–	0.491	0.083	0.003	0.126	82.9
South Manistique Lake	31.4	605.1	117.3	0.173	0.165	0.010	0.329	94.2
Big Manistique Lake	22.4	14.8	–	0.097	0.026	0.011	0.091	58.4
North Manistique Lake	14.0	–	–	0.000	0.000	0.000	0.001	–
Bond Falls Flowage	26.8	62.9	–	0.177	0.081	0.005	0.055	93.2
Grand Lake	9.7	16.1	43.1	0.454	0.003	0.002	0.012	38.8
Long Lake	14.2	18.7	18.7	0.113	0.023	0.005	0.031	79.4
Peavy Pond	20.6	33.9	21.9	0.256	0.132	0.004	0.040	86.3
Black Lake	12.9	39.6	11.1	0.094	0.036	0.009	0.052	74.8
Lake Gogebic	16.9	19.8	24.4	0.103	0.034	0.002	0.018	74.8
Lake Michigamme	15.2	41.0	13.0	0.222	0.048	0.005	0.034	88.5
Lake Charlevoix	3.2	35.3	20.3	0.177	0.008	0.002	0.007	72.8
Portage-Torch lakes	15.2	17.3	6.5	0.549	0.068	0.014	0.049	78.7
Elk-Skegemog lakes	9.1	24.1	36.5	0.176	0.022	0.003	0.017	84.0
Mullett Lake	–	20.7	–	0.217	0.026	0.004	0.018	79.3
Indian Lake	–	–	–	0.054	0.020	0.004	0.009	80.3
Mean	16.5	89.7	32.9	0.218	0.049	0.005	0.073	77.2
Median	15.2	34.6	23.2	0.177	0.026	0.004	0.031	79.9

[a] Estimated harvest divided by multiple-census abundance estimate.

[b] Estimated harvest divided by single-census abundance estimate.

[c] Catch per hr of all sizes of Northern Pike, both harvested and released.

Table 13.–Smallmouth Bass catch and harvest statistics from lakes surveyed in the Large Lakes Program from 2001–2010. Dash (–) indicates no estimate.

	Exploitation			Catch per hr [c]		Harvest		Percentage released
Lake	(reward tags)	(harvest/abundance [a])	(harvest/abundance [b])	(targeted)	(non-targeted)	per hr [d]	per acre	
Houghton Lake	–	–	–	–	0.011	0.007	0.094	38.1
Michigamme Reservoir	–	–	–	–	0.059	0.011	0.132	81.9
Crooked-Pickerel lakes	–	–	–	0.135	0.029	0.004	0.052	86.3
Burt Lake	–	–	–	0.047	0.009	0.001	0.007	85.7
Lake Leelanau	13.7	14.2	–	0.257	0.062	0.004	0.049	93.0
Cisco Lake chain	–	–	–	0.516	0.113	0.010	0.416	91.4
South Manistique Lake	4.3	42.2	34.3	0.058	0.016	0.001	0.026	94.7
Big Manistique Lake	21.1	8.6	46.6	0.334	0.022	0.006	0.048	72.8
North Manistique Lake	–	–	–	0.111	0.009	0.000	0.000	100.0
Bond Falls Flowage	–	–	–	0.353	0.077	0.022	0.218	71.7
Grand Lake	10.7	14.2	13.6	0.730	0.178	0.030	0.104	83.0
Long Lake	7.1	14.7	14.0	0.494	0.248	0.057	0.317	77.4
Peavy Pond	16.8	–	–	0.258	0.058	0.011	0.091	80.5
Black Lake	7.1	18.5	17.0	0.310	0.044	0.006	0.026	86.5
Lake Gogebic	19.3	–	58.5	0.727	0.079	0.011	0.088	85.7
Lake Michigamme	15.6	–	–	0.692	0.166	0.003	0.021	98.0
Lake Charlevoix	15.3	34.2	19.1	0.484	0.173	0.032	0.095	81.7
Portage-Torch lakes	19.1	–	–	0.285	0.145	0.014	0.033	90.2
Elk-Skegemog lakes	14.1	31.4	34.1	0.591	0.389	0.023	0.086	94.2
Mullett Lake	–	–	–	0.520	0.117	0.009	0.024	92.3
Indian Lake	–	–	–	0.351	0.044	0.010	0.009	76.7
Mean	13.7	22.3	29.7	0.382	0.098	0.013	0.092	83.9
Median	14.7	16.6	26.6	0.351	0.062	0.010	0.052	85.7

[a] Estimated harvest divided by multiple-census abundance estimate.

[b] Estimated harvest divided by single-census abundance estimate.

[c] Catch per hr of all sizes of Smallmouth Bass, both harvested and released during the open-water period.

[d] Calculated only using the open-water period.

Angler catch rates proved to be a valuable tool for corroborating other population data from the Large Lakes Program. Both the targeted catch rate (F = 10.877, df = 21, P = 0.004) and the nontargeted catch rate (F = 12.450, df = 22, P = 0.002) of all-sized Walleyes were positively related to the density of adult Walleyes (Figures 16 and 17). Similarly, the nontargeted catch rate of all-sized Northern Pike was related (r = 0.645, N = 21, P = 0.002) to the density of adult Northern Pike. The targeted catch rate for Northern Pike was not significantly (r = 0.424, N = 18, P = 0.079) related to the density of adult Northern Pike, but this was likely due to low sample size. Few anglers indicated that they were targeting Northern Pike specifically; thus, the targeted catch rates had low precision and were possibly inaccurate. In fact, at times the estimated total catch of Northern Pike by anglers targeting them was zero even though there was catch of Northern Pike by anglers targeting other species. Again this was a result of low targeted effort towards Northern Pike. In these situations, targeted catch rates were considered inestimable (no value) rather than using an estimate of a zero catch rate in analyses.

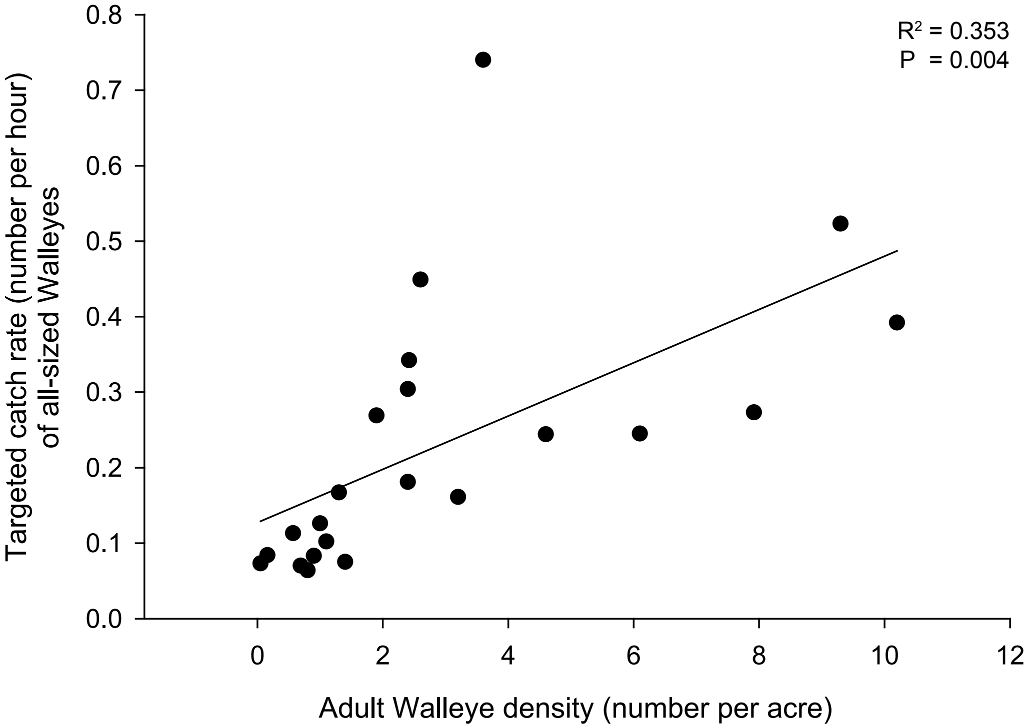


Figure 16.–Relationship between adult Walleye density (number per acre) and targeted catch rate (number per hour) of all-sized Walleyes for lakes surveyed in the Large Lakes Program in 2001–2010.

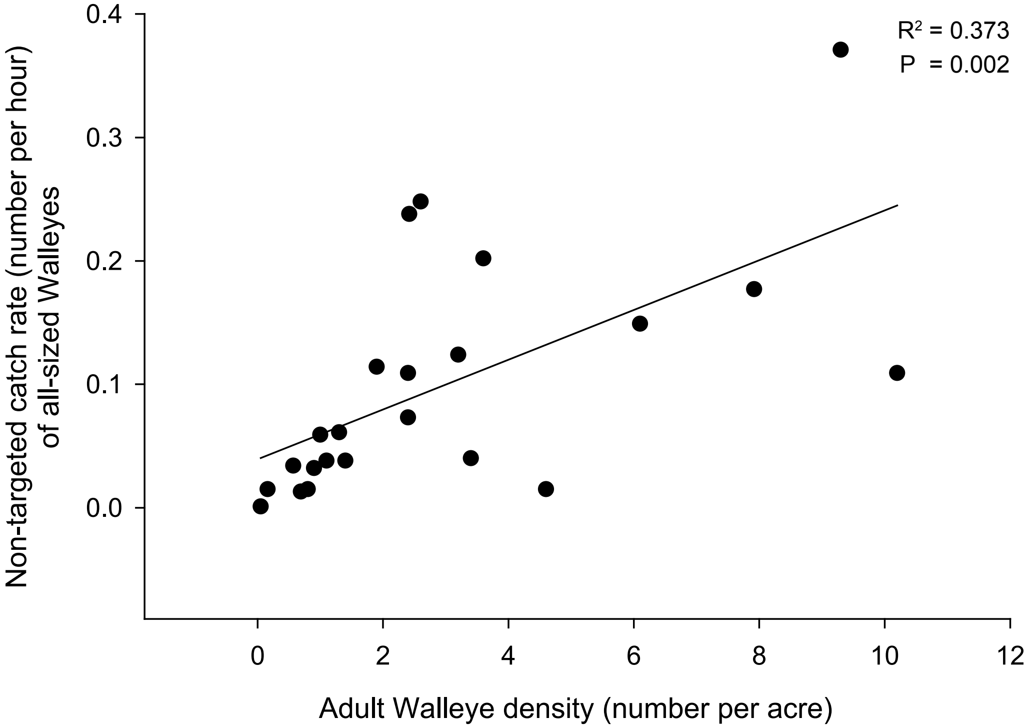


Figure 17.–Relationship between adult Walleye density (number per acre) and nontargeted catch rate (number per hour) of all-sized Walleyes for lakes surveyed in the Large Lakes Program in 2001–2010.

The average annual Walleye harvest was 0.46 fish per acre, ranging from 0.01 in Elk-Skegemog lakes to 1.61 in South Manistique Lake (Table 11). For comparison, Walleye harvest per acre in the 1842 Treaty-ceded territory of Wisconsin averaged 0.77 in 2010 (Cichosz 2012) and Walleye harvest per acre in Mille Lacs, Minnesota averaged 1.20 in the 2010–2011 angling season (Jensen 2012). The average annual harvest for Northern Pike was 0.07 fish per acre (range = 0.001 – 0.498; Table 12). The average annual harvest for Smallmouth Bass was 0.092 fish per acre (range = <0.001 – 0.416; Table 13). The average harvest across seven large (> 1,000 acres) Michigan lakes surveyed by Lockwood (2000) was 0.15 Northern Pike per acre, ranging from 0.002 per acre in Bond Falls Flowage to 0.65 per acre in Fletcher Pond. These lakes were also subject to similar gears and fishing regulations, including a 24-inch minimum size limit. The similarity between our estimates and Lockwood's (2000) suggest both a similarity in the fisheries in these large lakes and consistency in creel survey methods. Elsewhere, Pierce et al. (1995) estimated harvests from 0.7 to 3.6 per acre in seven smaller Minnesota lakes, which ranged from 136 to 628 acres in size and had no minimum size limit for Northern Pike.

The percentage of all Walleyes caught that were subsequently released was related to the size structure in the population. Although no differentiation was made between sublegal and legal-sized released fish, it could be inferred that most released Walleyes were not of legal size since there was a negative relationship (r = -0.985, N = 23, P < 0.001) between the percentage of angled Walleyes that were released and the percentage of legal-sized Walleyes that were observed in the spring surveys (Figure 18). Thus, in populations with a relatively high percentage of sublegal Walleyes, anglers tend to release a relatively higher proportion of Walleyes. The same relationship was true for Northern Pike (r = -0.584, N = 20, P = 0.007), but it was not true for Smallmouth Bass (r = -0.271, N = 21, P = 0.234). The relationship was not true for Smallmouth Bass likely due to the more prevalent catch and release behavior for black bass in general. For example, based on tag returns anglers released

33.8% of legal-sized Smallmouth Bass, compared to 17.3% of legal-sized Northern Pike and 2.1% of legal-sized Walleyes. For smallmouth bass, there are few tagging studies reporting on release rates of legal-size smallmouth bass with the same minimum size limit; however, our release rate was similar to that reported by Meyer and Schill (2014; 29.1%) for Idaho waters. Other studies have shown much higher release rates (>90%) for smallmouth bass, but they generally assessed all sizes (Slipke et al. 1998, Martin and Fisher 2008). These two studies generally assessed all sizes, which might contribute to their higher release rate estimates than in this study; but, I did not detect a relationship between percent of angled bass that were released and bass size. My findings indicate that care should be taken to avoid assuming that release rates for Smallmouth Bass are always high.

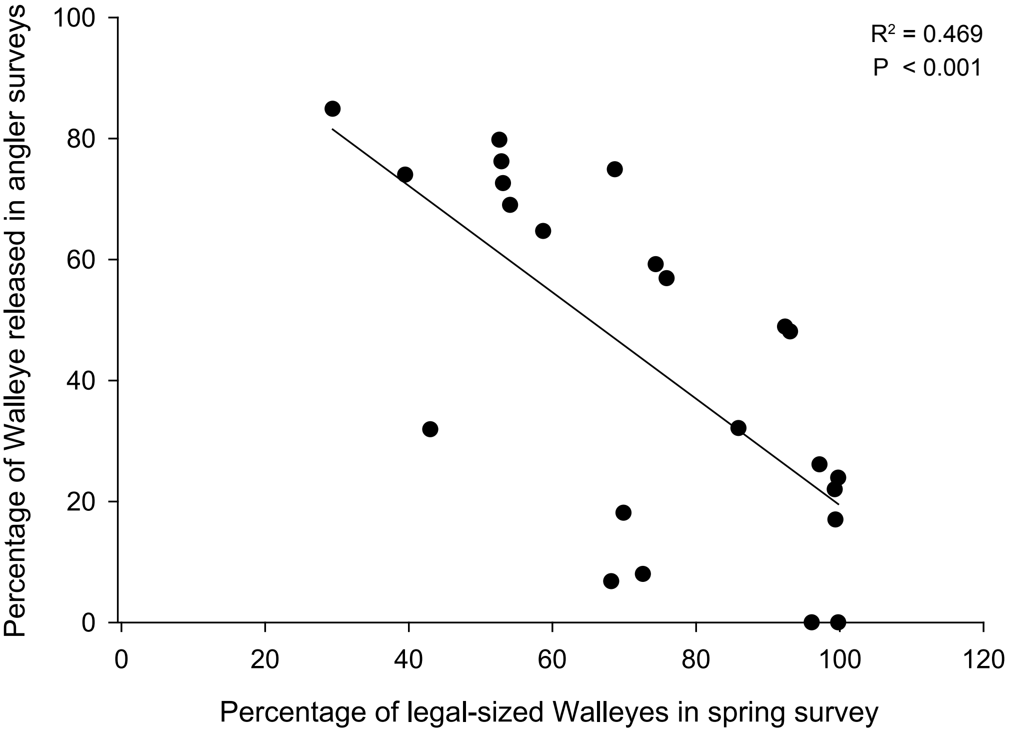


Figure 18.–Relationship between the percentage of legal-sized Walleyes observed in the spring surveys to the percentage of Walleyes that were released in angler surveys for lakes surveyed in the Large Lakes Program in 2001–2010.

To evaluate the overall seasonal variation in harvest, tag returns were summarized by month for all lakes combined. While the seasonal variation probably differs for individual lakes, this provided a general idea of when harvest is taking place for the various target species. The majority (24.4%) of Walleye tag returns were reported for June, followed closely by May (22.3%; Figure 19). Walleye catch rates were generally highest in May, but overall angler effort was higher in June resulting in more tag returns being reported. The month with the fewest tag returns reported was March, though Walleye season is only open for 15 days during March and up until 2008 the Walleye season was closed for the Upper Peninsula during March. For Northern Pike most tag returns were reported for May (30.9%) followed by June (26.7%) and July (15.9%). In fact, 73.5% of the annual Northern Pike tag returns were reported from May through July (Figure 20). The fewest Northern Pike tag returns were reported for April, though given the Walleye season in the Lower Peninsula of Michigan opens on the last Saturday of April, there are usually only a few days available for fishing in that month. The majority (30.4%) of Smallmouth Bass tag returns were reported for June, followed by May (19.7%) and July (16.3%; Figure 21).

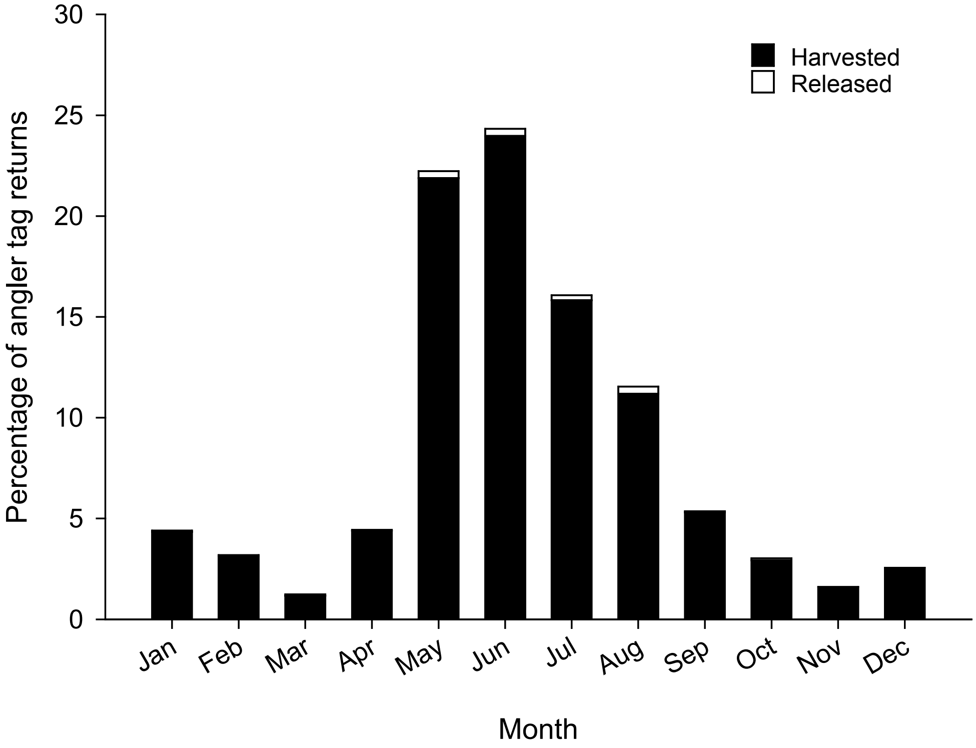
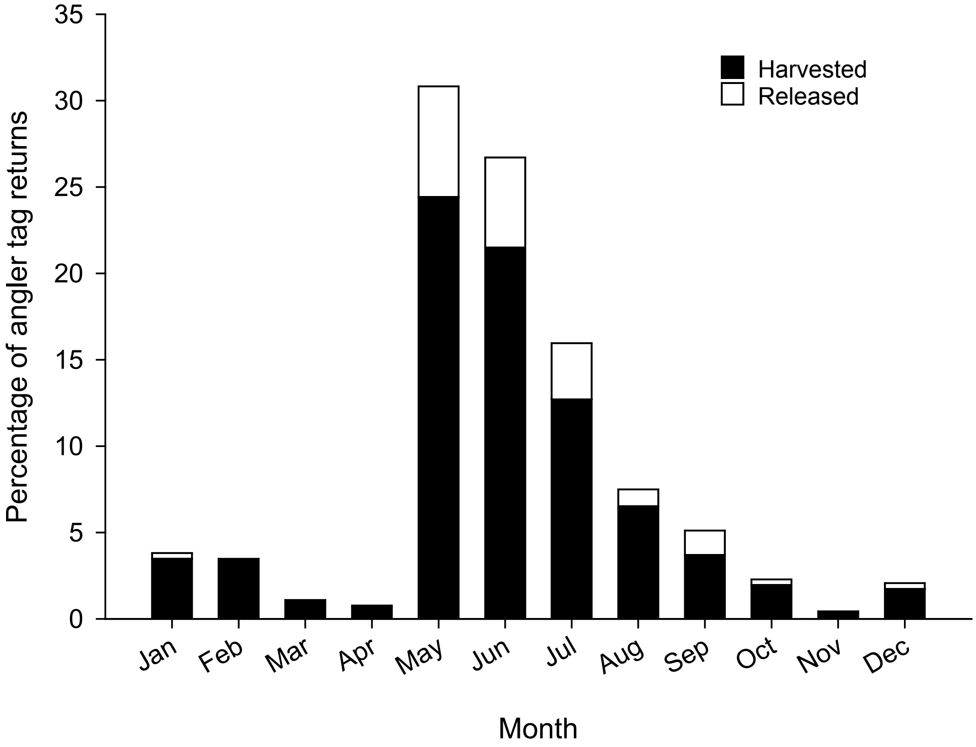


Figure 19.–Percentage of angler tag returns (harvested + released) by month for Walleyes from all lakes surveyed in the Large Lakes Program in 2001–2010.



Percentage of angler tag returns (harvested + released combined) by month for Northern Pike from all lakes surveyed in the Large Lakes Program in 2001–2010.

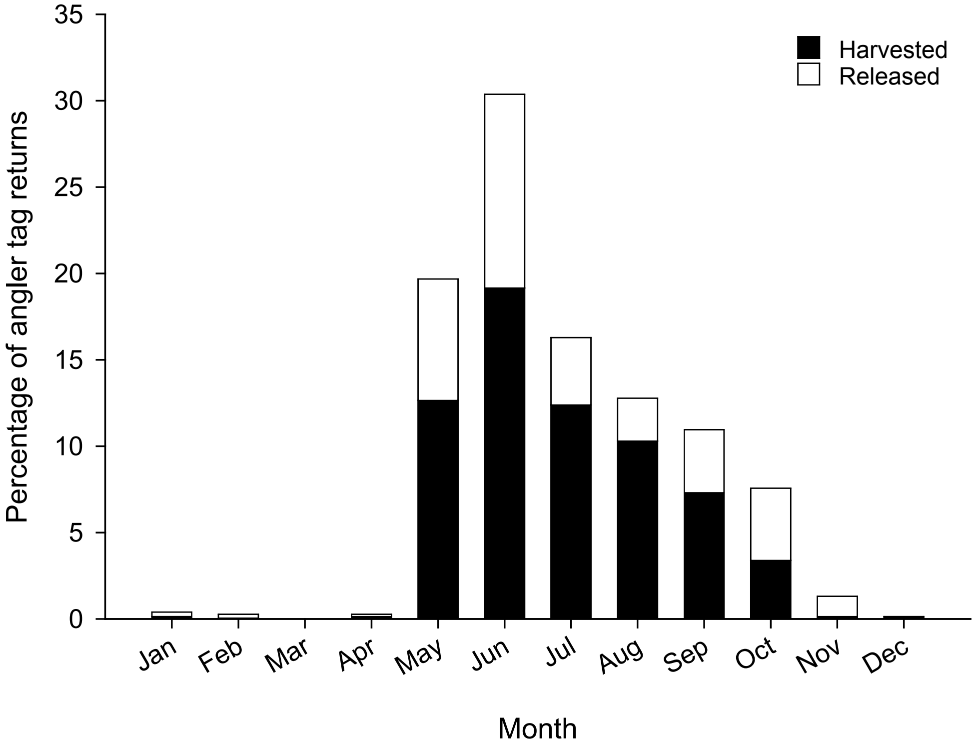


Figure 21.–Percentage of angler tag returns (harvested + released) by month for Smallmouth Bass from all lakes surveyed in the Large Lakes Program in 2001–2010.

Mortality

Total annual mortality varied widely among all predator populations, but was not excessive for any population. Additionally, there was no indication that angling exploitation was related to annual mortality for any of the target species. Total annual mortality for Walleyes averaged 39.4% and ranged from 23.9% in North Lake Leelanau to 56.6% in Long Lake (Table 8). Exploitation for Walleyes averaged 14.2% (range = 3.3% to 36.8%; Table 11), with an average of 14.8% for females and 12.6% for males (unadjusted for tag loss). Walleye exploitation also differed significantly ($t = -2.654$, $df = 12$, $P = 0.021$) between the peninsulas, with the Upper Peninsula having an average of 18.9% and the Lower Peninsula having an average of 9.9%. It is unknown whether this is due to differences in angler catch/effort or other factors such as lake size, depth, or connectivity with the Great Lakes. Lakes surveyed in the Lower Peninsula averaged 10,854 acres, while lakes in the Upper Peninsula averaged 6,434 acres. The Lower Peninsula also had more lakes with connectivity to the Great Lakes. It is possible that catchability in the larger lakes and lakes with connectivity to the Great Lakes is lower. Total annual mortality for Northern Pike averaged 48.3% and exploitation averaged 16.5% for legal-sized Northern Pike (Table 9). Exploitation was 15.2% for females and 10.5% for males (both estimates unadjusted for tag loss). Annual mortality was positively related to density ($r = 0.618$, $N = 21$, $P = 0.003$) for Northern Pike, but it was not related to annual exploitation ($r = 0.388$, $N = 19$, $P = 0.101$). These results agree with those of Allen et al. (1998) who found no relationship between annual exploitation and annual mortality for Northern Pike across their range. It appears that higher density Northern Pike populations have higher annual mortality, but it is likely due to natural sources rather than angling. Intraspecific competition and cannibalism have been suggested as possible causes for compensatory mortality in smaller Northern Pike (Mann 1982, Allen et al. 1998), while angling is generally the primary source of mortality for large Northern Pike (Pierce et al. 1995). Total annual mortality for Smallmouth Bass averaged 32.4% (Table 10) and exploitation averaged 13.7% (range = 4.3% to 21.1%; Table 13). Clady (1975) reported total mortality of 33% for Smallmouth Bass in a Michigan lake with no fishing, and 41% – 65% in a lake subject to simulated exploitation of 13% – 16%, while Bryant and Smith (1988) reported 58% total mortality of adult Smallmouth Bass from Anchor Bay of Lake St. Clair. Latta (1975) reported an average of 19% exploitation for a sample of Smallmouth Bass populations throughout the Great Lakes region and the northeastern United States. In Michigan, Latta (1963) reported 22% exploitation of Smallmouth Bass near Waugoshance Point in Lake Michigan, and Bryant and Smith (1988) reported a rate of 13% for Smallmouth Bass in Lake St. Clair. Although exploitation of Smallmouth Bass was not excessively high, it should be noted that it makes up a larger portion of annual mortality, relative to Walleye and Northern Pike. On average, Smallmouth Bass exploitation accounted for 44% of total mortality estimates, while it made up 39% and 35% for Walleye and Northern Pike, respectively. This may indicate that Smallmouth Bass populations in large lakes are more vulnerable to angling than Walleyes or Northern Pike. This is especially true given that the percentage of legal-sized Smallmouth Bass released was twice as high as that for Northern Pike and 16 times as high as that for Walleyes (see *Angler Survey Data* section).

Overall, the performance of jaw tags for estimating exploitation was good. First-year tag retention averaged 96.8%, 90%, and 96.4% for Walleyes, Northern Pike, and Smallmouth Bass, respectively, though it certainly could have been lower if clerks were not actually examining each fish during boat-based interviews as was mentioned previously in the *Abundance* section. The reporting rate of nonreward tags relative to reward tags (λ) averaged 81.8% for Walleyes and voluntary tag returns (reward and nonreward) made up, on average, 93.1% of the expected number of returns (X; minimum number of recaptures = 3). Hence, I believe that the true reporting of reward tags may have approximated 95% and surely was sufficient to obtain good minimum estimates of exploitation. For Northern Pike voluntary tag returns made up, on average, 66.2% of the expected number of returns. This lower return for Northern Pike was likely due to greater tag loss and the greater potential for release of Northern Pike, relative to Walleyes.

Based on tag returns, angling selectivity was higher for smaller Walleyes and anglers released larger Walleyes more often. Selectivity differed among sizes (*Chi-square* = 493.447, df = 15, P = 0.0001) and between sexes (*Chi-square* = 40.688, df = 1, P = 0.0001) when legal-sized Walleyes recaptured (both harvested and released) by anglers were compared with those collected and tagged in spring surveys. Angling selected for Walleyes from 15 to 18 inches while Walleyes 19 inches and larger were not represented in the angler catch in proportion to what was tagged (Figure 22). Additionally, females were overall more likely to be caught than males. Exploitation decreased with increasing size, with the estimate for 15-inch Walleyes being approximately 4.5 times higher than that for 30-inch fish (Figure 23). It should be noted that the exploitation by inch group used reward and nonreward tag returns, which is why the overall exploitation for Figure 23 appears lower than the average reported in Table 11. The percentage of legal-sized Walleyes released increased with increasing size from 16 to 25 inches (Figure 24). The relatively high release of 15-inch Walleyes was likely due, in part, to angler concern over them not being of legal size.

Angling selectivity and angler release behavior for Northern Pike were much different than for Walleyes. Selectivity differed among sizes (*Chi-square* = 28.475, df = 18, P = 0.055) and between sexes (*Chi-square* = 20.102, df = 1, P = 0.0001) when legal-sized Northern Pike recaptured (both harvested and released) by anglers were compared with those collected and tagged in spring surveys. There was no consistent trend in angling selection for Northern Pike across all inch groups, though small (18- to 23-in) Northern Pike seemed to be caught more readily by anglers, while larger (31- to 36-in) Northern Pike were not (Figure 25). Females were overall more likely to be caught than males. The highest exploitation was estimated for 22-inch Northern Pike, beyond which exploitation decreased with increasing size (Figure 26). The smallest Northern Pike (18–21 in) had relatively low exploitation, though they appeared to be selected for in the angler catch. Thus the lower exploitation was apparently due to the frequent release of these smaller fish (Figure 27). Overall there was a decreasing trend (r = -0.812, N = 17, P < 0.001) in the percentage of legal-sized Northern Pike released with increasing size, although anglers generally released at least 10% of legal-sized fish.

Smallmouth Bass also had differing selectivity among sizes (*Chi-square* = 11.037, df = 6, P = 0.087), though not to the same extent as Walleyes and Northern Pike. There was no consistent trend in angler selection for (Figure 28) or exploitation of (Figure 29) Smallmouth Bass across inch groups. The number of legal-sized Smallmouth Bass released decreased with increasing size, though the relationship was weak (r = -0.700, N = 7, P = 0.080; Figure 30). All inch groups had a minimum of 25% of the Smallmouth Bass released.

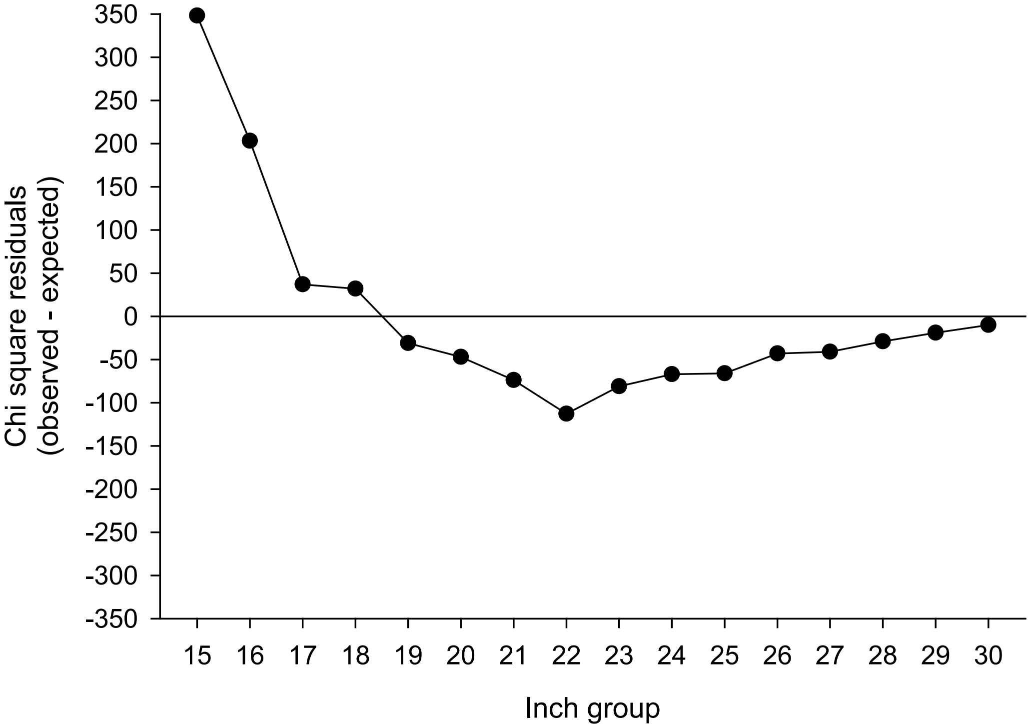


Figure 22.–Residuals from Chi square analysis of observed angler tag returns versus expected angler tag returns (based on known population tagged) by inch group for Walleyes from lakes surveyed in the Large Lakes Program in 2001–2010. Data only displayed for inch groups with a minimum of N=50 tag returns.

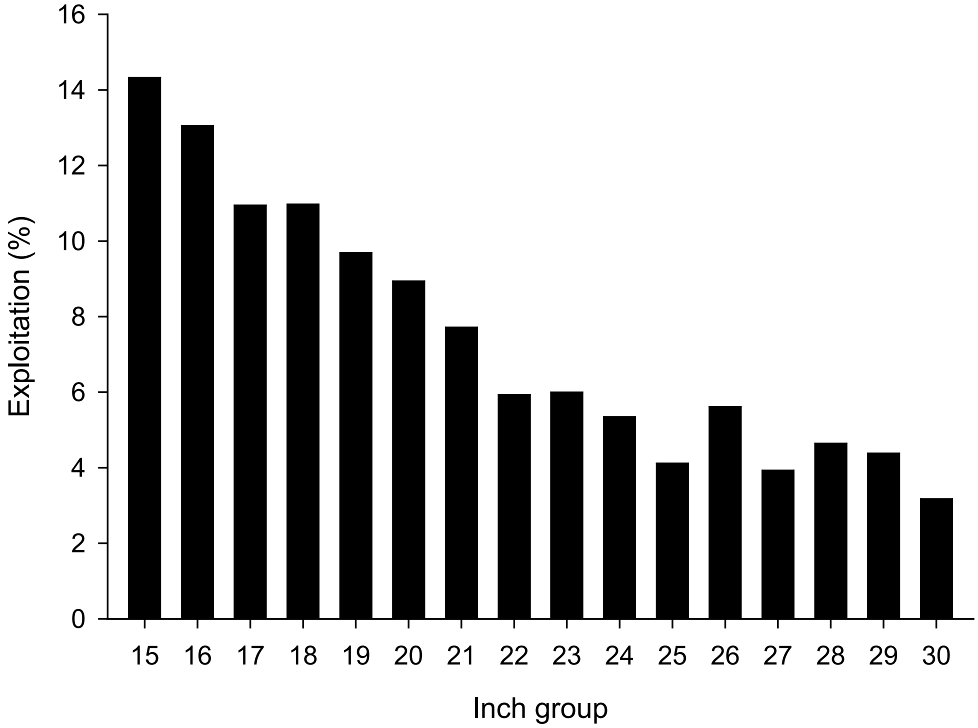


Figure 23.–Angler exploitation by inch group for Walleyes from lakes surveyed in the Large Lakes Program in 2001–2010. Minimum N = 50 tagged per inch group Data only displayed for inch groups with a minimum of N=50 tag returns. Only tag returns for fish caught in the angling year following tagging were used.

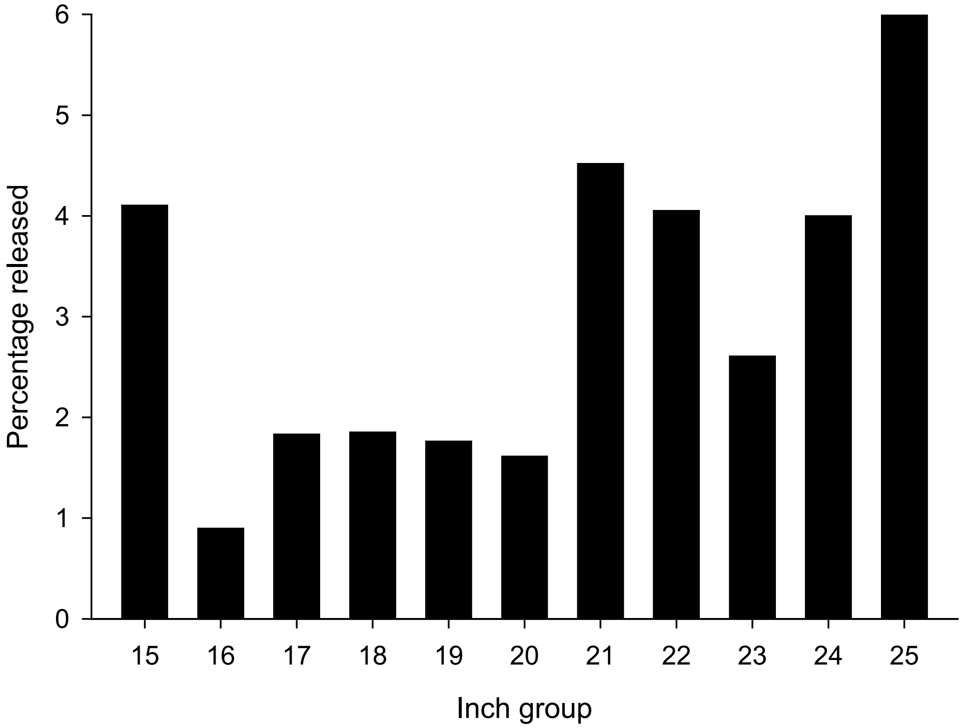


Figure 24.–Percentage of Walleye tag returns where the angler indicated that the Walleye was released by inch group for lakes surveyed in the Large Lakes Program in 2004–2010. The question about released fish was only on tag return forms in 2004–2010. Data only displayed for inch groups with a minimum of N=50 tag returns.

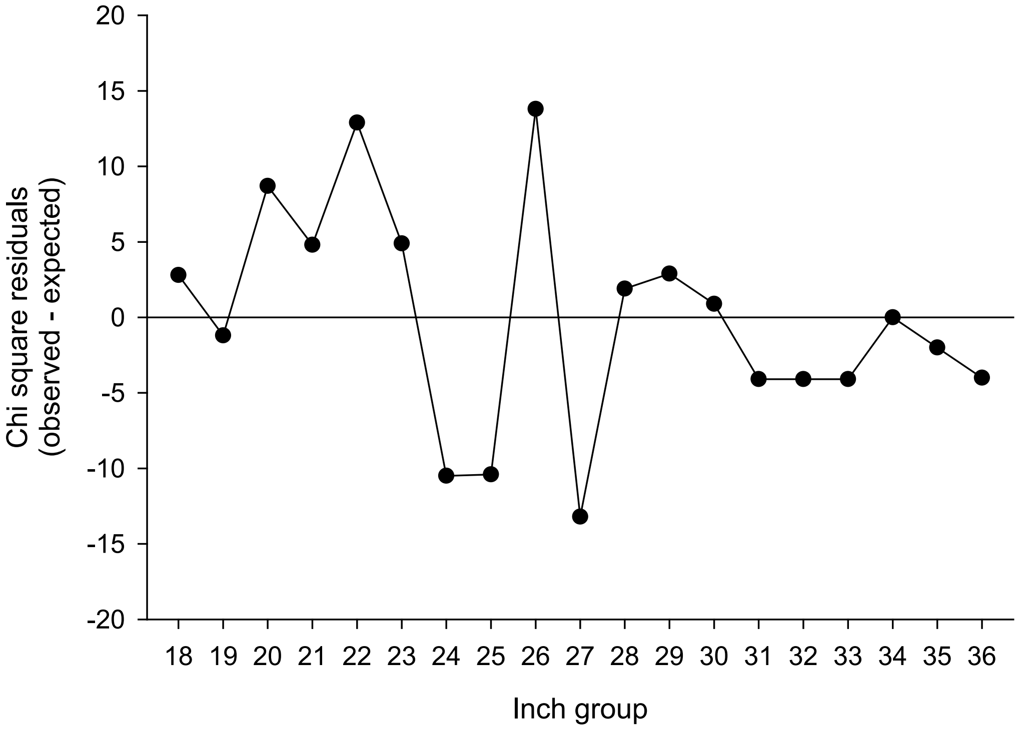


Figure 25.–Residuals from Chi square analysis of observed angler tag returns versus expected angler tag returns (based on known population tagged) by inch group for Northern Pike from lakes surveyed in the Large Lakes Program in 2001–2010. Data only displayed for inch groups with a minimum of N=50 tag returns.

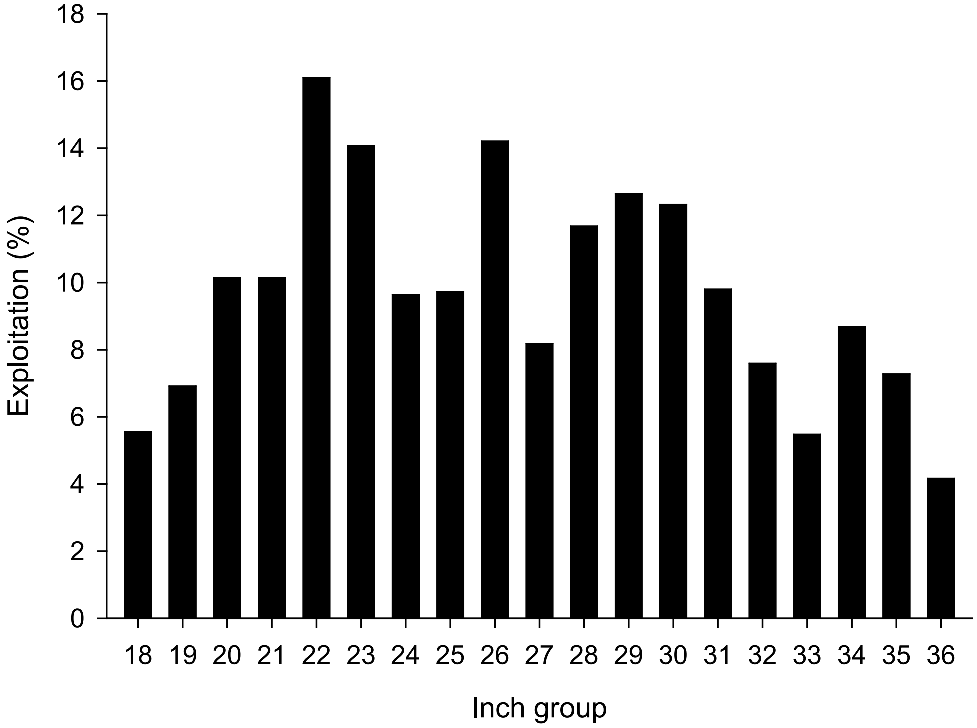


Figure 26.–Angler exploitation by inch group for Northern Pike from lakes surveyed in the Large Lakes Program in 2001–2010. Data only displayed for inch groups with a minimum of N=50 tag returns.Only tag returns for fish caught in the angling year following tagging were used.

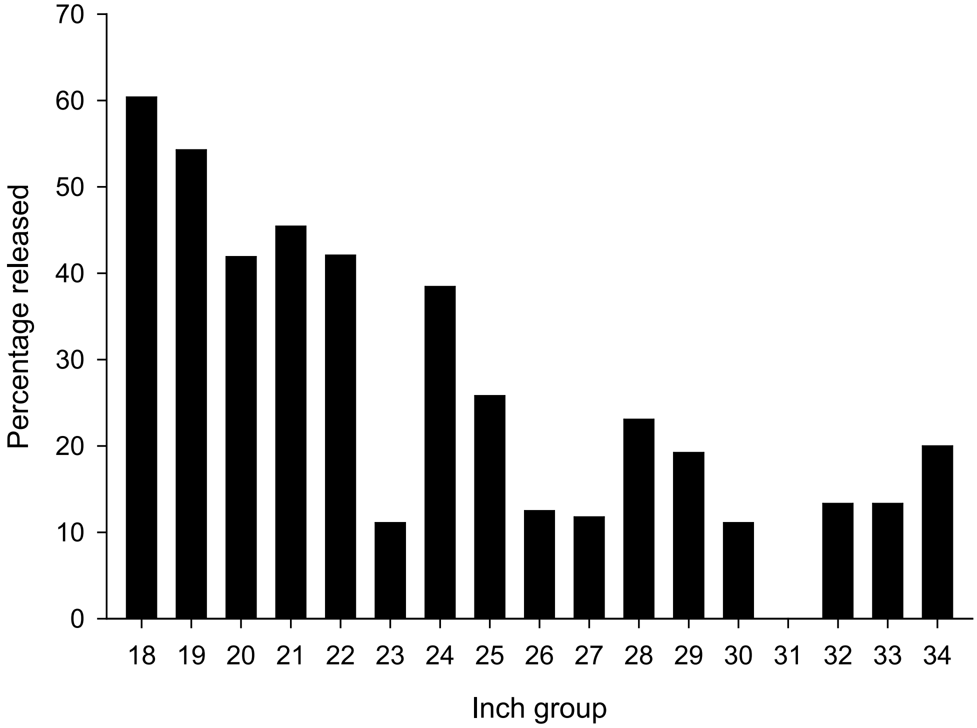


Figure 27.–Percentage of Northern Pike tag returns where the angler indicated that the fish was released by inch group for lakes surveyed in the Large Lakes Program in 2004–2010. The question about released fish was only on tag return forms in 2004–2010. Data only displayed for inch groups with a minimum of N=50 tag returns.

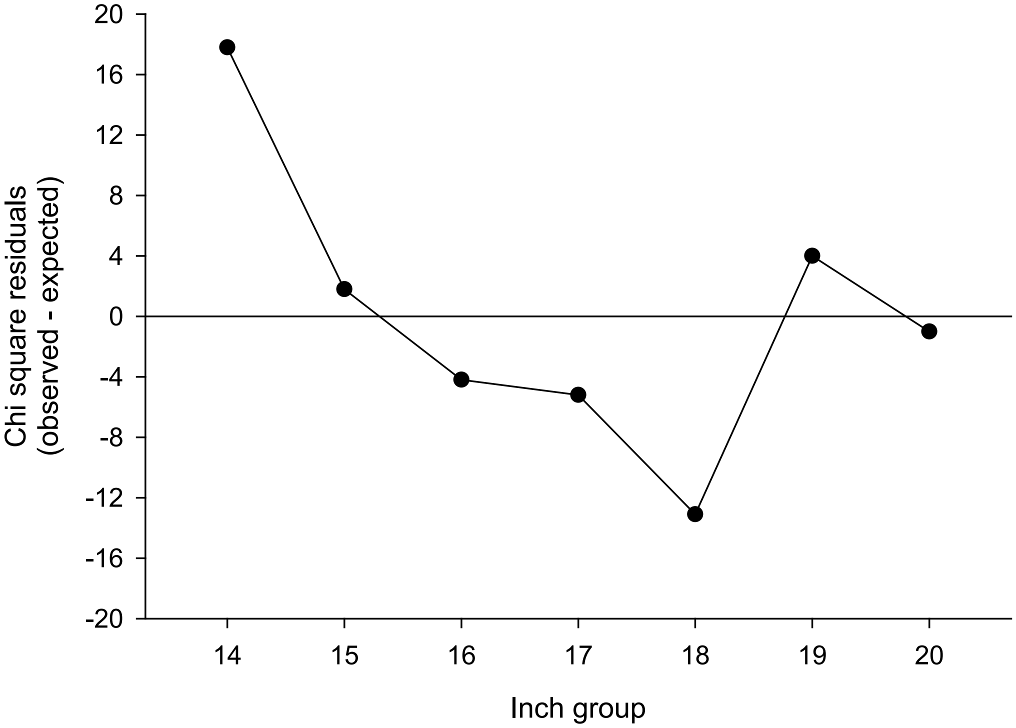


Figure 28.–Residuals from Chi square analysis of observed angler tag returns versus expected angler tag returns (based on known population tagged) by inch group for Smallmouth Bass from lakes surveyed in the Large Lakes Program in 2001–2010. Data only displayed for inch groups with a minimum of N=50 tag returns.

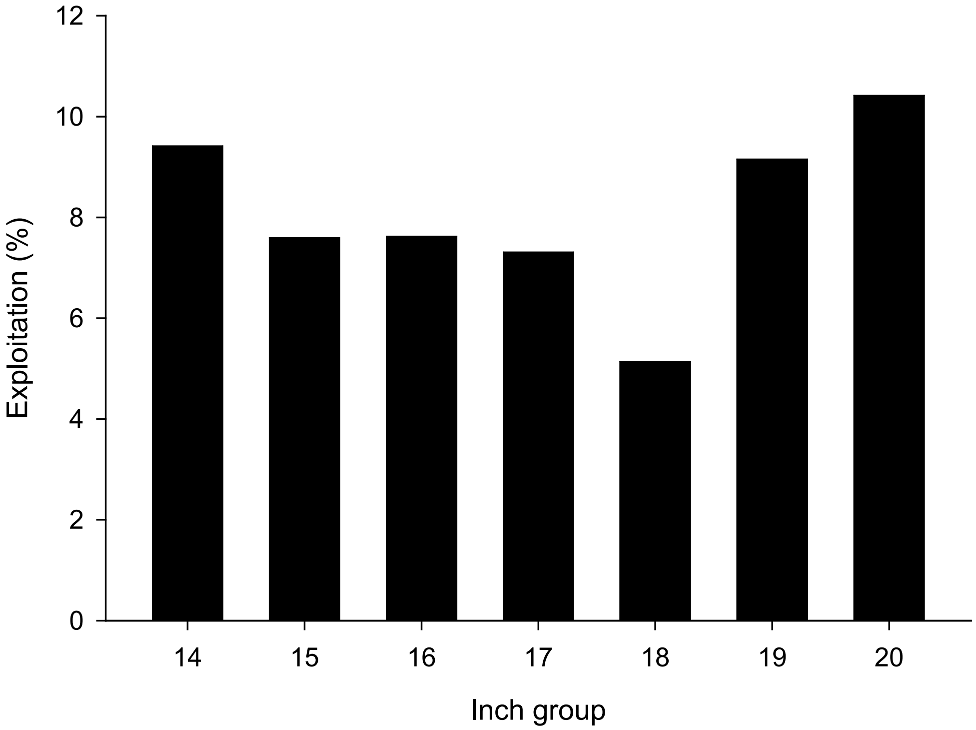


Figure 29.–Angler exploitation by inch group for Smallmouth Bass from lakes surveyed in the Large Lakes Program in 2001–2010. Data only displayed for inch groups with a minimum of N=50 tag returns. Only tag returns for fish caught in the angling year following tagging were used.

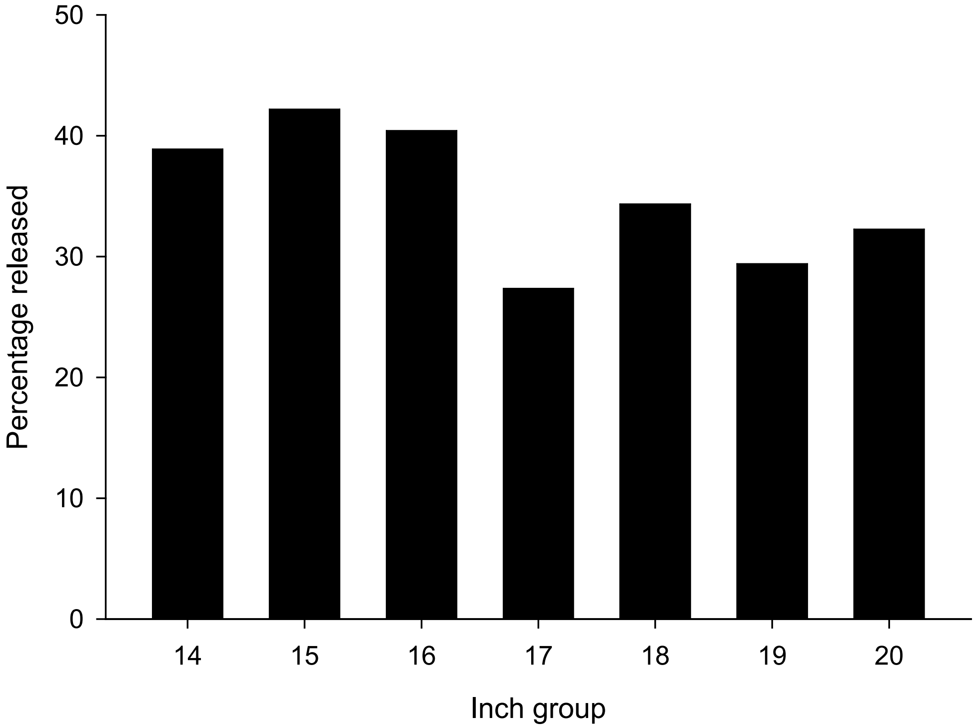


Figure 30.–Percentage of Smallmouth Bass tag returns where the angler indicated that the fish was released by inch group for lakes surveyed in the Large Lakes Program in 2004–2010. The question about released fish was only on tag return forms in 2004–2010. Data only displayed for inch groups with a minimum of N=50 tag returns.

Recruitment

This study focused on the collection of adult fish and only obtained population data for fish in a single year for each population; thus, a rigorous evaluation of recruitment was not a goal of this study. However, sufficient information to examine if relative year-class strength as determined from the residuals of the catch-curve regressions could serve as indices of year-class strength for Walleyes and Northern Pike was available and was conducted. Similarly, an examination of whether the coefficient of determination from the catch curve regressions (recruitment coefficient of determination; RCD) could serve as an index of recruitment variability was also completed. Overall, the residuals from the catch curve regressions performed poorly as indices of year-class strength as they rarely correlated with numbers of fish stocked or environmental variables known to affect year-class strength. Also, the residuals did not indicate any patterns in year-class strength among lakes over time (Table 14). That is, when all age data were combined on a single table most years had approximately 50% positive/negative residuals (33% – 68%), and only 1of the 25 years evaluated (with 3 or more values) had a majority of values of one type (1999 year class, 90% negative). Similarly, the RCDs were not significantly correlated to any biological variables. Maceina (2003 and 2004) related residuals from catch curves on crappies and largemouth bass to hydrologic variables and indices of juvenile abundance. Maceina (1997) also showed that the residuals from catch curves persisted over time, though the duration was only 2 years following additional analysis. For Walleyes, the catch curve regressions were completed using often 10 to 15 ages thus producing conditions where the inclusion/exclusion of a single age class (for example the first age class fully recruited to the sampling gear) can have a large effect on which residuals end up being positive and which end up being negative. For that reason alone, they do not appear to have much value as indices of year-class strength for Walleyes.

The RCD for Walleyes averaged 0.79 (Table 8), thus implying that 79% of the variation in relative abundance across age groups was explained by annual mortality alone. Given this relatively high percentage, it may be difficult to find variables that can explain additional variation in the catch-at-age. Perhaps the most interesting discovery was the fact that the RCD was lower (t = -3.545, df = 19, P = 0.002) for populations with stocking as the primary recruitment source. The RCD for stocked Walleye populations averaged 0.68 while populations with primarily natural reproduction averaged 0.85. The cause for the higher recruitment variability in stocked populations is unknown, though apparent recruitment variability could easily be affected by stocking cycles (e.g. stocking every 1–3 years). Based on the RCD, Northern Pike had more consistent recruitment than Walleyes, with an average RCD of 0.89; however, this may be been due, in part, to the fewer number of age classes generally represented in the catch curve regressions for Northern Pike. Smallmouth Bass had an average RCD value of 0.80, which was rather similar to that for Walleyes. Overall, there appears to be limited value for the use of the residuals from catch curve regressions as indices of year-class strength in Walleye and Northern Pike.

Movement

Walleye movement estimated during spring spawning provided little novel information. Walleyes were recaptured an average of 0.91 miles (median = 0.51 miles) from their point of initial capture during the spawning season. Male Walleyes were recaptured further away (Z = -4.876, P < 0.001, N = 7,685) from their point of initial capture (median = 0.52 miles) than females (median = 0.43 miles). Northern Pike were recaptured an average of 0.97 miles from their point of initial capture during the spawning season. Unlike Walleyes, female Northern Pike were recaptured further away (Z = 3.601, P < 0.001, N = 1,253) from their point of initial capture (median = 0.58 miles) than males (median = 0.48 miles).

For the three Great Lakes Walleye populations, the minimum distance between points of tagging and recapture by anglers showed a bimodal distribution with the most frequently occurring distances being

Table 14.–Year-class strength (positive and negative values) based on the standard residuals from catch curve regressions of Walleye populations surveyed in the Large Lakes Program from 2001–2010.

	Lake																					
Year class	Houghton Lake	Michigamme Reservoir	Crooked-Pickerel lakes	Burt Lake	Muskegon River system	South Lake Leelanau	North Lake Leelanau	Cisco Lake chain	South Manistique Lake	Big Manistique Lake	North Manistique Lake	Bond Falls Flowage	Grand Lake	Long Lake	Peavy Pond	Black Lake	Lake Gogebic	Lake Michigamme	Lake Charlevoix	Portage-Torch lakes	Mullett Lake	Indian Lake
2007																						+
2006																						-
2005																						+
2004																					+	-
2003																					+	-
2002																			+		-	-
2001																			+	+	-	-
2000																	-		-	-	-	-
1999									+		-				-	-	-	-	-	-	-	-
1998							+		+		-	+	+	-	-	+	-	+	-	-	+	+
1997				-			-		-		-	-	+	+	+	-	-	+	+	-	+	+
1996				-		+	-	-	-	-	+	-	+	+	+	+	+	-	-	-	+	+
1995	-	+	-	+	-	+	+	+	+	-	+	+	-	+	-	+	+	+	+	+	-	+
1994	-	+	+	+	-	-	+	+	+	+	+	+	-	-	+	-	+	+	+	+	-	+
1993	+	-	+	-	+	-	-	-	-	-	+	+	-	-	-	-	-	-	+	+		-
1992	+	-	-	-	+	-	-	-	+	+	-	-	-	+	+	+	+	+	+	+		
1991	+	-	-	-	+	+	+	+	+	+	-	+	+	+	+		+	-	-	+		
1990	+	-	-	+	+	+	+	+	-	+	-	-	+		-		-	+		+		
1989	+	+	+	+	-		-	+	+	+		-	+		+			-		-		
1988	-	+		+	-			+	-	-		+						-		-		
1987	-	+		-	-			+		-		+								-		
1986		-		+	+			-														
1985		+		-	+																	
1984		-		-																		
1983				+																		
Total																						

between 0–10 miles and 30–40 miles. The peak at 30–40 miles was largely a result of the Muskegon population and the distance between primary spawning locations in the river and the mouth of the river near Lake Michigan. Walleyes were recaptured by anglers on average 17.4 miles (median = 6.6 miles) from their point of initial capture. Both the minimum distance moved ($Z = -7.881$, $P < 0.001$, $N = 1,525$) and the number of miles per day ($Z = -2.707$, $P = 0.007$, $N = 1,525$) differed significantly between sexes, with females moving an average of 21.7 miles at a rate of 0.2 miles per day and males moving 15.1 miles at a rate of 0.04 miles per day. Additionally, the minimum distance moved was positively related ($r = 0.42$, $P < 0.001$, $N = 1,538$) to the total length at tagging. For example, the average distance moved for 30-inch Walleyes (31.2 miles) was about 6 times higher than for 15-inch Walleyes (5.1 miles). These results agreed with other Great Lakes studies (Schram et al. 1992; Wang et al. 2007) in that female Walleyes moved greater distances than males, and minimum distance moved was positively related to length at tagging.

Summary and Management Recommendations

The Large Lakes Survey Program has proved to be a valuable program for obtaining quality information on some of the State's most valuable fisheries. While the survey efforts required a high amount of effort and expense, the information gained has been very useful in supporting fisheries management decisions. For example, an examination of angler tag returns by week from Lower Peninsula lakes was used to support the extension of the Walleye and Northern Pike season from February 28 to March 15 in the Upper Peninsula. Population and angler harvest data were also used several times for evaluating fishery regulations such as simulating minimum size limits for Walleye in Lake Gogebic, evaluating possession limits for Yellow Perch in Lake Gogebic, as well as providing evidence for removing the 24-inch minimum size limit on Northern Pike in some waters. Growth, density, and recruitment data obtained from the Large Lakes Survey Program were also used to reduce or eliminate Walleye stocking in several lakes where natural reproduction was identified as the primary recruitment source. Finally, the abundance estimates from the Large Lakes Survey Program have provided the base for a regression model to predict Walleye abundance based on lake surface area where empirical estimates do not exist.

This study also resulted in several interesting relationships between population metrics and characteristics of lakes or fish communities. For example, both Walleyes and Northern Pike exhibited evidence of density-dependence in terms of both size structure and growth, each with a threshold density above which populations exhibited relatively slow growth. At lower densities, factors other than density influence growth. This study also showed that fyke-net CPUE is the preferred index of relative abundance for spawning Walleyes across Michigan, though both fyke nets and trap nets provide suitable indices of relative abundance for spawning Northern Pike. Angler catch rates also proved to be useful indices of relative abundance and were positively related to both Walleye and Northern Pike density. Adult Walleye abundance was positively related to lake surface area, but not littoral area or measures of productivity; thus, future regression models used to predict Walleye abundance should likely only consider total surface area.

The evaluation of methods for estimating Walleye abundance resulted in several recommendations though not a perfect resolution to the issue. Single-census estimates using the creel survey as the recapture gear were likely the most accurate, though they were less precise than multiple-census estimates. Additionally, there were potential problems with using a creel survey as a recapture method. First, we likely encountered some reduction in data quality from anglers and/or creel clerks being unable to identify jaw tags or fin clips. In some surveys, many of the fish observed for marks were observed by the angler alone, such as when a clerk would interview an angler from a moving boat (i.e. actively trolling). While this was discouraged, it was a reality in a roving creel survey during which anglers did not always want to stop fishing for an interview. Shore-based, completed-trip interviews would have prevented this, but we would have missed many interviews on these large lakes that had hundreds of residences that could each serve as an access point. The issue of tag loss could be addressed with higher-retention tags such as PIT tags, but PIT tags are much more expensive. Ultimately, tags are only needed when information on fish movement is desired as both abundance and angler exploitation can be estimated from fin clips and a creel survey. The exploitation estimates based on creel survey estimates can be used to delineate populations into low, medium, and high exploitation categories which are likely sufficient for management purposes. The issue of fin regeneration was addressed during the study by switching to a dorsal spine clip that does not regenerate within the year. Another problem from using the creel survey as the recapture method was the varying R/C ratio observed throughout the year. This may have been due to loss of or poor recognition of marks, but could also have been due to seasonal segregation of mature and immature Walleyes. If the decrease in R/C observed throughout the year was primarily due to Walleye behavior, then the optimal time for a recapture sampling is likely when the mature and immature fish are well mixed, which is likely during late June or July. While performing a recapture sample in the summer may address the problem of incomplete mixing, it presents another problem since Walleyes are more evenly distributed at that time and more difficult to sample efficiently. Sampling during the summer would also require the use of gill nets, which would be acceptable in large lakes, but potentially problematic in smaller lakes where mortality resulting from surveying is unacceptable. Ultimately, my recommendation for estimating the abundance of legal-sized Walleyes in large lakes is to mark using dorsal fin clips during the spawning period followed by a summer survey for the recapture sample, with netting being the most desirable gear and angler capture as a secondary method. In smaller lakes, managers should err on the side of caution as to which method is used for a recapture sample since mortality due to sampling could be detrimental to the population. While we did not truly assess single-census methods for estimating the abundance of adult Walleyes, it appears that in lakes less than 2,000 acres, multiple-census methods, based solely on spring sampling efforts, are sufficient for estimating the abundance of adult Walleyes.

For creel surveys, I recommend that fin clip or tag presence data only be collected by trained creel clerks via in-hand inspection. If the information is collected by the angler, it should be denoted in the interview data how it was collected. Additionally, targeted catch and harvest rates should be estimated and regularly reported from all creel surveys on inland lakes. Targeted catch rates were correlated with adult Walleye density and they provide the best metric for evaluating the success rate of anglers targeting Walleyes. For Northern Pike, the targeted catch rates were actually not as useful as the nontargeted rate since relatively few anglers targeted Northern Pike in these large lakes. In other lakes where Northern Pike are highly sought after, the targeted catch rates likely provide the best indicator of angler success. This topic warrants future research.

Results from the Large Lake Survey Program also provided some insights into angler behavior that may be useful for future discussions of fishing regulations. For example, angler selectivity and release data for both Walleyes and Northern Pike could be used to substantiate and refine various regulations such as maximum size limits or protected slot limits. For Smallmouth Bass, the exploitation data in combination with the release information provide insight into the potential exploitation that could occur if more anglers chose to harvest the fish that they caught. The tag return data could also be used to evaluate potential change to the catch and release fishing seasons for various species.

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