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EVALUATION OF STANDARD FISHERY ASSESSMENT TECHNIQUES FOR USE IN LONG-TERM MONITORING

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Abstract – Minnesota Department of Natural Resource's Section of Fisheries annually conducts over 600 fish population assessments. The methods involved in these assessments are necessarily standardized to monitor population trends of recreationally and economically important species. Additionally, age and growth information from important species are routinely collected during these assessments. Resulting data on population trends and age/growth are valuable for managers interested in status of fish population and evaluating management activities such as stocking and regulation evaluations. However, these metrics have not been evaluated in the development and implementation of a long-term ecological monitoring program. Within this context, this study evaluated standardized sampling gear (gill nets, trap nets, and electrofishing), specialized sampling (ice-out trap netting) and the collection of aging structures for age and growth analyses. Frequency of sampling was also evaluated. Based on established statistical thresholds, sampling recommendations were made for adequately sampling fish species and populations so that changes in population trends and age and growth can be identified, and subsequently studied in relation to other components of lake ecology.

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Preface

In response to a growing body of evidence that strongly suggests human development and activities are cumulatively affecting habitat and fish populations in Minnesota lakes, the Minnesota Department of Natural Resource's Section of Fisheries in 2008 initiated a multi-year effort to establish a long-term ecological monitoring program for its medium and small lakes. The vision of this effort, commonly referred to SLICE (Sustaining Lakes in a Changing Environment) was to develop a series of metrics that could be used by managers and researchers to determine the role and extent of various environmental stressors on the State's aquatic resources. A better understanding of these complex interactions and how they affect aquatic ecosystems are keys to successfully managing dynamic ecosystems. However, given fiscal and personnel limitations, any long-term monitoring effort within the State needed to be nested within current sampling programs. To that end, the first objective of the effort was to evaluate the feasibility of methods currently practiced by the Section of Fisheries for sampling the state's fish populations for metric development and to recommend modifications to those efforts when necessary to provide a sustainable, precision-based long-term monitoring program. Concurrent to evaluations of fish population sampling, staff from other DNR disciplines evaluated current practices associated with the monitoring of zooplankton, aquatic plants and benthic macroinvertebrates.

The Section of Fisheries annually conducts more than 600 fishery population assessments. These surveys provide the foundation for local management activities such as stocking and regulation development and assessment. However, because these surveys were designed primarily for making locally-based decisions, their applicability in assessing statewide or regional trends needed to be evaluated. The accuracy and precision of metrics collected with gears associated with standardized population assessments were evaluated, including gill nets, trap nets, and electrofishing, to determine the most appropriate sampling method, sampling frequency, and sample size for a given metric. In addition, different boney structures (e.g. scales and otoliths) and structure sample size were evaluated as it is hypothesized that any age and growth metrics derived from these structures are likely to be affected by large-scale environmental changes. These evaluations encompassed the 24 Sentinel Lakes over a 4-year period, an effort that produced a considerable amount of data. The data and analyses that accompanied them will be used to direct fish sampling on the 24 lakes for the next 15 to 20 years. To guide that sampling, a group of management and research staff identified potential 'indicator species' and made recommendations for sampling those populations (see Appendix A). These recommendations will be evaluated on an ongoing basis.

Area Fisheries management staff from Aitkin, Bemidji, Brainerd, Detroit Lakes, East Metro, Glenwood, Grand Marais, Hinckley, Hutchinson, International Falls, Little Falls, Montrose, Ortonville, Park Rapids, Tower, Spicer, Walker, Waterville, and Windom conducted a great deal of the additional sampling required for these evaluations. The synthesis of the data and analyses was led by Mike McInerny; given the amount information collected in the four year pilot study, this was no small task.

As mentioned, zooplankton (abundance, species composition, etc.) were also evaluated as a potential metric for long-term ecological monitoring. Though not part of this study, the results of those evaluations, along with additional research regarding Cisco populations, paleolimnological analyses of Sentinel Lakes, and whole-lake physical models of three lakes, can be found here: http://www.lccmr.leg.mn/projects/2009/finals/2009_05c.pdf.

In addition to the aforementioned sampling evaluations, considerable effort was expended to develop standardized protocols for sampling and assessing aquatic plant communities. The standard, point-intercept method was evaluated as were several indices of plant community health, including an index of biotic integrity and a floristic quality index. Again, the completion of this additional sampling fell largely on Area fisheries management staff. The final report of the aspect of the project was published in the journal Ecological Indicators as:

> *Beck, M.W., C.M. Tomcko, R.D. Valley, and D.F. Staples. 2014. Analysis of macrophyte indicator variation as a function of sampling, temporal, and stressor effects. Ecological Indicators 46 (2014) 323-335.*

Brian Herwig, John Hoxmeier, and David Staples provided helpful reviews of the initial drafts of the report. David Staples also provided advice on statistical analyses. Martin Jennings and Craig Paukert provided reviews of the fish sampling proposals which can be found in the Appendix. Ray Valley was the initial coordinator of SLICE and without his persistent energy and forethought this project would not have been possible.

Jeffrey Reed
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INTRODUCTION

The long-term monitoring program is designed to evaluate the effects of large-scale stressors on Minnesota's aquatic habitats and fish communities. Ultimately, this monitoring effort will support long-term, sustainable lake ecosystem management strategies. The Section of Fisheries, in conjunction with a coalition of partners, selected 24 sentinel lakes that are representative of the state's major aquatic ecosystem types (Figure 1).

Of the 24 lakes within the long-term monitoring program, all have fisheries and nearly all are being actively managed. These management actions range from stocking of game fishes, primarily Walleye and Northern Pike, implementation of restrictive harvest regulations, and various habitat manipulations including lake reclamation and winter destratification (i.e., aeration). Many of these actions could also mask effects on native or naturalized species caused by environmental stressors.

The primary sampling methods used to assess fish populations by the Minnesota Department of Natural Resources (MNDNR) are standardized gill netting and trap netting during summer (June, July, or August) and electrofishing in spring or fall. Standard gill netting and trap netting target all larger fish species, whereas electrofishing targets Smallmouth Bass and Largemouth Bass. Standard gill nets possess five panels of different bar mesh webbing (0.75-, 1.0-, 1.25-, 1.5-, and 2.0-in bar), and standard trap nets consist of two 3 x 6 ft. frames wrapped with 0.75-in mesh, and a single 40ft lead of 0.75-in mesh. Sampling methodology for standard gill netting, standard trap netting, and spring electrofishing is described in the MNDNR lake survey manual (LSM; MNDNR 1993).

Sampling methods used in long-term monitoring programs must be consistent, and samples must be either unbiased or biases must be consistent and understood. Although MNDNR revised and standardized its lake survey program in 1993, potential sources of bias within the program have not been thoroughly examined. For example, net locations used in MNDNR lake survey traditionally were not randomly selected. Rather nets were set in a variety of habitats that were subjectively selected by staff or set in locations thought to provide the highest catch of a specific species, usually walleye (MNDNR 1993). However, even if net locations were randomly selected, biases still could occur if the same locations are used for each assessment or effort is not sufficient. Biased estimates of metrics can result if size and number of fish caught differ consistently among locations (and adjustments are not made), or if sampling fails to provide sufficient samples of species other than those targeted.

Current LSM guidelines for electrofishing are inconsistent and could produce biased samples of black basses. The guidelines suggest that electrofishing occur at times and locations where the most bass can be caught rather than at randomly selected locations during a defined sampling time when catchability is most consistent (MNDNR 1993). For example, spring electrofishing is encouraged after water temperatures reaches 10^{o} C even though these temperatures are colder than when either bass species spawns (12 to 20^{o} C; Coble 1975; Heidinger 1975). In addition, the LSM does not currently incorporate concepts of the power transfer theory and offers little guidance regarding electrode configurations or crew size. Although unknown or not well understood at the time when the LSM was produced, it is now known that all these factors affect electrofishing catchability of black basses. Furthermore, estimates of relative abundance from sampling only those locations perceived to yield high bass catches will be positively biased if perceptions of optimal habitats are true because specific habitat types support different life stages of this species (Hubbard and Miranda 1987; Annett et al. 1996). Also, the electroshock response in fish is a function of electric power (Watts), not voltage or amperage, transferred from water to fish (Reynolds and Kolz 2012), so inconsistencies in catchability occur when voltage or amperage is fixed but water conductivity varies (Hill and Willis 1994; Reynolds and Kolz 2012). Additionallly, catchability drops 30-50% if one anode is used rather than two (Miranda and Kratochvil 2008), and MNDNR electrofishing boats possess a variety of anodes. Crew size and experience have also been shown to affect size structure and relative abundance estimates of Largemouth Bass in Florida lakes, and density dependent effects on catchability of Largemouth Bass differed if one rather than two people net stunned fish (Hardin and Connor 1992; McInerny and Cross 2000; Schoenebeck and Hansen 2005).

Over 30 fish species are captured with the combination of gill netting, trap netting, boom electrofishing, and ice-out trap netting (MNDNR lake survey database), and numerous **metrics** (catch per effort (CPUE); various estimates of length distributions, age/length at maturity, growth, age structure, etc.) can be estimated for each species. To maintain a focus of identifying metrics of ecological change, a pre-sampling committee chose as target species White Sucker, Northern Pike, Lake Trout, Cisco, Rock Bass, Pumpkinseed, Bluegill, Smallmouth Bass, Largemouth Bass, Black Crappie, Yellow Perch, and Walleye. Each species has some public value because all have harvest regulations except White Sucker and Cisco, and it was hypothesized that each species would be affected directly or indirectly from effects of global climate change, changing land-use, changes in angling, or aquatic invasive species. White Sucker and Rock Bass were chosen primarily because they appear lightly exploited by angling and were viewed to remain that way for some time (Cook and Younk 2001). Lastly, Cisco was chosen because evidence already existed that some populations of this species were declining, and these declines were linked to global climate change and changes in land-use (Jacobson et al. 2008).

Catches in gill netting, trap netting, electrofishing, and ice-out trap netting will provide data to calculate numerous metrics reflecting abundance, size structure, growth, and maturity of these target species. However, these metrics should possess high precision, reflect accurately the population metric being measured, and must be collected cost-effectively if they are to be used. Metrics potentially reflecting population density and size structure can be estimated for each species captured with standard gill netting, standard trap netting, and electrofishing, and metrics reflecting size structure can be estimated from catches with ice-out trap netting. Metrics describing population density include catch per lift (CPUE) for gill netting and trap netting and CPH or catch per kilometer of shoreline for boom electrofishing. Size structure metrics include mean total length, structural indices (i.e., proportional stock distributions), or length frequency distributions in various length bins. Aging structures can also be collected from many species captured with these gears; thus, assuming accurate age estimates, metrics describing age structure and growth can also be estimated. Age and growth metrics include mean age of fish captured, mean lengths of age classes at capture, mean back-calculated lengths at age, and growth patterns. Lastly, gonads of target species can be examined to determine sex and maturity, thus, metrics segregated by sex can also be estimated as well as length and age at maturity.

Sample size requirements for size structure estimates differ depending on the metric being estimated, size and mortality of the population, and lengths of the species. Estimates of length frequency distributions via 1-cm length bins requires sample sizes of 7 to 16 times more than those required for estimates of mean total length or proportional size distributions in order to get the same precision (Miranda 2007). Lower sample sizes are required for length frequency distributions with 2.5-cm bins than for 1-cm bins (Vokoun et al. 2001; Miranda 2007). Furthermore, more samples are required for larger species and when population size is high coupled with low annual mortality (Miranda 2007).

Size structure metrics for each target species will be biased because standard gill netting, standard trap netting, electrofishing, and ice-out trap netting are size selective (McInerny and Cross 1996; Hubert et al. 2012; Reynolds and Kolz 2012), understanding where these biases occur will increase the value of these metrics. Size-selectivity in gill nets is further complicated because these nets possess five panels with different mesh sizes, each having their own specific size-selectivities (Hubert et al. 2012). Size-selectivity has not been defined for any target species except Northern Pike and Walleye sampled with gill nets and for Northern Pike sampled with ice-out trap netting. Standard gill netting selects against the shortest and longest Northern Pike and Walleye most likely from limited mesh sizes, and corrections for this bias have been made (Hamley and Regier 1973; Pierce et al. 1994; Anderson 1998; Grant et al. 2004). Ice-out trap nets caught wider length ranges of Northern Pike than gill nets in a northern Minnesota lake, but modes of length distributions were similar between gears (Pierce and Tomcko 2003).

Similarly, catch per effort (number per lift; CPUE) of Northern Pike and Walleye in standard gill nets and electrofishing catch per hour (CPH) of Smallmouth Bass and Largemouth Bass reflect population densities of these species; however, it is not known if gill net CPUE or trap net CPUE reflects population density of the other target species. Gill net CPUE of Northern Pike increased with increasing population density within and among Minnesota lakes (Pierce and Tomcko 2003; Pierce et al. 2010), and gill net CPUE of Walleye increased with increasing density among Minnesota lakes (MNDNR unpublished data). Spring electrofishing CPH of Smallmouth Bass and Largemouth Bass also increased with increasing population density within and among lakes in Minnesota and Wisconsin (Coble 1992; McInerny and Cross 2000; Schoenebeck and Hansen 2005).

Understanding size-selectivity can also improve value of abundance metrics if lengths not well sampled are omitted from these estimates as well as various estimates of growth. For example, trap net CPUE of Black Crappie less than 200 mm TL in fall and spring did not reflect population density among Minnesota lakes; however, CPUE of Black Crappie 200 to 249 mm TL and > 250 mm TL did (McInerny and Cross 2006). Thus, omitting Black Crappie less than 200 mm TL should improve value of CPUE estimates. Inclusion of fast growing cohorts of shorter, younger age classes and slow-growing cohorts of older, longer age classes causes Rosa Lee phenomenon in back-calculated lengths at age (Quist et al. 2012). Thus, exclusion of these under-sampled age classes reduces bias from Lee's phenomenon (causing negative bias in back-calculated length at age estimates).

The LSM provides guidance on sampling protocol for collecting aging structures, but leaves open opportunities for inconsistent sampling methodology and inadequate samples for aging. The LSM encourages a fixed subsampling protocol where age structures be collected from 10 individuals per 1-cm length group; however, it leaves the option of subsampling at a rate of 5 per length group (MNDNR 1993). For fast growing populations with few age classes, the latter effort appears sufficient; however, it is not known if even the 10-per length group is sufficient for estimating growth for slower growing populations with many age classes. Besides size-selectivity biases and faulty aging technique, Lee's phenomenon occurs if relationships between scale radii and fish body length change with changing body length (Quist et al. 2012). The LSM also does not provide guidance on where on a fish's body scales should be removed; thus scale radii-body length relationships will also vary depending on where on the body scales are removed because scale size differs among regions of a given fish. Understanding scale-radii-body length relationships will also be useful because some length groups would not need to be sampled if relationships appear non-linear. Conversely, the number of sampling options increases if these relationships appear linear.

Understanding incremental growth patterns in fish populations helps identify which growth metrics have the best value. For example, a first-year growth metric likely will have high value if populations exhibit von Bertalanffy growth because most growth occurs in the first year and this growth increment likely explains length at age in most subsequent years (Quist et al. 2012). Conversely, first-year growth has marginal value if populations exhibit Gompertz or logistic growth patterns because the fastest growth increment occurs after the first year of life and explains very little length at age after the first year (McInerny and Cross 1999).

Length or age at maturity also appears to be a metric that could change as a response to one or more of the environmental stressors (Trippel 1995); however, it is not known if these metrics can be estimated from catches with standard lake survey methods. Preliminary examination of the MNDNR statewide database suggest that each gear selects against shorter individuals of each target species, thus, shorter individuals of early maturing target species might not be captured. Also, because target species spawn at different times of the year, it is not known if maturity can be estimated by visual examination of gonads.

Both sample size and dispersion of observations around the mean can affect coefficient of variation (CV; standard deviation/mean), a common measure of precision. Sample size can be controlled; however, factors affecting dispersion in fish population metrics usually cannot. The more normal distributions tend to have lower dispersion than non-normal distributions. Factors likely affecting dispersion include spatial distribution patterns and behavior of target species, gender effects, fish morphometry affecting catch in sampling gears, and others.

Spatial distribution patterns and behavior can affect catch distributions of target species captured with gill nets, trap nets, and boom electrofishing. For example, catch distributions (i.e., frequency of nets with zero fish, frequency of nets with 1 fish, etc.) of relatively mobile, non-schooling fish species captured in passive gears such as gill nets or trap nets should be more normal than distributions of relatively non-mobile, schooling species. Nearly all nets per assessment would catch some individuals of those former species, whereas few nets would capture nearly all individuals of those latter species. For active gears such as electrofishing, normal distributions of CPH should occur if spatial distributions were random or rather uniform regardless of length of sampling segment. However, non-normal distributions of CPH would be expected if segment lengths were short coupled with patchy distributions of target species because odds are higher that very high or a zero CPH would result (Miranda et al. 1996). Odds are higher that more cover types would be sampled with longer segment lengths.

Because growth often differs between sexes in target species, dispersion of size structure estimates, estimates of length at capture of age classes, and back-calculated lengths at age will increase with increasing growth differences coupled with 50:50 sex ratios. Dispersion should also be affected if sex ratios differ over time. Female White Sucker, Northern Pike, Walleye, and Yellow Perch grow faster than males, and male Rock Bass, Bluegill, and Black Crappie often grow faster than females (Beckman 1949; Carlander 1950; 1969; 1977; Isermann et al. 2010). Growth of Ciscoes, Lake Trout, and Smallmouth Bass does not appear to differ between sexes, and growth of Pumpkinseed and Largemouth Bass often differs between sexes but not consistently among populations (Carlander 1969; Coble 1975; Heidinger 1975; Becker 1983).

Precision of mean total length metrics, the least costly of the size structure metrics, would improve if length frequency distributions appear normal rather than non-normal. However, with the exception of Northern Pike and Walleye sampled with gill nets and Northern Pike in ice-out trap nets, it is not known if length distributions of target species caught with each capture gear are normally distributed. Overall, length frequency distributions of Northern Pike caught with gill nets (all meshes combined) and ice-out trap nets, and distributions of Walleye caught with gill nets (all meshes combined) appear relatively normal (Anderson 1998; Pierce and Tomcko 2003). Despite these findings, mean lengths of fish caught with gill nets might not be normal because of the size selectivity inherent in each of the five mesh sizes.

Two goals were set for the fish sampling aspect of this study; first, provide a list of sample metrics with a range of precision which was based largely on sample size. Estimates of precision were then tested to determine if they reflect the populations being measured. Second, provide recommendations whereby either a specific methodology, i.e., gill netting, or study design can be modified to optimize the chance that metrics included in the long-term monitoring sampling will reflect responses to a range of environmental stressors.

This study includes numerous objectives which will be used to accomplish these two goals. Specific objectives include determining the likelihood that samples are representative of the population being measured; determine if sampling methodology is consistent; determine precision of gill net CPUE, trap net CPUE, and electrofishing CPH, and identify factors affecting precision of these abundance metrics; determine precision of size structure estimates from catches in gill nets, trap nets, electrofishing, and ice-out trap nets, and identify factors affecting precision of these metrics; determine if Lee's phenomenon occurs in estimates of back-calculated lengths-at-age and identify factors affecting Lee's phenomenon; determine precision in length-at-age estimates and factors affecting precision of these metrics; evaluate if sampling methodology for collecting age structures provided sufficient samples for estimating age and growth of target species; and determine if age and length at maturity can be estimated with either gill netting, trap netting, or electrofishing.

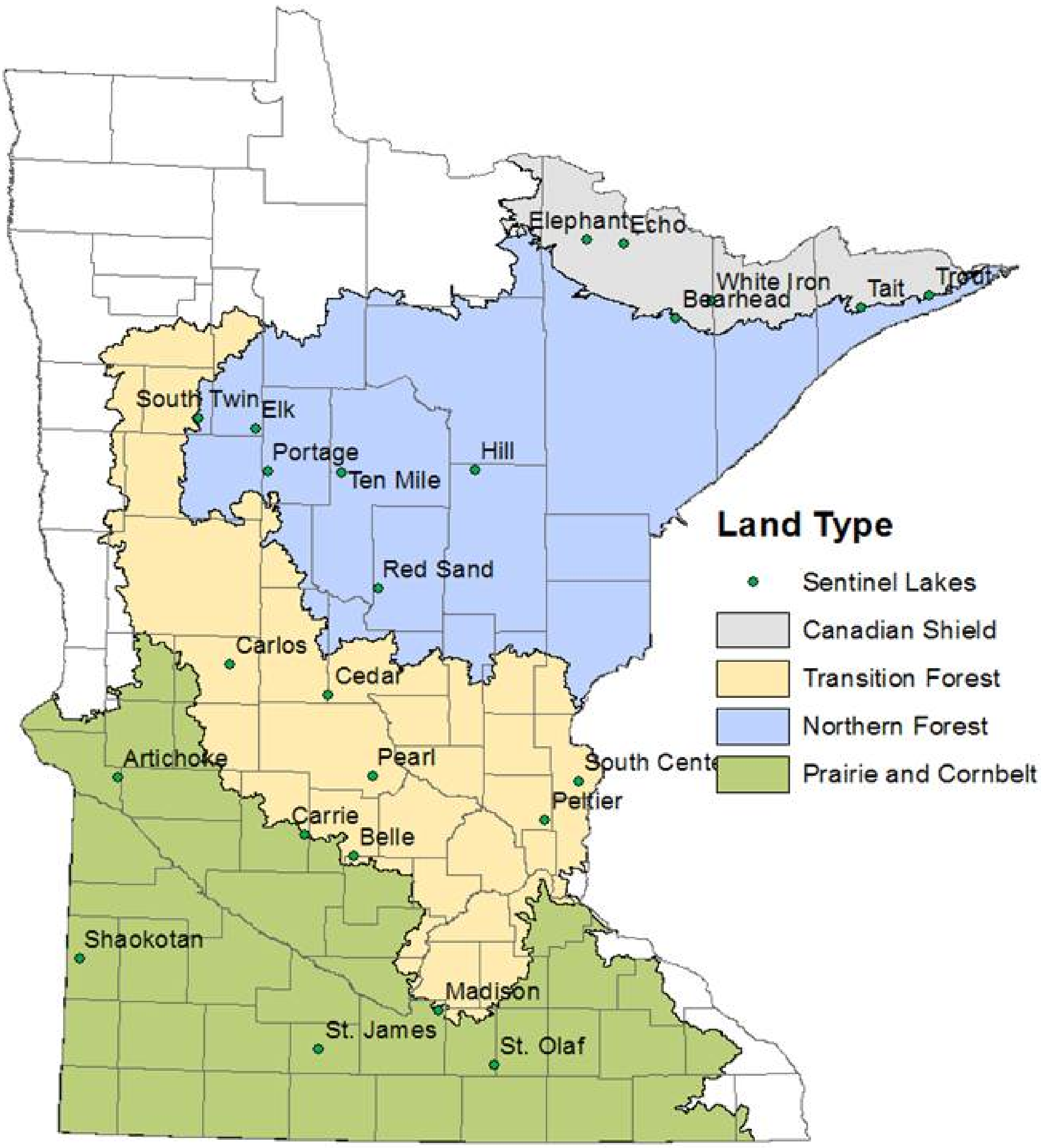


Figure 1. Locations of Sentinel Lakes in Minnesota.

METHODS

Fish sampling

Fish populations in each sentinel lake were sampled with varied combinations of standard trap netting, gill netting, electrofishing, and ice-out trap netting. Gill netting was done annually at Carlos, Belle, Madison lakes and with reduced numbers of sets at South Twin, Shaokotan, and Artichoke lakes (Table 1). Gill netting with the full or nearly full complement of nets was done twice at Trout, Tait, White Iron, Ten Mile, Hill, and Pearl lakes and once in the remaining lakes except Cedar where no gill netting occurred. Netting effort ranged from two net sets at Red Sand and Carrie lakes to 15 at Ten Mile and Carlos lakes (Table 1). Standard gill netting at Trout Lake included five deep sets (below the thermocline with sufficient dissolved oxygen concentration) and three shallow sets; whereas, gill nets were set at or above the thermocline in all other lakes. With few exceptions, annual standard trap netting occurred in all 24 lakes from 2008 through 2011 (Table 2). Netting effort ranged from 5 sets at Carrie Lake to 15 at four lakes. Because of the state government shutdown in 2011 (1-20 July), no netting occurred at Elk and South Twin lakes and was delayed in Madison and St. James lakes (data from these dates were excluded from analyses). Northern Light Lake was replaced by Tait Lake in 2009 as the shallow, low productive lake in the Glacial Shield ecoregion.

Attempts were made to use the same net locations and sampling times as population assessments completed since 1993. Exceptions included White Iron Lake, where 6 of the 15 trap net locations were moved to different locations, and three new locations for each net type were added at Ten Mile Lake. All data collected at gill net location 1 and trap net location 1 for Hill Lake assessments were excluded from analyses because these sets occurred in a very small lake connected to the main lake via a narrow canal rather than within the lake itself. Gill netting and trap netting occurred concurrently within all lakes except Bear Head, White Iron, and Artichoke. Trap nets in these three lakes were set in June and gill nets were set in August or September (Tables 1 and 2).

All fish captured with standard trap nets and standard gill nets were identified to species, and either all or a subsample of 10 to 25 individuals of each species was measured (total length (TL) in mm) from each gill net mesh and each trap net in most cases (MNDNR 1993). Aging structures (scales and otoliths) were usually collected from Rock Bass, Bluegill, Smallmouth Bass (gill nets only), Largemouth Bass (gill nets only), and Black Crappie by using one of two fixed subsampling methods or by a more random approach. In some cases subsampling was done and fixed subsampling was used most often, i.e., either collecting structures from the first five or 10 individuals per 1-cm length group (Table 3). When gill netting and trap netting occurred simultaneously, fixed subsampling was sometimes separated by gear but subsampling from the combined catch from both gears usually occurred. Aging structures from Bluegills and Black Crappies were only collected from individuals caught in trap nets in Bear Head in 2008, Elephant Lake in 2009, White Iron Lake in 2008 and 2010, Echo Lake in 2009, and Carlos Lake in 2008 and 2009. Because fixed sampling can cause positive bias in estimates of dispersion about the means (Bettoli and Miranda 2001), a random sampling approach was tried in Elk Lake in 2008, 2009, and 2010, and Elephant, Echo, and Carlos lakes in 2010 and 2011 (Table 3). Scales and otoliths were collected from all or up to 25 randomly selected individuals in eight trap nets set in Elk Lake per assessment, from all centrarchids in four trap nets set in Elephant and Echo lakes, from all centrarchids caught with gill netting at Lake Carlos in 2010 and 2011, and from all centrarchids caught in four trap nets set in Lake Carlos in 2011. Sex was usually determined from those centrarchids in which otoliths were removed.

Annual night-time electrofishing for black basses was done during spring (May or June) in all lakes except White Iron and Shaokotan which were sampled in the fall. Besides collecting metrics on black basses, this sampling was used to set a benchmark of zero black bass in the three lakes (Trout, Tait, and Shaokotan lakes) that currently do not support either species. Similar to sample site selection for trap nets and gill nets, guidelines in the lake survey manual were used for selecting sampling locations. During the study, electrofishing was encouraged to be done at the same stations used in prior assessments and with the same amount of effort. In lakes not electrofished prior to 2008, it was recommended that two hours of effort be allotted via 4 to 6 sampling stations equally distributed throughout the lake. On smaller lakes the entire shorelines of were sampled (Carrie, St. Olaf, and Elk lakes). All bass captured were identified to species and measured (TL in mm), and sampling date, electrofishing on-time (seconds), water temperature, number of netters, and the number and type of anodes were recorded. Aging structures, usually scales, of both bass species were usually collected from all bass caught with electrofishing even if more than 5 or 10 per 1-cm length group were sampled. Sex was determined in bass sacrificed for otolith removal.

Annual ice-out trap netting was used to capture Northern Pike in 14 lakes and to sample Lake Trout in Trout Lake; this sampling was done to estimate size structure of these species because annual gill netting was viewed to kill excessive numbers of fish in these lakes (except Belle). Northern Pike at White Iron Lake were sampled in 2009 and 2010 but not the other two years. Single-frame trap nets with 1.9-cm bar mesh were used at Red Sand, Belle, Carrie, St. Olaf, and St. James lakes, and standard double-frame trap nets were used at Elephant, Tait, White Iron, Echo, Elk, Hill, and Cedar lakes. Net type or mesh was not recorded for ice out netting at Portage or Peltier lakes. Netting occurred for up to four consecutive days or until catch approximated 100 Northern Pike or Lake Trout. Sex was determined via external examination. Because the objective of this netting was to estimate size structure, not relative abundance, nets failing to capture these species were moved to new locations. Ice out netting was done in 2008 at South Center Lake but was discontinued afterward because additional gill netting was done. Annual ice-out sampling also occurred at Pearl Lake, but sampling gear (double-frame trap netting, hoop netting or back-pack electrofishing) differed among years.

Evaluation of sampling methodology

Several aspects in sampling methodology were evaluated for consistency because inconsistencies in these could lower precision of metrics. These aspects include equipment, timing of sampling, effort, and sample locations because each of these can be adjusted in order to improve precision of estimates. Although gill nets and trap nets are of standard dimensions within lakes and years, electrofishing is more variable due to differences in anode configurations, numbers of netters, and varied environmental conditions. . Thus, electrofishing equipment and procedures were compared within and among lakes. Start and end dates for each gear were compared within lakes to determine if sampling dates were consistent among years. Numbers of nets, and amount of electrofishing on-time within lakes were compared among years in order to determine if similar efforts was applied.

A two-fold approach was used to test if capture gears act as random samplers for estimates of relative abundance metrics (CPUE and CPH) when either nets or electrofishing were done at the same locations or shoreline segments during at least two assessments. First, for each species in each lake and gear, a two-way analysis of variance test was used to test if CPUE or CPH differed among sampling locations while accounting for differences in catch among years (CPUE (or CPH) = f (location + year; both location and year were categorical variables)), if $P < 0.05$ for location effects, then Tukey's Honest Significant Difference (HSD) tests were applied to identify the specific location(s) that differed ($P < 0.05$). Some data were excluded within some lakes because the number or location of net sets differed. For example, single trap nets at Elk and South Center lakes were tampered with in 2008 and not reset. Therefore, data from these net locations were excluded from analyses. Standard numbers of trap nets were not set at South Twin and Madison lakes in 2008, at St. James Lake in 2009, and at St. Olaf Lake a different set of trap net locations was used in 2009 than in 2008, 2010, and 2011. In these lakes, data from years when the odd sets of nets were set were excluded from these analyses as well.

Second, aerial photos and lake contour maps coupled with GIS layers with sampling locations were examined to determine the distribution of sampling effort within lakes. The lack of location effects (P > 0.05) coupled with well distributed sampling effort suggests that the appropriate gear acts as random samplers. Conversely, significant location effects (P < 0.05) coupled with disproportionate sampling effort within lakes could suggest that gears were not acting as random samplers. Location effects linked to physical features within lakes (i.e. bays, arms, etc.) suggest that these lakes could be partitioned by strata. Significant location effects coupled with well distributed sampling effort suggests unique habitat features that either enhance or deter catchability of the appropriate target species; however, these features may not be definable.

Metrics describing size structure

Mean total length was chosen as the metric for reflecting size structure of target fish populations because preliminary examination of length distributions in the MNDNR statewide databases suggest that sample sizes (> 75) would be sufficient to estimate this metric but seldom sufficient to estimate length frequency distributions in 1-cm length groups. In order to achieve the same precision as in mean length estimates, the latter required sample sizes 7 to 16 times higher (Miranda 2007). Furthermore, overall length frequency distributions in 1-cm length groups of gill net catches of Northern Pike and Walleye appear normally distributed (Pierce et al. 1994; Anderson 1996), thus mean lengths appear to be a useful surrogate.

Mean total length of each target species caught with gill netting, trap netting, electrofishing, and ice-out trap netting was estimated from the entire measured catch per assessment; no adjustments for subsampling were made because sizes of these subsamples were too small (< 25) to estimate to the nearest millimeter a length distribution estimate. A coefficient of variation (CV; standard deviation of the mean length of the sample/mean length of the sample) was calculated for each mean length estimate for each gear per assessment. Because gender could be determined externally, mean lengths and CV of mean lengths were also estimated for female and male Northern Pike caught with each ice-out trap net assessment.

A two-fold test was used to determine the effects of sample size and mean length on CV. First, two sets of plots were made for each target species; one was CV of mean length as a function of the total number of individuals measured and the other was CV of mean length as a function of mean length. These plots were segregated by gear. If sample sizes are sufficient these plots will provide visual clues about the relationship between CV of mean length and these variables, and one plot will reveal threshold sample sizes at which CV of mean length stabilizes with respect to sample size. These thresholds can be interpreted as the minimum sample sizes providing practical precisions for mean length metrics. Second, (to aid in interpretation of these plots) general linear models were used to test the effects of the number of individuals measured, mean length, and the number measured*mean length interaction on CV of mean length (CV = f (number of fish measured + mean length + number measured*mean length). Ideally these analyses should be done within each lake; however, in this case CV of mean length was pooled from all lakes and years in order to achieve the widest range of sample sizes. Therefore, these estimates should be viewed as starting points for sample size targets.

General length-frequency distributions in 1-cm length groups were constructed for each gear in order to provide an estimate of size-selectivity. This was accomplished by calculating by 1-cm length groups proportions of the total catch in trap nets and spring electrofishing, and in gill nets proportions by 1-cm length groups and by mesh for each assessment within each lake. Adjustments were made for subsampling of gill net and trap net catches whereby the proportion by 1-cm length groups of unmeasured fish in gill net mesh or trap net equaled that of the subsample, and then the catch by 1-cm length groups of the unmeasured catch was added to the total catch. To account for variable sampling effort and variable size structures of target species among lakes, mean proportions of 1-cm length groups were first calculated for each lake. The final general length distributions equaled the means among all lakes where target species were caught.

Length at age metrics

Mean lengths at capture by age class and back-calculated mean lengths at annulus formation were calculated for each year-class of each centrarchid species and then evaluated. However, several steps were taken to develop these metrics.

Age was estimated from scales and otoliths, however, otoliths were not collected from all centrarchids sampled for aging. Scale impressions were made on acetate, and these impressions were viewed with the same microfiche reader at a constant magnification. Distances between the scale focus and scale radii and between the focus and each annuli were measured along the horizontal transect between the focus and anterior-median edge (Hurley et al. 1997; Quist et al. 2012). Measurements were made with either a digitizing pad or a ruler; gradations between the two methods were similar but not exact. Sagittal otoliths were snapped in half transversely, which exposed the kernel area. The broken edge was placed above a candle flame until singed, after which the unsinged edge was embedded in clay. A drop of oil was placed on the singed surface, and then this otolith was placed under a dissecting microscope and magnified.

The following steps were taken in an attempt to establish quality control for age estimates. First, the same person estimated age from both scales and otoliths. Secondly, age-bias plots with scale age as a function of otolith age were made (Campana et al. 1995). These plots provide the age(s) where scale age deviates from otolith age. Otolith age was assumed to be the correct age for all of the centrarchids because otolith age of Largemouth Bass and Black Crappie equaled known-aged individuals of these species (Buckmeier and Howells 2003; Ross et al. 2005). Therefore, only scale ages with high odds of being equal to otolith age were used herein.

Mean total lengths of each age class at capture were estimated for all Rock Bass, Bluegill, and Black Crappie caught with gill nets and trap nets, and for Smallmouth Bass and Largemouth Bass caught during spring electrofishing. Age-length keys were used to assign to un-aged individuals an age. If fish were sexed by 1-cm length groups, a sex-length key was used to assign unsexed individuals a sex in the same proportion as found in the same 1-cm length group. Age-length keys were then used to assign un-aged individuals an age in the same proportion as found in the sexed and aged sample. It should be noted that only the measured sample was used to estimate mean length at capture for each age class sampled, and age estimates from otoliths were used whenever available.

Mean lengths at capture of each age class were compared between sexes. For each target species within each lake, an ANOVA testing for effects of sex, age, and sample year on mean length was used to identify if mean lengths differed by sex (mean length = f (sex + age + year + sex*age + sex* year; age and year were defined as categorical variables). Sample size per age class included a minimum of two females and two males.

If mean lengths at capture differed between sexes then CV of mean length at age (standard deviation of mean length at age of sample/mean length at age of sample) was estimated separately for each sex and age. These CV's of mean length at age by sex were then compared with CV of the mean length at age estimates made from all lengths (both sexes plus individuals where sex was not determined) measured from that same age class. An ANOVA was used to test if CV of mean length at age differed between sexes and between each sex and the combined sample while controlling for length and sample size (CV of mean length at age = f (sex + sample size + mean length at age + all interactions among independent variables). Percent of the measured catch that were female was calculated for each age class of Rock Bass, Bluegill, Black Crappie, Smallmouth Bass, and Largemouth Bass caught in each gear. Coefficients of variation of mean lengths at age per assessment of sexed centrarchids would likely be lower than CV of mean lengths (all individuals combined) if growth differed greatly between sexes, percent female neared 50%, and if percent female varied little. Therefore, frequency histograms in 10-% bins were constructed in order to demonstrate variability in percent female among age classes.

A two-fold test was also used to test the effects of sample size and mean length at age on CV of mean length at age estimates. Two sets of plots were made for each target species caught with each gear; segregated by sex if CV of mean length at age differed between sexes or if CV of mean length at age of each sex differed from combined samples. One plot was CV of mean length at age as a function of the total number of individuals measured and aged (including un-aged fish assigned an age), and the other was CV of mean length at age as a function of mean length at age. These analyses included all age classes, lakes, and years combined for each target species. Assuming sufficient data, these plots should reveal threshold sample sizes where CV stabilizes, and show visually relationships between CV and these two variables. To aid in interpretation of these plots, general linear models were used to test the effects of the number of individuals measured and aged, mean length at capture, and the number measured*mean length at capture interaction on CV of mean length at age (CV = f (number of fish measured + mean length + number measured*mean length).

Mean back-calculated lengths at age for each age class were estimated with the Fraser-Lee method, using scale measurements and standard intercepts (MNDNR 1993; Quist et al. 2012). Coefficients of variation (standard deviation of sample mean length at age/sample mean length at age) of mean back-calculated lengths at ages 1 through 5 were estimated if aging structures were collected randomly, and further segregated by sex if back-calculated mean lengths at age differed between sexes. For each annulus (1 through 5), an ANOVA was used to test if mean back-calculated length at age differed between sex among lakes (mean back-calculated length at age = sex + lake + lake*sex interaction). Test samples included all individuals in each year-class where at least two of each sex was sampled, and when scale age appeared accurate based on the appropriate age-bias plot. Analyses were also segregated by annulus because total sample sizes decrease with increasing annuli. For samples collected with fixed subsampling, CV's of mean back-calculated lengths at age were likely positively biased (Bettoli and Miranda 2001); thus, they were not calculated.

Graphical plots coupled with ANOVA tests were used to show relationships between CV of mean back-calculated lengths at age a function of sample size and mean back-calculated lengths at age. Plots consisted of CV as a function of the number of fish aged, and CV as a function of mean-back-calculated lengths at age (different sets of plots were done for each age; 1 through 5). For mean back-calculated lengths at ages 1 through 5, the ANOVA model equaled CV = f (number of individuals aged + mean back-calculated lengths at age + number of individuals aged *mean length interaction).

Effects of Rosa Lee's phenomenon on back-calculated lengths at age on each centrarchid species were evaluated from those year-classes in which aging structures were collected for 3 to 4 consecutive years and if scale age estimates seldom differed from otolith age estimates based on age-bias plots. Lee's phenomenon was judged as occurring if mean back-calculated lengths at the same ages in younger cohorts consistently exceeded mean lengths of older cohorts. Standard errors of these means were calculated; these were unbiased when aging structures were collected via random subsampling but could be inflated when collected with fixed subsampling (Bettoli and Miranda 2001).

Gill netting, trap netting, and electrofishing were evaluated to determine the age when centrarchids become fully vulnerable to these gears. Identifying and eliminating younger age classes not fully vulnerable to capture gears would remove positive bias in estimates of back-calculated lengths at age caused by sampling faster growing cohorts. Assuming length frequencies of age classes are normally distributed, plots of length distributions (1-cm length bins) of year-classes captured in consecutive years were made. The age when a year-class becomes fully vulnerable to a particular gear equaled the age when length distributions appeared normal and all 1-cm length groups clearly exceeded the minimum 1-cm length group identified in general length frequency distributions for the appropriate species and gear (see Metrics for describing size structure section).

For each centrarchid species, scale radii were plotted as a function of fish body length in order to determine if relationships were linear or non-linear, the latter suggesting inconsistent scale to body length which can be another factor causing Lee's phenomenon in Fraser-Lee estimates of length at age. For each species, two-way full-factorial ANOVA (scale radius = f (body length + lake-year combination + body length*lake-year interaction) coupled with Tukey's HSD tests (when no interactions occurred) were used to determine if slopes and intercepts differed within lakes. If not, data within lakes were pooled, and a second model (scale radius = f (body length + lake + body length*lake interaction) was run. A sample size of 10 was arbitrarily picked. Because measurements of scale radii and annuli made with the digitizing pad differed from those made with a ruler, analyses were separated by measurement method.

Lastly, a general description of growth patterns for each centrarchid species in each lake was done to aid in identification of meaningful length at age metrics. First, means of each centrarchid species at each lake were estimated for each year-class and then all samples were combined to determine a lake-wide mean among year-classes. These mean back-calculated lengths at age were also estimated from scale ages deemed accurate based on age-bias plots. These growth patterns were categorized into one of three types:von Bertalanffy, Gompertz, or logistic. A von Bertalanffy growth pattern best describes a population where first-year growth is fastest, and subsequent annual growth rates decline with increasing age (Quist et al. 2012). Gompertz patterns describe growth when second-year growth is similar or faster than first-year growth, but declines after age 2. Logistic growth describes a pattern when the fastest growth occurs at age 3 and growth after age 3 declines (Quist et al. 2012). Thus, if all populations exhibit von Bertalanffy growth but not Gompertz or logistic growth, various simple metrics such as lengths at capture of a certain age could be used universally among populations. Conversely, if the other growth patterns occur, then different metrics (i.e., number of years to reach a certain length) would likely be better.

Metrics describing relative abundance

Mean CPUE and CV (standard deviation of mean CPUE estimated from all nets per assessment /mean CPUE from all nets per assessment) of mean CPUE were calculated for all gill net and trap net assessments done for each target species sampled with these two gears. Similarly, mean CPH and CV of mean CPH were calculated for Smallmouth Bass and Largemouth Bass caught with each spring electrofishing assessment at each lake.

Graphical plots coupled with ANOVA tests were used to show relationships between CV of mean CPUE as a function of sample size and mean CPUE. Therefore, for each target species CV of mean CPUE was plotted as a function of the number of nets set and plotted as a function of mean CPUE among all lakes and years combined. All CV calculated from CPUE < 1 were excluded in order to simplify plots and eliminate excessively high CV. These plots should reveal narrowing ranges of CV coupled with slight downward declines in CV with increasing number of net sets and increasing mean CPUE. Full-factorial ANOVA's (CV = f (number of net sets + mean CPUE + number of net sets*mean CPUE) were done to explain the effects of number of nets and CPUE on CV, which should aid in interpretation of these plots. These ANOVA tests were done with untransformed and log-transformed mean CPUE; test results reported herein are those with the more uniform residual plots.

Effects of segment length and electrofishing CPH were tested to determine which has the most influence on CV of mean CPH. Coefficients of variation of electrofishing CPH were calculated, and plotted as a function of the length of shoreline segments (expressed as the number of seconds of electrofishing effort per segment) and mean electrofishing CPH. Analysis of variance was used to test the effects on CV of mean CPH caused by length of sampling segments and mean CPH from pooled data among all lakes and years (CV = f(segment length + mean CPH + segment length*mean CPH).

To determine mechanisms affecting CV of mean CPUE per assessment, frequency distributions in 1- to 10-fish/lift bins were constructed for gill net or trap net CPUE of each target species. Similarly, frequency distributions in 10-fish per hour bins were also constructed for electrofishing CPH of both bass species in order to determine mechanisms affecting CV of mean CPH. However, inclusion in this report all of these analyses will result in an excessive number (number of target species X number of lakes with a given target species) of frequency distributions to display. Therefore, these catch distributions of a given target species were constructed for only two lakes with relatively high CPUE coupled with at least 30 net sets and in the two lakes with higher CPH coupled with the most electrofishing runs during the period between 2008 and 2011 (all nets or electrofishing runs and years pooled). This approach is assumed to provide representative frequency distributions for each species caught with one or two gears; these distributions when CPUE or CPH is low will probably be right-skewed because most nets or electrofishing segments will have a zero catch or zero or very low CPH.

To test if mean CPUE in nets or mean CPH reflects population density of centrarchids, CPUE or CPH of stronger year-classes estimated each year were compared to determine if they declined each year (they should because of mortality). To accomplish this, mean CPUE or CPH of each year-class captured per gill net, trap net, or electrofishing assessment at each lake per year was estimated. For each subsampled trap net catch and subsampled catch for each gill net mesh, the proportion of ages in the unmeasured, un-aged portion of the catch equaled the proportion of ages in the subsample. Then, catch of an age class per net (or mesh) equaled the sum of the total number of that age class in the subsample plus the product of the un-aged sample size and proportion of that age in the subsample. For trap net sets and for gill net meshes in which fish were counted but not measured, catch of an age class equaled the product of the total catch in the net (or mesh) and the proportion of the same age in the pooled measured catch within the same assessment (these included adjustments for subsampling). If age estimates were made in consecutive years, CPUE or CPH was estimated and plotted as a function of consecutive years in those lakes where sampling occurred annually. If CPUE or CPH of a year-class failed to decline among consecutive years, it can be concluded that factors other than population density affected these metrics of abundance.

Previous examination of length frequency distributions (1-cm length bins) suggested that gill nets, trap nets, and electrofishing all select against smaller target species (MNDNR statewide databases), thus, excluding smaller individuals could improve precision and accuracy of relative abundance metrics. Therefore, mean CPUE and CV of mean CPUE were also calculated for Rock Bass > 180 mm TL, Pumpkinseed > 150 mm TL, Bluegill > 150 mm TL, Black Crappie > 200 mm TL, and Yellow Perch > 200 mm TL caught in gill nets and trap nets. Mean CPH and CV of mean CPH were also calculated for Smallmouth Bass > 180 mm TL and > 250 mm TL and for Largemouth Bass > 200 mm TL and > 300 mm TL. These length categories reflect standard length criteria for quality- or memorable-sized categories for proportional size distributions used within and outside of Minnesota (Neumann et al. 2012).

Annual variation and trends in metrics

This study was designed to provide at a minimum an estimate of annual variation in these metrics. Standard errors of the mean among assessments during the study were calculated for each metric evaluated. These standard errors provide a crude, but important, indicator of annual variability during this study. However, because it is unclear if this four-year timeframe is adequate to determine annual variation, variation within the time frame of this study was also compared with variation of the same metric estimated between 1993 (the first year of a state-wide standardized sampling protocol, MNDNR 1993) and 2008. For each metric, means and 95% confidence intervals were estimated for each assessment, plotted as a function of year, and compared visually to determine if confidence intervals overlapped. For CPUE and CPH metrics, year effect was also tested with a general linear model (mean CPUE (weighted by the inverse of variance of mean CPUE) = f (year); net location was fixed if location effects occurred; see Evaluation of sampling methodology section) in order to determine if these abundance metrics increased or decreased during this timeframe (1993 through 2011). Variation within this study did not differ among years before 2008 or if a significant trend did not occur, then it can be concluded that the entire 19-year period can be viewed as stable and used to estimate annual variability normal variation. Conversely, if an upward or downward trend is detected, then the 2008-2011 timeframe was used to estimate current annual variability. Therefore, metric estimates must be clearly different from this variation in order to conclude that a change is occurring.

Age and length at maturity

Gill netting, trap netting, and spring electrofishing were evaluated to determine if age or length at maturity could be estimated for Rock Bass, Pumpkinseed, Bluegill, Smallmouth Bass, Largemouth Bass, Black Crappie, and Yellow Perch. Females were judged as mature if ovaries contained eggs or ova, and judged immature if lacking these. Males were judged as mature if testes appeared whitish. Samples were crudely divided by date; all samples collected before July 15 were pooled and identified as early summer, and samples collected after July 15 were pooled and called late summer. All samples of each species within each sample period were pooled regardless of where caught or gear used. Gears were judged as adequate for estimating maturity if all of the shortest length groups of mature fish exceeded the shortest length groups estimated from the overall length frequency distributions of that species caught with that gear (see metrics describing size structure) and all immature fish were shorter than the longest length group captured.

Table 1. Number of gill nets set and start and end dates of gill netting during 2008, 2009, 2010, and 2011 at 23 sentinel lakes (* sampling either did not occur or occurred later than normally scheduled dates because of the state shutdown); Cedar Lake was not sampled with gill nets.

		Start and end dates			
Lake	Number of sets	2008	2009	2010	2011
Trout	8		27-31 July		2-5 August
Bear Head	12	19-21 August			
Elephant	9		3-7 August		
Tait	9		3-7 August		26-29 July
White Iron	9	2-5 September		7-10 September	
Echo	9		17-21 August		
Ten Mile	15	28 July – 1 August		26-30 July	
Elk	6	8-9 July			*
Hill	11		27-31 July	26-30 July	
South Twin	4	7-11 July	7-10 July	7-9 July	*
Red Sand	2	9-10 June			
Portage	9		10-13 August		
Carlos	15	21-24 July	20-23 July	19-22 July	25-29 July
South Center	12	4-14 August		16-20 August	
Pearl	9	25-29 August			22-26 August
Belle	12	9-13 June	15-19 June	7-11 June	6-10 June
Peltier	5		10-12 August		
Carrie	2				20-22 June
St. Olaf	3				13-16 June
Madison	12	7-16 July	6-15 July	6-14 July	25-29 July*
St. James	3				8-11 August*
Shaokotan	3	4-7 August	3-4 August	2-5 August	1-4 August
Artichoke	5	25-28 August	24-26 August	4-10 August	1-4 August

Table 2. Number of trap nets set and start and end dates of trap netting during 2008, 2009, 2010, and 2011 at 24 sentinel lakes (* sampling not done or delayed because of the state government shutdown; 1-20 July 2011).

		Start and end dates			
Lake	Number of sets	2008	2009	2010	2011
Trout	12	28 July – 1 August	21-24 July	19-23 July	25-29 July
Bear Head	12	9-12 June	8-11 June	7-9 June	6-8 June
Elephant	12	30 July – 1 August	3-7 August	16-19 August	8-10 August
Tait	12		3-7 August	13-16 July	15-29 July
White Iron	15	23-27 June	22-25 June	23-25 June	27-29 June
Echo	12	18-20 August	17-21 August	2-5 August	10-12 August
Ten Mile	15	28 July – 1 August	3-5 August	26-30 July	11-19 August
Elk	8 or 9	9-11 July (8 nets)	7-9 July (9 nets)	7-9 July (9 nets)	*
Hill	11	28-31 July	27-31 July	26-30 July	25-28 July
South Twin	6 or 12	7-10 July (6 nets)	6-10 July (12 nets)	6-9 July (12 nets)	*
Red Sand	9	9-11 June	9-10 June	1-3 June	8-9 June
Portage	9	11-14 August	10-13 August	2-5 August	15-17 August
Cedar	9	21-25 July	21-23 July	19-22 July	21-26 July
Carlos	15	21-24 July	20-23 July	28-30 July	25-27 July
South Center	11 or 12	4-13 August (11 nets)	5-7 August (12 nets)	16-20 August(12 nets)	1-3 August (12 nets)
Pearl	12	25-29 August	24-26 August	23-26 August	22-26 August
Belle	12	9-13 June	15-19 June	7-10 June	6-10 June
Peltier	9	11-13 August	12-14 August	2-5 August	8-10 August
Carrie	5	19-20 June	22-23 June	17-18 June	20-22 June
St. Olaf	9	16-19 June	25-26 June	14-17 June	13-16 June
Madison	9 or 12	7-17 July (9 nets)	6-14 July (12 nets)	6-13 July (12 nets)	25-29 July (12 nets)*
St. James	4 or 9	28-31 July (9 nets)	14-16 July (4 nets)	19-22 July (9 nets)	8-11 August (9 nets)*
Shaokotan	12	4-7 August	3-5 August	2-5 August	1-4 August
Artichoke	15	24-26 June	30 June – 2 July	16-22 June	20-22 June

Table 3. Number of structures collected per 1-cm length group of centrarchids captured with gill nets or trap nets in sentinel lakes during 2008, 2009, 2010, and 2011 (BLG = bluegill; BLC = black crappie; R = random sample; ^{g} denotes samples from gill nets, ^{t} denotes samples from trap nets, ^{gtc} denotes samples from gill nets and trap nets combined, ^{gts} denotes samples from gill nets and trap nets separate)

	Year			
Lake	2008	2009	2010	2011
Bear Head	10^{t}	5^{t}	5^{t}	5^{t}
Elephant	5^{t}	5^{t}	R^{t}	R^{t}
Tait		5^{t}	10^{t}	10^{t}
White Iron	5^{t}	5^{t}	5^{t}	5^{t}
Echo	5^{t}	5^{t}	R^{t}	R^{t}
Ten Mile	10^{gtc}	10^{t}	10^{gts}	10^{t}
Elk	R^{gts}	R^{t}	R^{t}	
Hill	10^{t}	5^{gtc}	5^{gtc}	5^{t}
South Twin	10^{t}	5^{gtc}	10^{gts}	
Red Sand	5^{t}	10^{t}	5^{t}	5^{t}
Portage	5 BLC^{t}, 10 BLG^{t}	5^{gts}	10^{t}	10^{t}
Cedar	10^{t}	5^{t}	10^{t}	10^{t}
Carlos	10^{t}	10^{t}	$10^{t}R^{gs}$	R^{gts}
South Center	5^{gtc}	10^{t}	10^{gts}	5^{t}
Pearl	10^{gtc}		10^{t}	10^{g}
Belle	5^{gtc}	5^{gtc}	5^{gtc}	5^{gts}
Peltier	5^{t}		10^{t}	10^{t}
Carrie	10^{t}	10^{t}	10^{t}	10^{gts}
St. Olaf	5^{t}	10^{t}	5^{t}	10^{gts}
Madison	10^{gtc}	5^{gtc}	5^{gtc}	10^{gtc}
St. James	10^{t}		10^{t}	10^{gts}
Shaokotan			5^{t}	
Artichoke	5^{gts}	5^{gts}	5^{gts}	5^{gts}

RESULTS

CPUE and mean length from gill netting

Gill net effort was well distributed throughout most lakes. In the 13 lakes with two or more assessments sampling dates were consistent with netting occurring within the same week- to 10-day period in all lakes except Artichoke.

Mean gill net CPUE per assessment differed among species and lakes (Table 4). Gill net CPUE of Lake Trout in Trout Lake averaged 3 (s.e. < 1) per lift. Excluding mean CPUE < 1 per lift, lower CV of gill net catch occurred for Northern Pike, Walleye, and Black Crappie, whereas average CV of gill net catch exceeded 90% for Lake Trout, White Sucker, Rock Bass, Bluegill, and Yellow Perch (Table 5). Gill netting captured an average of 1 Smallmouth Bass per lift at Ten Mile Lake, and gill netting either failed to capture Smallmouth Bass or CPUE averaged less than 0.5 per lift at the other four lakes where this species exists. Thus, CV was not calculated for this species caught with this gear.

Numbers of net sets, magnitude of mean gill net CPUE, frequency distributions of CPUE within lakes, and location of net sets affected CV of gill net catch, but not consistently among species. Ranges and magnitudes of CV of gill net catch of Northern Pike were lowest in lakes with 15 nets, and CV of Walleye gill net catch increased with increasing numbers of net sets (Figure 2; Table 6). CV of gill net catch decreased curvilinearly with increasing mean CPUE of Northern Pike, White Sucker, Black Crappie, and Yellow Perch. Inflection points at which CV of gill net catch decreases with respect to CPUE differed among species ranging about seven per lift for Northern Pike to approximately 20 per lift for Black Crappie (Figure 2; Table 6). Mean gill net CPUE of White Sucker was too low to determine an inflection point. In lakes with higher mean CPUE, frequency distributions of gill net catches of Northern Pike in Ten Mile and Carlos lakes appeared normally distributed; frequency distributions of Walleye in Belle Lake, and Black Crappie in Belle and Madison lakes also approached normal distribution patterns (Figure 3). Conversely, the frequency distribution of gill net catches of Yellow Perch in Belle Lake was right-skewed, and the distribution of Rock Bass at Ten Mile Lake lacked a clear mode.

Location of gill nets affected catch and precision of gill net CPUE. Location effects occurred for Lake Trout at Trout Lake (F = 4.53; df = 7; P = 0.0322 for location effect; F =1.07; df = 1; P =0.3358 for year effect) because with the exception of one trout all other fish were caught with the deeper gill net sets. Excluding those three shallow net sets caused CV of gill net catch per assessment to drop from a mean of 94% (s.e. = 12) to 48% (s.e. = 6). Location effects were detected for Rock Bass at Ten Mile Lake (F = 4.47, df = 14, P = 0.0042 for location effect; F = 1.19; df = 1; P =0.2930 for year effect). Locations 5 and 14 (northeast bay) consistently yielded the lowest catches during both gill net assessments, and excluding catch from these two locations reduced CV of gill net catch per assessment from 73% (s.e. = 3) to 58% (s.e. = 5). The gill net at Location 3 in Tait Lake consistently caught more Yellow Perch than the other eight nets (F = 10.23; df = 8; P =0.0018 for location effect; F = 0.35; df = 1; P = 0.5691 for year effect); excluding this net dropped CV of gill net catch from 117 (s.e. = 1) to 78% (s.e. = 17) per assessment. Location effects did not occur in the other lakes supporting these three species. Gill net catch of Northern Pike, White Sucker, Bluegill, Largemouth Bass, Black Crappie, and Walleye appeared unaffected by net location in lakes where two or more gill net assessments were made during this study. However, detection of location effects could eventually occur for Bluegill and Yellow Perch at Hill Lake and for Bluegill at Ten Mile and Pearl lakes after additional gill net assessments are made.

Preliminary evidence suggests that gill net CPUE of Black Crappie usually reflects population density, but data were lacking to test whether or not CPUE of Rock Bass, Bluegill, Largemouth Bass, or Yellow Perch reflects density. Mean CPUE of stronger year-classes of Black Crappie usually declined over time. Exceptions were the 2007 year-classes at Belle and Madison lakes (Figure 4); Black Crappie appear to fully recruit to the gear by age 1 at Artichoke and age 2 at Belle and Madison lakes. Analyses independent of this study suggest that gill net CPUE of Northern Pike and Walleye also increased with increasing population density within or among lakes (Pierce and Tomcko 2003).

Gill net CPUE of most target species appeared relatively stable during the study, and variation in CPUE within the study period was similar to that occurring between 1993 and 2007. Standard errors of mean gill net CPUE among years was usually less than 25% of the mean CPUE in lakes with relatively high CPUE and gill netted at least twice (Table 5). Exceptions include Black Crappies in Artichoke Lake and Yellow Perch in Belle and Shaokotan lakes. In Carlos and Belle lakes, annual variation in mean CPUE of Northern Pike, White Sucker, Rock Bass, Bluegill (Belle only), Largemouth Bass, Black Crappie, Walleye (Carlos only), and Yellow Perch appeared similar to variation in gill net CPUE preceding 2008 (Figure 5.5; $P > 0.05$). Therefore, the variation between 1993 through 2011 should be viewed as normal variation for this metric of these target species. Conversely, gill net CPUE could be declining for Bluegill (t = - 2.93; n = 7; P = 0.0328) in Lake Carlos and declining for Walleye (t = -3.30; n = 9; P = 0.0109) in Belle Lake. Thus variation during 2008 through 2011 could be viewed as normal variation for these species (Figure 5).

Sample sizes for estimating mean length varied among species and lakes. An average of 21 Lake Trout was caught with gill net assessments at Trout Lake. For the other target species, average sample sizes per assessment ranged from 2 to 166 Northern Pike, 0 to 48 White Suckers, 0 to 308 Rock Bass, 0 to 354 Bluegill, 0 to 56 Largemouth Bass, 0 to 14 Smallmouth Bass, 0 to 350 Black Crappie, and 0 to 425 Yellow Perch (Table 7). Mean lengths of each species also differed among lakes (Table 8).

Overall, length distributions (1-cm length groups) of Rock Bass, Bluegill, and Black Crappie in gill net catches appear fairly normal and modal lengths of Lake Trout and Largemouth Bass are within the middle of the length distributions. Thus, mean length estimates appear to be an appropriate surrogate for more complex length-frequency distributions (Figure 6). Conversely, distributions of Yellow Perch appear skewed right. Thus, mean length estimates of these two species will contain that bias.

Coefficients of variation of observed fish lengths per assessment appear to be a function of the number of individuals measured and mean total length per assessment; however, effects of these variables on sample CV differed among species. Based on plots of CV of length as a function of the number measured per assessment, CV of length does not stabilize until at least 50 Largemouth Bass, 100 Northern Pike, Rock Bass, and Bluegill, 150 Yellow Perch, and 200 Black Crappies are measured (Figure 7). Strong (P < 0.05) mean length*number measured interactions occurred for White Sucker and Walleye (Table 9). For White Sucker, CV of length dropped after sample sizes reached 22 and mean length exceeded 420 mm TL, and the same occurred for Walleye when sample size exceeded 66 and mean length exceeded 410 mm TL. Coefficients of variation of observed lengths in samples increased with increasing mean length of Yellow Perch (Table 9; Figure 7). When controlling for the number of individuals measured, CV of length of Northern Pike, Rock Bass, Largemouth Bass, and Black Crappie did not decline with increasing mean length per assessment; however, CV of length for Bluegill probably did (Table 9; Figure 7).

Mean total lengths of most target species appeared relatively stable during the study, and variation in mean lengths within the four year period was similar to that occurring between 1993 and 2007. Standard errors of mean lengths were usually less than 10% of the mean within lakes gill netted at least twice (Table 8). Exceptions include Northern Pike at Tait and Shaokotan lakes and Walleye at Pearl Lake. Annual variation of mean length estimates of each species at Carlos and Belle lakes during this study was similar to variation of this metric before 2008. Exceptions include Bluegill at Lake Carlos and Yellow Perch at Belle Lake (Figure 8). Higher variation occurred in mean length of Bluegill at Lake Carlos during 2008 through 2011 than before 2008. Although variation appeared similar, mean lengths of Yellow Perch at Belle Lake during 2008 through 2011 are lower than those sampled before 2008 (Figure 8). Variation in mean length between 1993 through 2011 could be viewed as normal variation for the remaining species.

<u>Recommendations</u>:

Mean gill net CPUE is relatively a precise metric reflecting relative abundance of Northern Pike, Walleye, and Black Crappie, and CPUE reflects population density of the former two species (Pierce and Tomcko 2003; MNDNR unpublished data). Because downward trends appear detectable in Carlos and Belle lakes, gill net CPUE of White Sucker appears to be a useful metric for measuring relative abundance; however, this metric will likely be imprecise because of low abundance or low catchability. Catchability of Rock Bass in gill nets usually exceeds that in trap nets; thus, odds are higher that useful length-based metrics can be obtained from individuals captured in gill nets. Because of high mesh size selectivity, mean length estimates of Yellow Perch appear relatively insensitive for detecting change. To ensure better estimates of mean length, a minimum of 25 randomly selected individuals per species per mesh should be measured for total length (MNDNR 1993).

Annual or biannual gill netting should be continued in sentinel lakes larger than 500 acres because this gear appears to provide useful data for long-term monitoring. However, gill netting frequency should be greatly reduced or discontinued in the smallest sentinel lakes as effects on target species populations from gill net mortality increase with decreasing lake size or depth. When recommended numbers of gill nets are used per assessment, gill net mortality of Northern Pike increased with decreasing lake surface area among 12 Minnesota lakes smaller than 500 acres, but estimates averaged 1.1 % among three larger (627 to 1890 acres) lakes (R.B. Pierce, MNDNR, personal communication). The following equation was used to estimate mortality of Northern Pike in lakes < 500 acres: % mortality = - 0.0129 (lake area in acres) + 6.84. For Walleye, gill net mortality decreased with increasing lake depth and lake surface area. Among 21 lakes (26 estimates of population size and gill net CPUE) with maximum depths ranging from 4 to 208 feet and surface areas ranging from 196 to 4,782 acres, gill net mortality for lakes with maximum depths < 12 feet was about 1.1% per net regardless of lake area. For lakes with maximum depths $\geq$ 12 feet, mortality was estimated at 0.44% per net in lakes < 576 acres, 0.19% per net in lakes $\geq$ 576 and less than 837 acres, and 0.15% per net in lakes $\geq$ 837 acres (S.E Persons, personal communication; MNDNR unpublished data). Gill net mortality of Lake Trout was estimated at 0.2% per set (S.E. Persons, personal communication); thus, gill netting probably killed about 1% (0.2% X 5 deep gill net sets) of the Lake Trout per assessment at Trout Lake. Lastly, about 1.6% of adult Muskellunge in Elk Lake is expected to be killed per gill net assessment (J.A. Younk, MNDNR, personal communication). It is not known if gill net mortality is additive with the other sources of mortality for each of these species.

Sample sizes for length metrics of each target species in Carrie, St. Olaf, and St. James lakes were insufficient because netting effort (2 or 3 nets) was too low. Thus, if additional nets cannot be set because of concerns over excessive mortality, alternative means to obtain these metrics should be employed. Conversely, three gill nets at Lake Shaokotan sampled relatively high numbers of yellow perch and walleye, and CV of CPUE and CV of mean length per assessment appeared consistent from 2008 through 2011.

Only South Twin and Red Sand lakes can be sampled with more nets than set during this study based on sampling guidelines in the LSM (MNDNR 1993); however, assuming similar CPUE as observed in this study, adding extra nets will benefit metrics at South Twin Lake much more. For example, doubling netting effort from four to eight at South Twin Lake will likely provide sufficient numbers of Northern Pike and Walleye for estimating mean length metrics, and the precision of mean CPUE of Northern Pike will improve because mean CPUE exceeded 7. Conversely, because CPUE of Northern Pike equaled 2.5 per lift, increasing netting effort from two to nine (the recommended maximum for this lake size) at Red Sand Lake will not greatly improve precision of CPUE estimates of Northern Pike. Because of higher gill net CPUE (> 7 per lift), frequency distributions of gill net CPUE of Northern Pike at South Twin will likely be normal but this distribution will likely be right-skewed at Red Sand Lake. Furthermore, projected sample sizes of Northern Pike (< 25) and yellow perch (< 60) would be insufficient for precise mean length estimates at Red Sand Lake.

Finally, these recommendations are based on results gathered from pooled samples from all lakes and years sampled during this study rather than from data collected within lakes over time. Thus, sampling effort with respect to precision should be re-evaluated after additional samples are collected within each lake.

Table 4. Mean (s.e.) gill net catch per lift (CPUE) among gill net assessments of northern pike (NOP), white sucker (WTS), rock bass (RKB), bluegill (BLG), largemouth bass (LMB), black crappie (BLC), walleye (WAE), and yellow perch (YEP) at each sentinel lake during 2008 through 2011 (Cedar Lake was not gill netted during these years; gill netting at St. James occurred several weeks later than prior assessments thus data were not reported).

	Species							
Lake	Northern pike	White sucker	Rock bass	Bluegill	Largemouth bass	Black crappie	Walleye	Yellow perch
Trout		0						1.3 (1.3)
Bear Head	5.7	3.0		5.2	1.2	0.6	9.0	0.6
Elephant	1.3	2.3		0.8		0.2	6.1	7.8
Tait	0.9 (0.1)	5.4 (0.2)		0			8.7 (2.6)	5.6 (0.4)
White Iron	2.4 (0.2)	2.8 (0.2)	0.5 (0.5)	0.1 (0.1)	0	0.2 (0.2)	11.5 (1.7)	8.3 (0.4)
Echo	4.7	9.3	0	0.2	0	9.2	14.6	7.1
Ten Mile	11.0 (3.0)	1.4 (0)	20.6 (1.8)	2.0 (0.1)	1.9 (0.5)	1.0 (0.03)	5.5 (0.4)	11.7 (0.2)
Elk	5.3	0	2.2	0.5	0.7		4.2	44.7
Hill	2.5 (0.4)	2.0 (0.5)	0.6 (0.2)	3.0 (0.3)	0.7 (0.5)	1.6 (0.4)	8.9 (0.2)	3.8 (0.1)
South Twin	13.7 (2.6)	3.7 (0.6)	1.2 (0.6)	2.8 (1.1)	2.2 (0.4)	0.3 (0.1)	8.2 (1.8)	1.4 (0.9)
Red Sand	2.5			0	0	0	0	6.5
Portage	6.6	0.7	0	2.1	0.1	2.7	4.8	1.9
Carlos	10.8 (0.9)	1.7 (0.7)	5.6 (0.7)	1.7 (0.2)	3.7 (0.8)	1.4 (0.2)	5.0 (1.0)	1.8 (0.2)
South Center	2.3 (0.5)	0.6 (0.4)		29.5 (7.2)	0.2 (0.4)	15.8 (0.4)	3.5 (0.3)	2.0 (1.0)
Pearl	16.9 (2.8)	1.9 (0.1)		16.3 (2.0)	1.4 (0.9)	8.4 (2.4)	5.6 (0.4)	0
Belle	2.4 (1.0)	1.0 (0.5)		0	0.02 (0.02)	7.7 (2.6)	5.9 (0.8)	24.9 (12.4)
Peltier	7.4	0		13.2	0.2	21.2	0.4	85.0
Carrie	13.0	1.0		0	0	5.5	2.5	34.0
St. Olaf	1.7	0.3		6.3	0	8.3		13.3
Madison	2.2 (0.1)	0.3 (0.2)		7.7 (1.6)	0.1 (0.1)	27.3 (8.4)	5.9 (0.7)	17.2 (4.8)
Shaokotan	0.5 (0.2)	0.1 (0.1)		0			19.8 (1.0)	38.8 (12.9)
Artichoke	2.2 (1.3)	0		0.2 (0.1)	0	45.1 (25.8)	16.2 (3.1)	0.2 (0.2)

Table 5. Mean and range of coefficients of variation (CV) of gill net catch (mean catch ≥ 1 per lift) estimates for gill netting and trap netting of target species among 24 sentinel lakes during 2008 through 2011.

	CV of gill net Catch			**CV of trap net Catch**		
Species	Mean	range	n	Mean	range	n
Lake trout	94	82-106	2			
Northern pike	66	7-167	35			
White sucker	92	39-170	26			
Rock bass	92	65-150	10			
Bluegill	92	33-135	23	103	40-290	63
Largemouth bass	95	57-164	12			
Black crappie	74	25-132	26	106	39-194	55
Walleye	68	11-138	40			
Yellow perch	95	18-195	34			

Table 6. Sample size, *t* statistics, probabilities that *t* = 0 for full factorial ANOVAs testing the effects of the number of net sets (≥ 3) and mean catch per lift (CPUE; log transformed; CPUE ≥ 1) on coefficients of variation of gill net catch of northern pike, white sucker, rock bass, bluegill, largemouth bass, black crappie, walleye, and yellow perch and trap net CPUE estimates of bluegill and black crappie (all samples within and among sentinel lakes combined).

		Independent variables					
		net sets		Mean CPUE		net sets*mean CPUE	
Species	n	*t*	*P*	*t*	*P*	*t*	*P*
				Gill nets			
Northern pike	35	-0.22	0.8287	-7.29	<0.0001	-1.04	0.3055
White sucker	26	-1.69	0.1060	-6.00	<0.0001	0.60	0.5519
Rock bass	10	0.55	0.6052	-1.62	0.1565	0.49	0.6418
Bluegill	23	1.44	0.1653	-1.69	0.1069	0.21	0.8377
Largemouth bass	12	-0.41	0.6948	-1.47	0.1788	0.15	0.8842
Black crappie	26	1.88	0.0740	-3.27	0.0035	1.88	0.0991
Walleye	40	3.07	0.0040	-1.46	0.1533	0.73	0.4706
Yellow perch	34	-0.79	0.4347	-5.23	<0.0001	0.13	0.8971
				Trap nets			
Bluegill	67	0.12	0.9016	-6.61	<0.0001	-1.96	0.0539
Black crappie	55	0.17	0.8642	-2.89	0.0056	0.37	0.7154

Table 7. Mean (s.e.) number of cisco (TLC), lake trout (LAT), northern pike (NOP) white sucker (WTS), rock bass (RKB), pumpkinseed (PMK), bluegill (BLG), largemouth bass (LMB), smallmouth bass (SMB), black crappie (BLC), walleye (WAE), and yellow perch (YEP) sampled per gill net assessment in 22 sentinel lakes during 2008 through 2011 (Cedar Lake was not gill netted, and gill netting at St. James occurred several weeks after normal sample dates).

Lake	Species										
	TLC	LAT	NOP	WTS	RKB	BLG	LMB	SMB	BLC	WAE	YEP
Trout	0	21 (3)		0							12 (12)
Bear Head			68	36		63	14		7	108	7
Elephant			12	21		7		2	2	55	70
Tait			8 (1)	48 (2)		0				78 (24)	50 (4)
White Iron	88 (36)		22 (2)	26 (2)	4 (4)	< 1	0	2 (2)	2 (2)	104 (16)	75 (4)
Echo			42	84	0	2	0	0	83	131	64
Ten Mile	0		166 (44)	21 (0)	308 (28)	30 (1)	29 (7)	14 (4)	14 (< 1)	82 (6)	180 (2)
Elk	86		32	0	13	3	4			25	268
Hill			28 (4)	22 (6)	7 (2)	33 (3)	8 (6)		18 (4)	98 (2)	42 (1)
South Twin	12 (3)		55 (10)	15 (2)	5 (2)	11 (4)	9 (2)		1 (< 1)	33 (7)	6 (4)
Red Sand			5			0	0		0	0	13
Portage			59	6	0	19	1		24	43	17
Carlos	2 (2)		163 (14)	25 (10)	85 (10)	26 (3)	56 (12)	< 1	21 (3)	76 (15)	26 (4)
South Center			28 (6)	8 (4)		354 (86)	2 (< 1)		190 (4)	42 (4)	24 (12)
Pearl			152 (25)	17 (1)		126 (22)	13 (8)		76 (22)	50 (4)	0
Belle			28 (12)	12 (5)		0	< 1		92 (31)	71 (9)	299 (149)
Peltier			37	0		66	1		106	2	425
Carrie			26	2		0	0		11	5	68
St. Olaf			5	1		19	0		29		40
Madison			45 (18)	18 (2)		98 (15)	2 (1)		350 (74)	84 (14)	171 (53)
Shaokotan			2 (1)	< 1		0				60 (3)	116 (39)
Artichoke			11 (6)	0		1 (<1)	0		225 (128)	81 (16)	1 (< 1)

Table 8. Mean (s.e.) total length of northern pike, white sucker, rock bass, bluegill, largemouth bass, black crappie, walleye, and yellow perch caught with gill nets during 2008 through 2011 (Cedar Lake was not gill netted, and gill netting at St. James occurred several weeks after normal sample dates).

	Species							
Lake	Northern pike	White sucker	Rock bass	Bluegill	Largemouth bass	Black crappie	Walleye	Yellow perch
Trout								184
Bear Head	574	443		133	315	236	350	155
Elephant	695	468		159		260	361	172
Tait	514 (78)	405 (39)					353 (1)	226 (18)
White Iron	586 (10)	395 (12)	209	215		203	353 (11)	188 (7)
Echo	595	410		184		209	304	169
Ten Mile	548 (2)	412 (18)	192 (1)	135 (10)	281 (6)	239 (15)	454 (8)	189 (1)
Elk	599		187	121	313		437	213
Hill	539 (8)	383 (23)	205 (19)	180 (12)	255 (16)	230 (12)	410 (39)	160 (1)
South Twin	466 (4)	438 (5)	165 (2)	130 (8)	253 (21)	204 (34)	373 (9)	158 (12)
Red Sand	575							187
Portage	545	442		160	265	204	301	150
Carlos	502 (3)	417 (10)	204 (2)	141 (11)	280 (4)	230 (9)	427 (34)	180 (3)
South Center	700 (3)	469 (20)		160 (<1)	284 (6)	190 (5)	445 (32)	163 (5)
Pearl	522 (8)	460 (17)		161 (4)	354 (5)	198 (10)	450 (52)	
Belle	656 (36)	418 (23)			233	177 (6)	438 (18)	166 (5)
Peltier	577			172	166	172	298	166
Carrie	536	308				195	419	172
St. Olaf	718	393		171		191		163
Madison	679 (27)	436 (8)		168 (2)	319 (57)	197 (11)	514 (10)	174 (3)
Shaokotan	506 (50)	316					388 (12)	217 (13)
Artichoke	488 (41)			136 (20)		177 (12)	402 (23)	143

Table 9. Sample size, *t* statistics, probabilities that *t* = 0 for full factorial ANOVAs testing the effects of the number of individuals measured and mean total length (TL; mm) on coefficients of variation of observed length per assessment of northern pike, white sucker, rock bass, bluegill, largemouth bass, black crappie, walleye, and yellow perch in gill nets, rock bass, bluegill, black crappie, and yellow perch in trap nets, smallmouth bass and largemouth bass in spring electrofishing, all (a), female (f), and male (m) northern pike caught with ice out trap netting, and mean length at age of rock bass, bluegill, black crappie caught in gill nets (gn) and trap nets (tn), and largemouth bass caught with spring electrofishing within and among sentinel lakes, and mean back-calculated lengths at ages 1 of bluegill caught in trap nets and largemouth bass caught with electrofishing (all lakes and years pooled).

		Independent variables					
		# measured		Mean TL		measured*TL	
Species	N	*t*-ratio	*P*	*t*-ratio	*P*	*t*-ratio	*P*
Gill nets							
Northern pike	41	0.71	0.4838	0.46	0.6473	0.98	0.3344
White sucker	31	0.22	0.8251	-3.40	0.0021	-2.48	0.0197
Rock bass	12	-1.30	0.2284	-1.24	0.2510	0.08	0.9353
Bluegill	26	-1.22	0.2363	-2.02	0.0552	0.20	0.8406
Largemouth bass	18	-1.22	0.2436	-1.05	0.3112	0.82	0.4256
Black crappie	32	0.02	0.9850	0.01	0.9954	-0.18	0.8562
Walleye	41	0.44	0.6613	-2.20	0.0345	-2.21	0.0330
Yellow perch	39	0.28	0.7776	3.61	0.0010	-1.70	0.0984
Trap nets							
Rock bass	26	0.23	0.8187	-2.69	0.0134	-0.66	0.5184
Bluegill	81	-1.24	0.2189	-4.12	<0.0001	-3.59	0.0006
Black crappie	72	-2.19	0.0316	-3.59	0.0006	-1.00	0.3190
Yellow perch	58	-0.06	0.9558	1.35	0.1813	1.02	0.3132
Spring electrofishing							
Smallmouth bass	8	1.01	0.3699	-0.15	0.8889	0.70	0.5239
Largemouth bass	48	-0.37	0.7114	-2.95	0.0051	-1.07	0.2912
Ice-out trap netting							
Northern pike (a)	53	0.47	0.6408	-1.88	0.0667	0.91	0.3652
Northern pike (f)	45	2.27	0.0286	-1.01	0.3183	2.52	0.0157
Northern pike(m)	45	0.85	0.4019	-1.07	0.2897	1.22	0.2288
Mean length at age							
Rock bass (gn)	70	2.23	0.0292	-3.16	0.0024	-0.39	0.6975
Rock bass (tn)	60	0.05	0.9620	-3.33	0.0015	-0.46	0.6491
Bluegill (gn)	103	-0.70	0.4863	-2.67	0.0088	-0.12	0.9033
Bluegill (tn)	368	3.08	0.0022	-8.44	<0.0001	-2.53	0.0119
Black crappie(gn)	109	0.35	0.7269	-4.32	<0.0001	-1.00	0.3180
Black crappie (tn)	234	0.74	0.4587	-5.32	<0.0001	-0.40	0.6891
Smallmouth bass	43	0.01	0.9960	-3.42	0.0015	0.19	0.8497
Largemouth bass	185	-0.03	0.9773	-6.13	<0.0001	-0.41	0.6825
Mean back-calculated lengths at age 1							
Rock bass	21	2.98	0.0083	1.27	0.2196	1.79	0.0911
Bluegill	22	0.29	0.7771	0.01	0.9944	-2.57	0.0192
Largemouth bass	131	2.25	0.0264	-0.10	0.9198	-2.17	0.0322

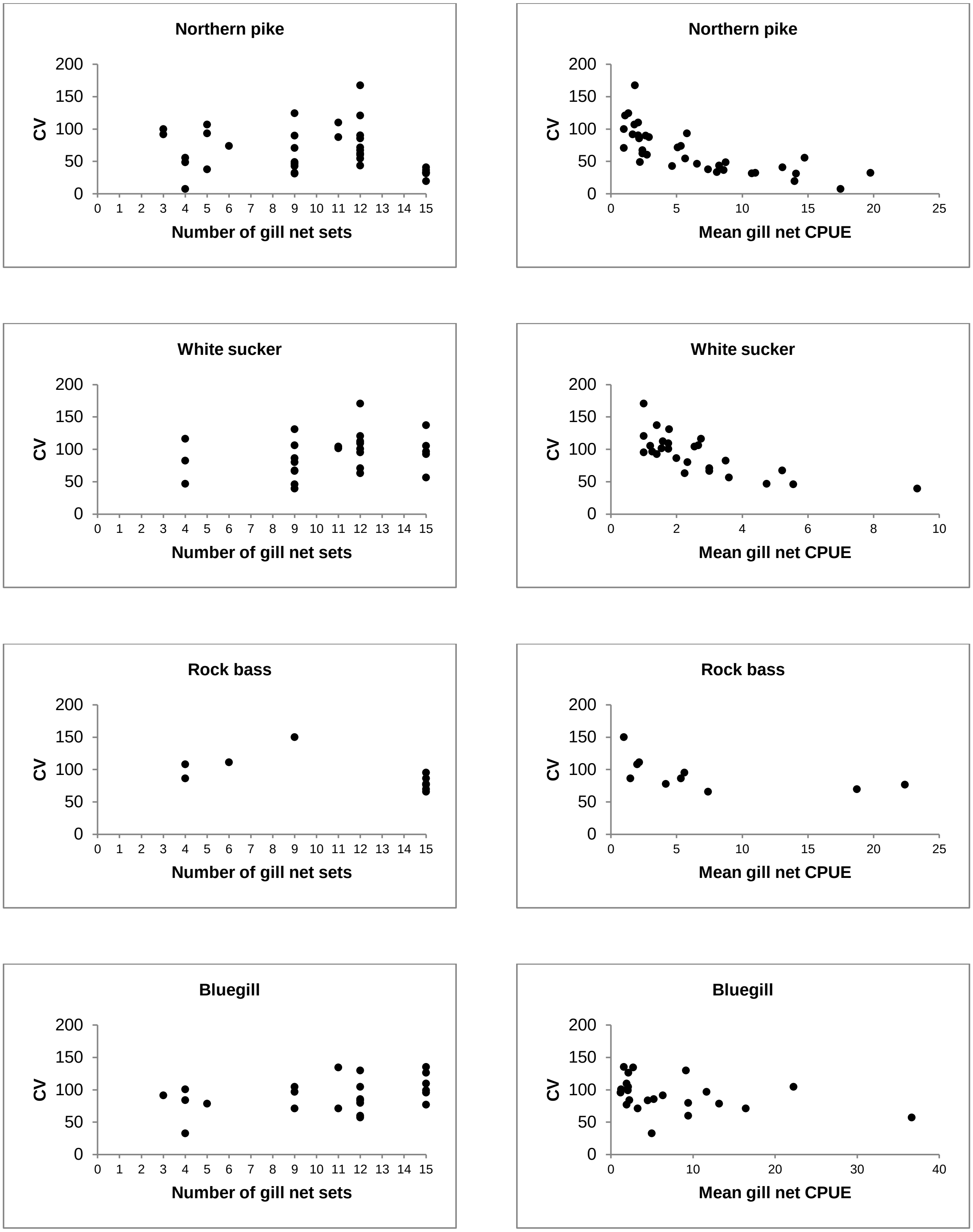
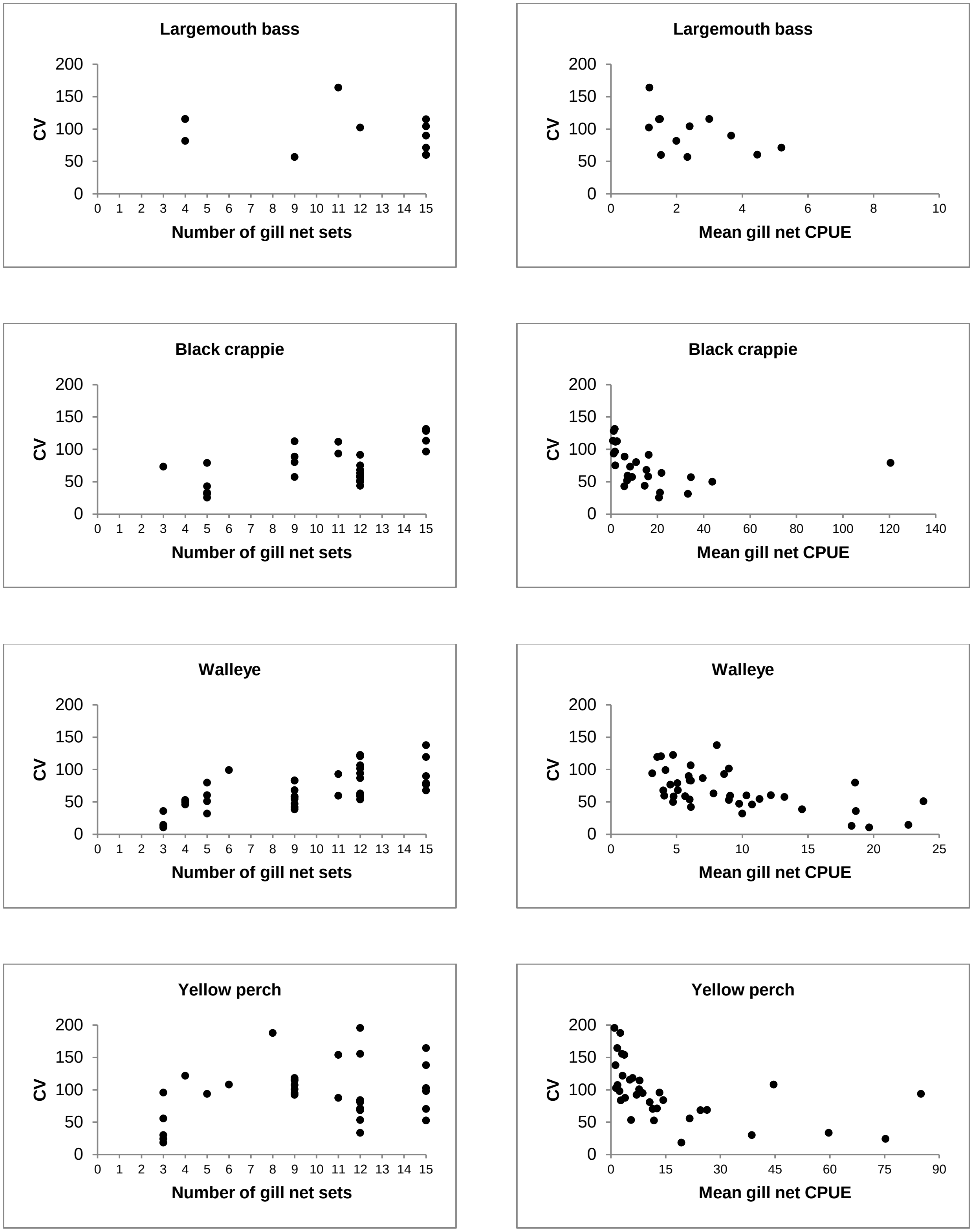


Figure 2. Coefficient of variation (CV) of gill net catch (n $\geq$ 3 net sets) as a function of the number of net sets within lakes and as a function of mean ($\geq$ 1 per lift) gill CPUE per assessment for northern pike, white sucker, rock bass, bluegill, largemouth bass, black crappie, walleye, and yellow perch among sentinel lakes between 2008 and 2011.

(Figure 2 continued on next page.)



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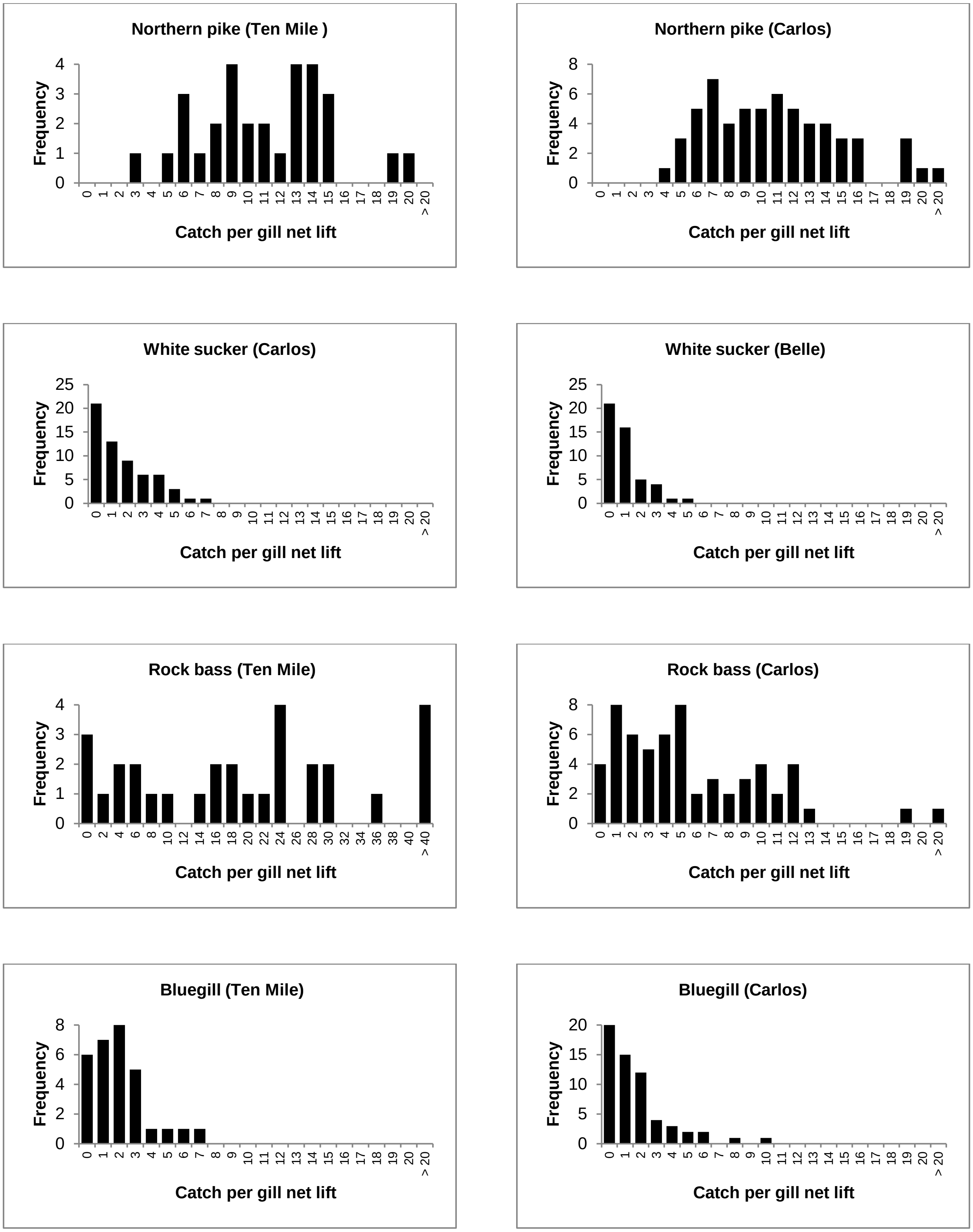
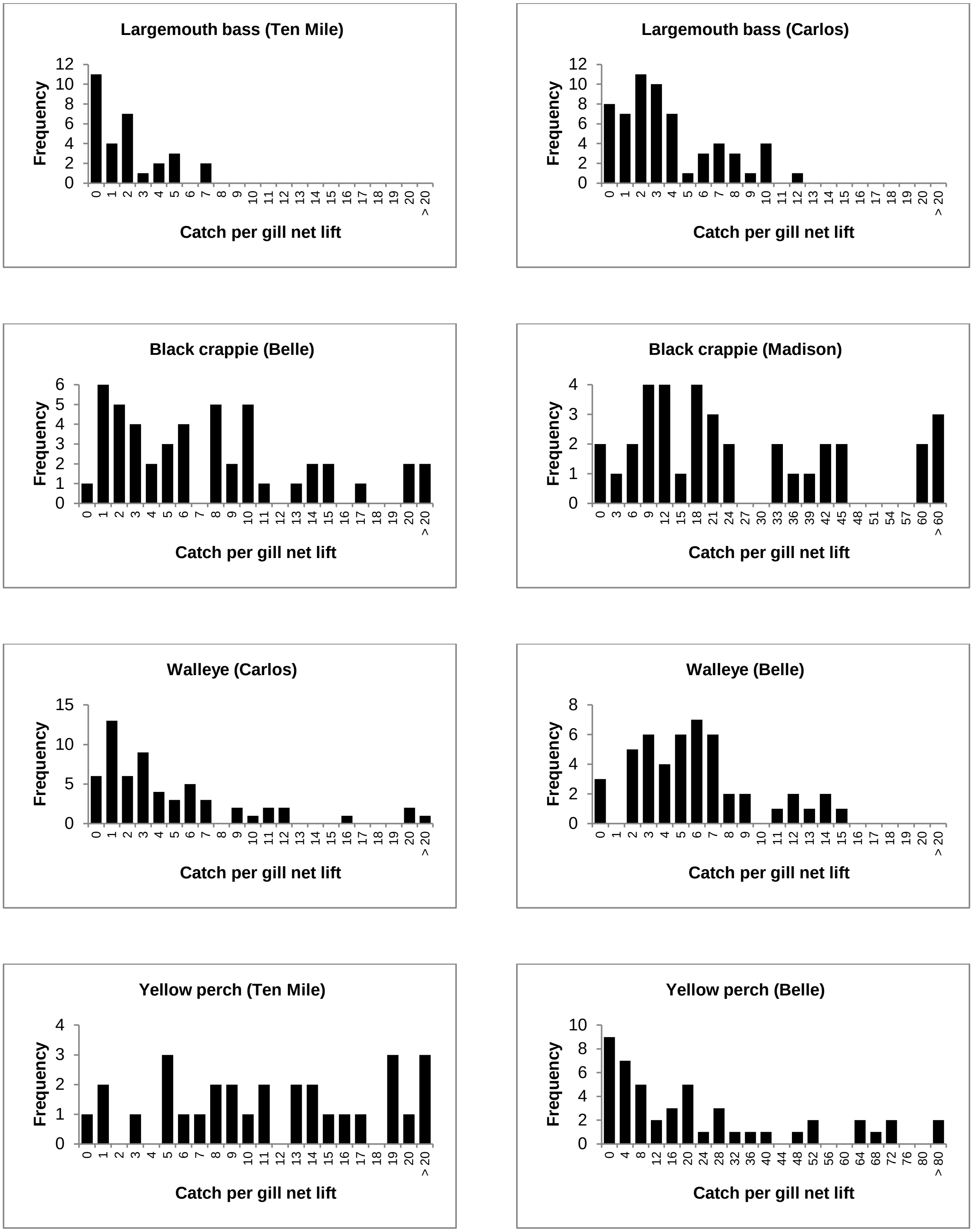


Figure 3. Frequency distributions of gill net catch of northern pike, white sucker, rock bass, bluegill, largemouth bass, black crappie, walleye, and yellow perch in two sentinel lakes with high gill net CPUE coupled with a minimum of 30 net sets per species from 2008 through 2011.

(Figure 3 continued on next page.)



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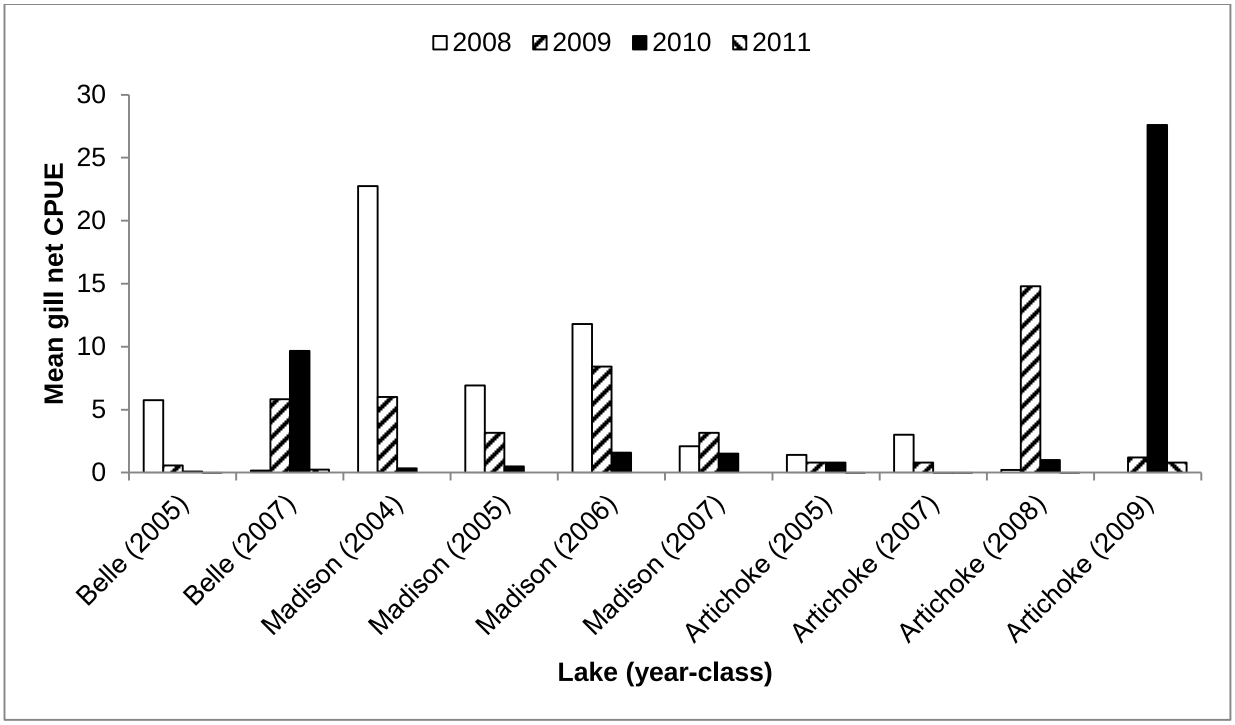


Figure 4. Mean gill net catch per lift of selected year-classes of black crappie caught in consecutive years (2008, 2009, 2010, and 2011) in Belle, Madison, and Artichoke lakes.

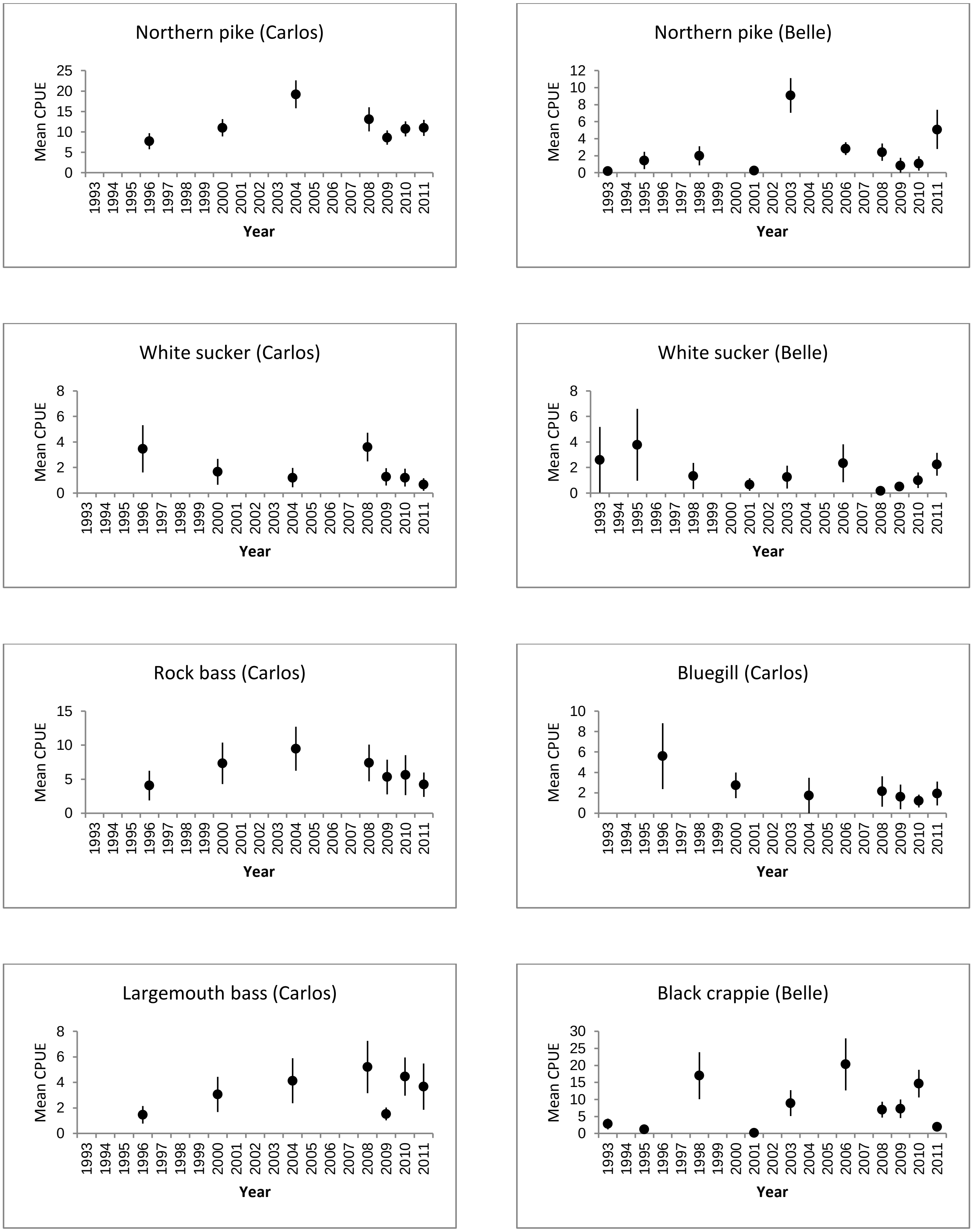
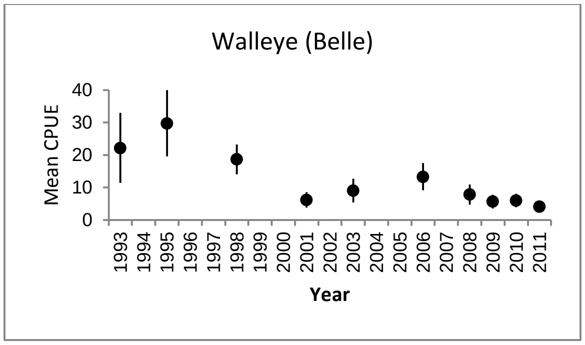
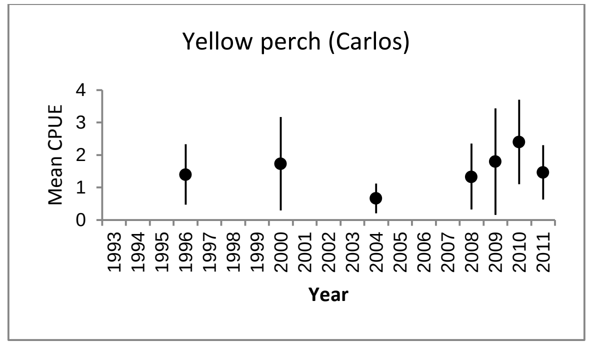
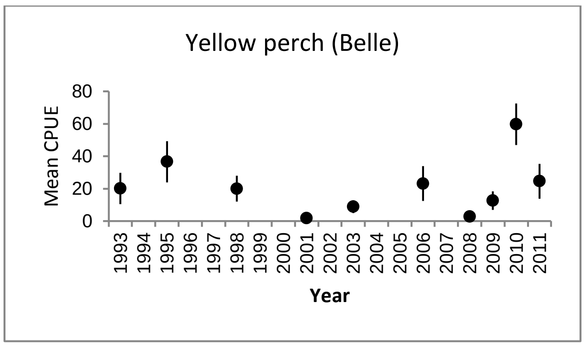


Figure 5. Mean (± 95% confidence limits) catch per gill net lift (CPUE) of northern pike, white sucker, rock bass, bluegill, largemouth bass, black crappie, walleye, and yellow perch in lakes Carlos and Belle from 1993 through 2011.

(Figure 5 continued on next page.)







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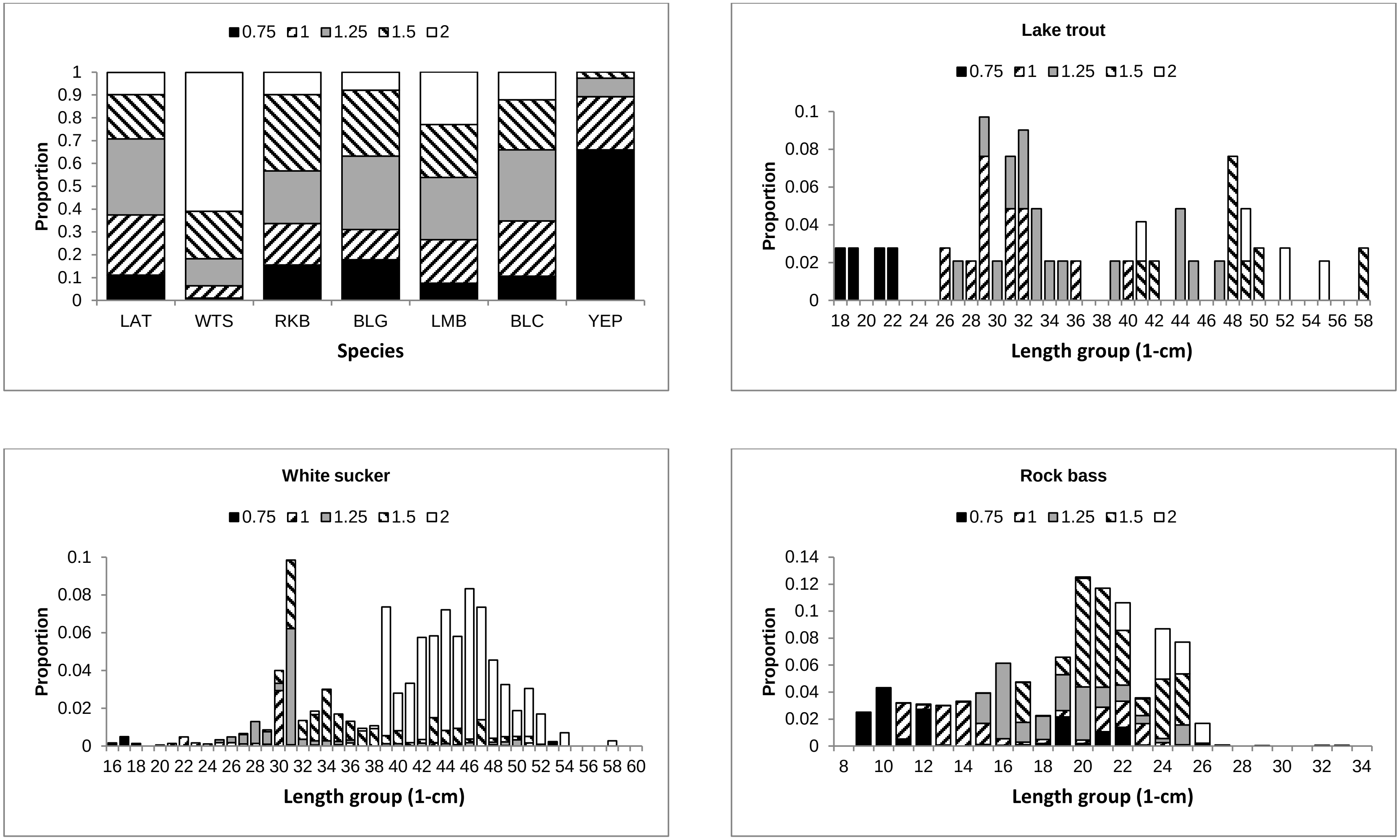
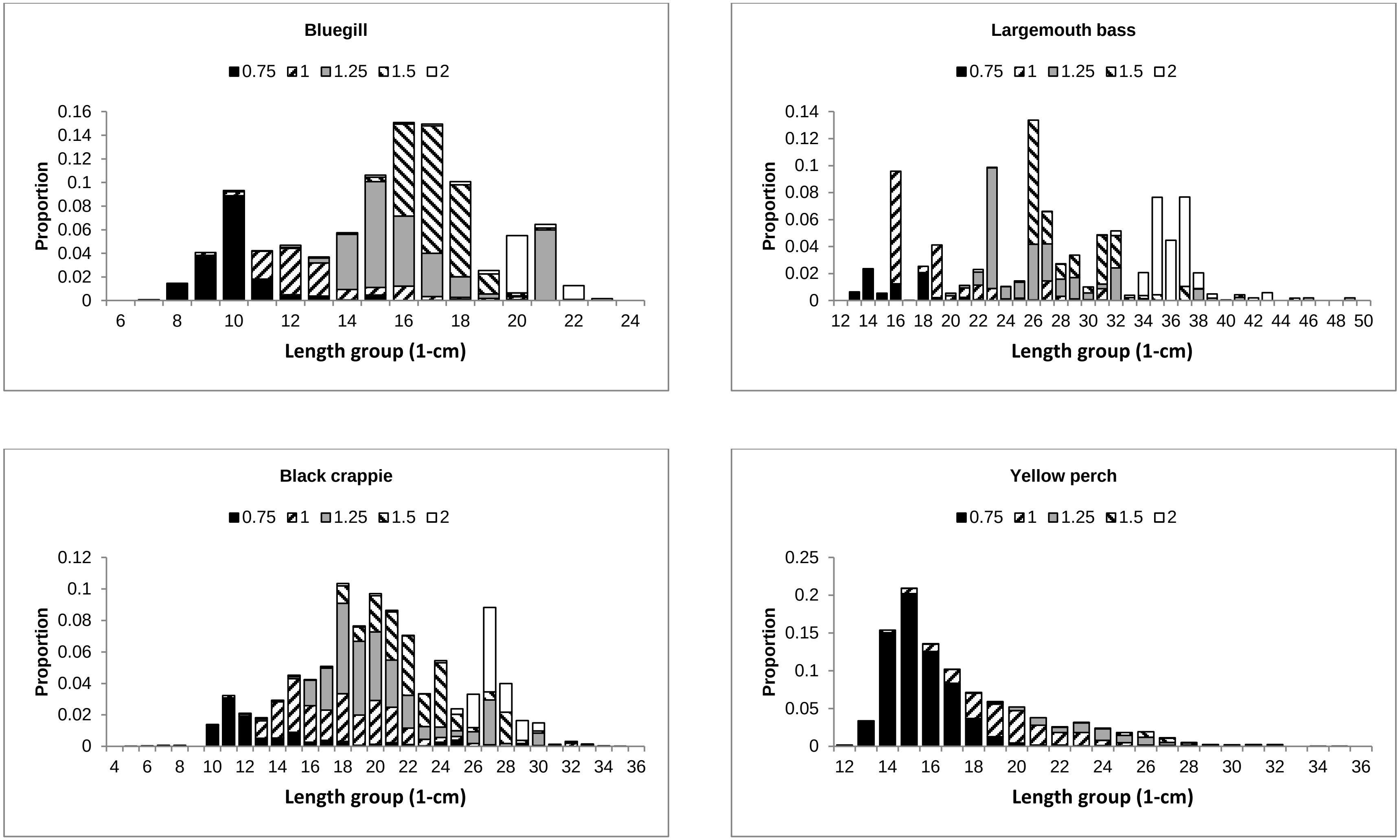


Figure 6. Mean (all 24 lakes and four years combined) proportion of gill net catch of lake trout (LAT), white sucker (WTS), rock bass (RKB), bluegill (BLG), largemouth bass (LMB), black crappie (BLC), and yellow perch (YEP) among 0.75-, 1 - , 1.25-, 1.5- and 2-in mesh sizes and by 1-cm length groups of each species within each mesh size.

(Figure 6 continued on next page.)



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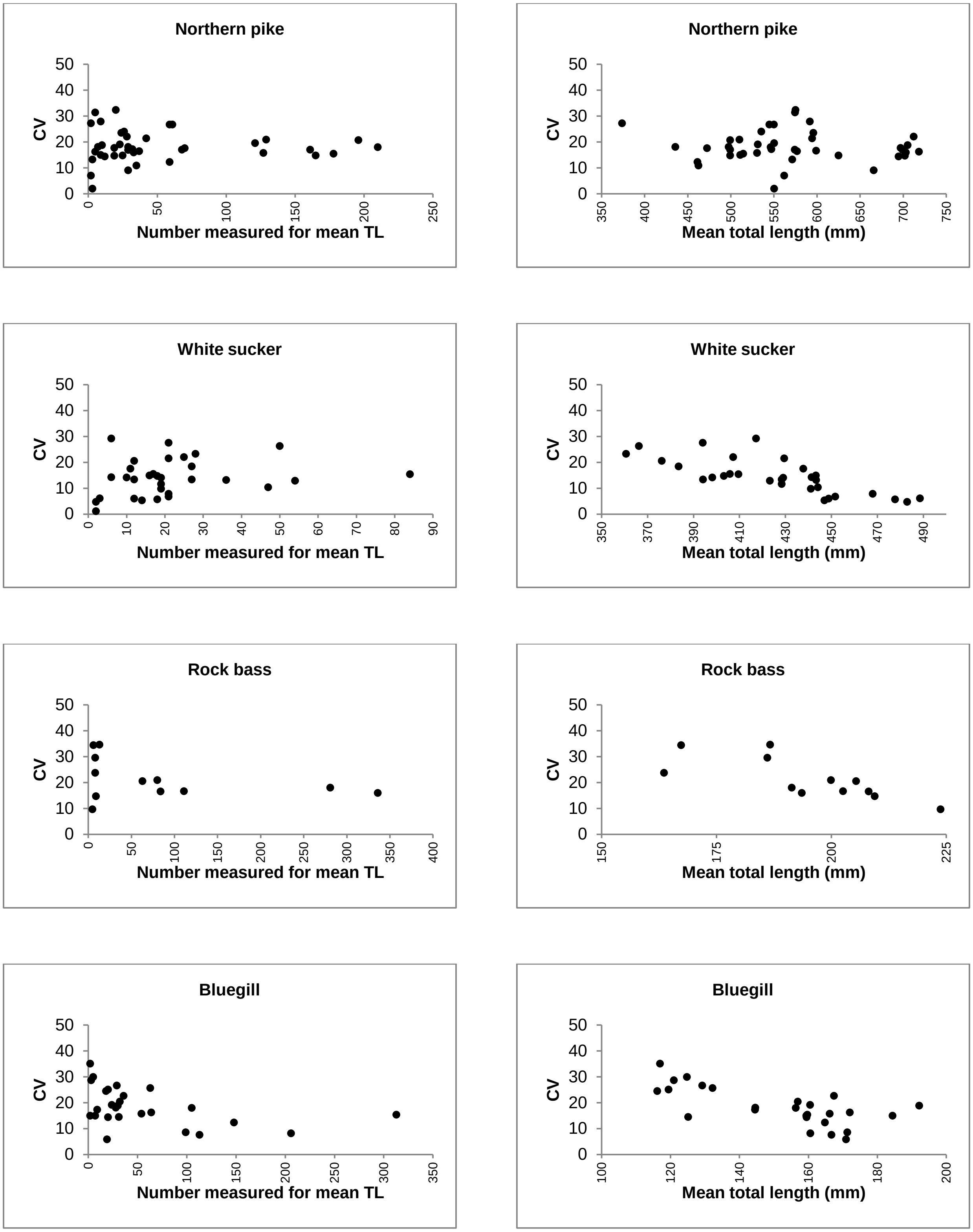


Figure 7. Coefficient of variation (CV) of fish length as a function of sample size and mean total length of northern pike, white sucker, rock bass, bluegill, largemouth bass, black crappie, walleye, and yellow perch captured with standard gill netting in 24 sentinel lakes from 2008 through 2011.

(Figure 7 continued on next page.)

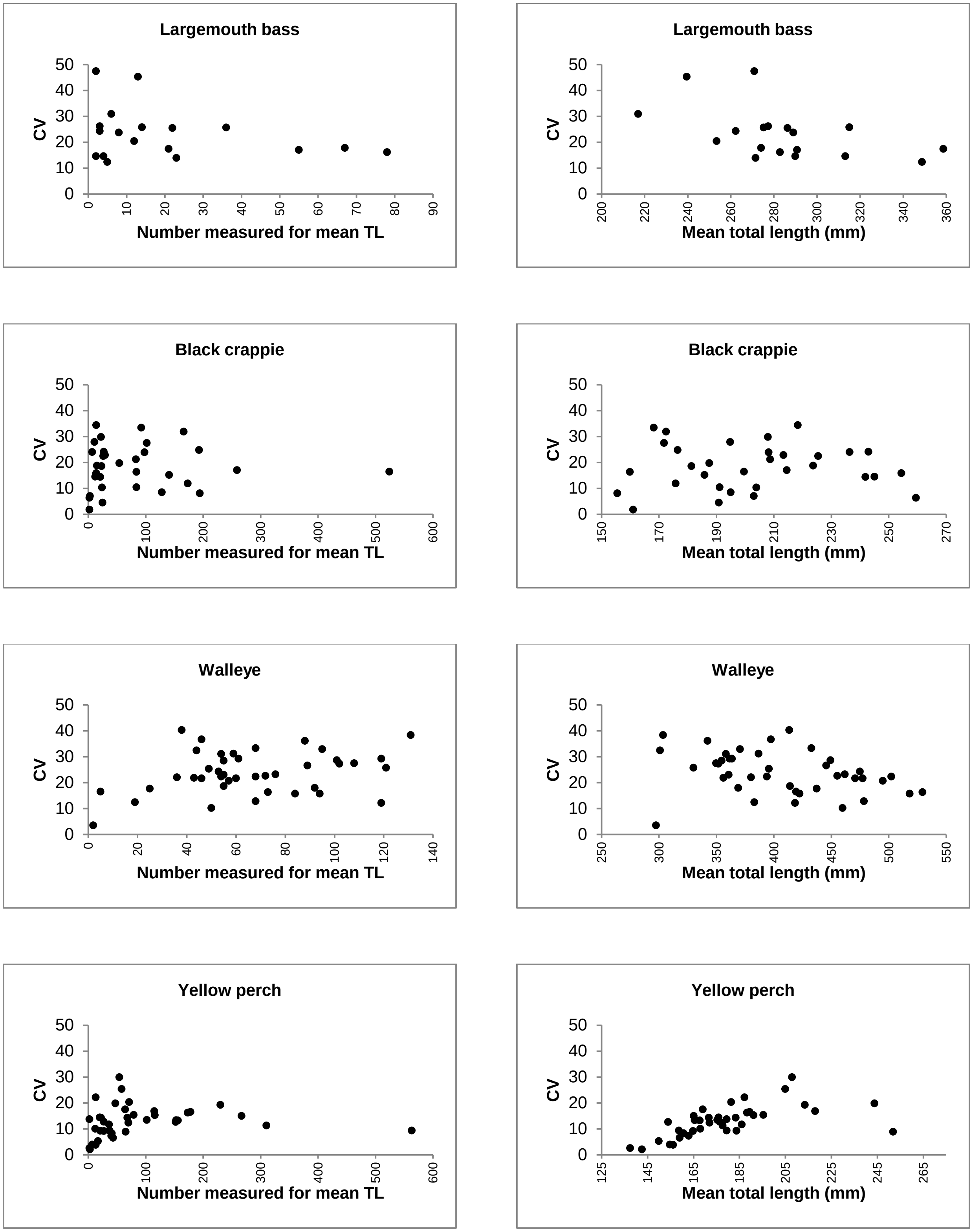


Figure 7. (continued).

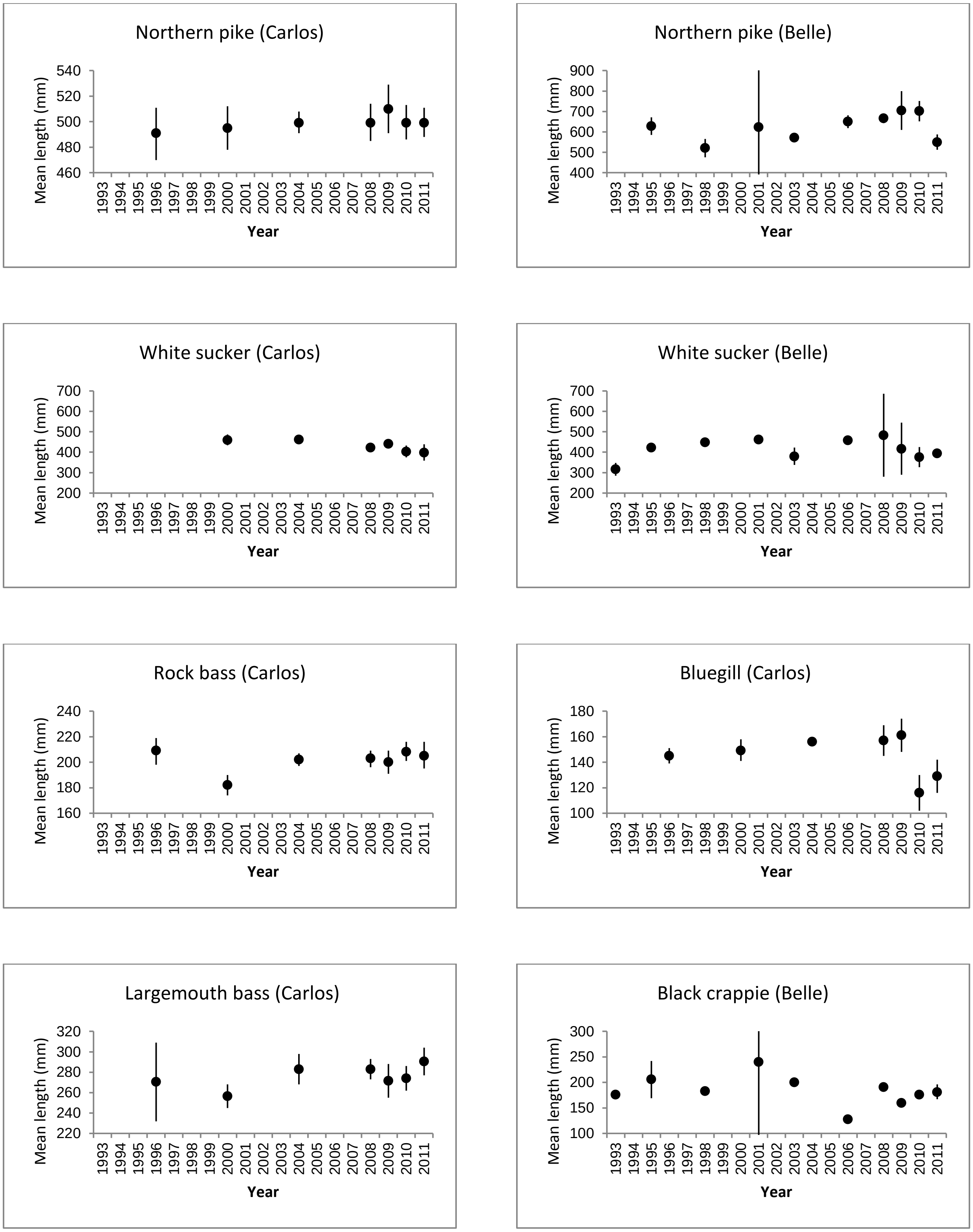
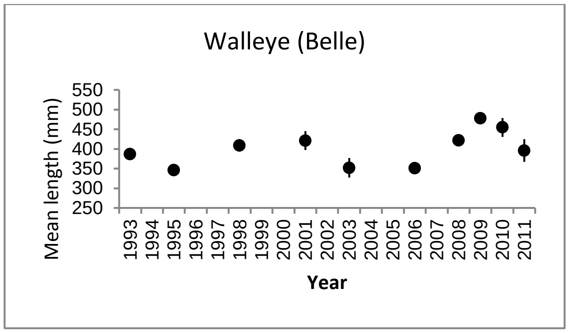
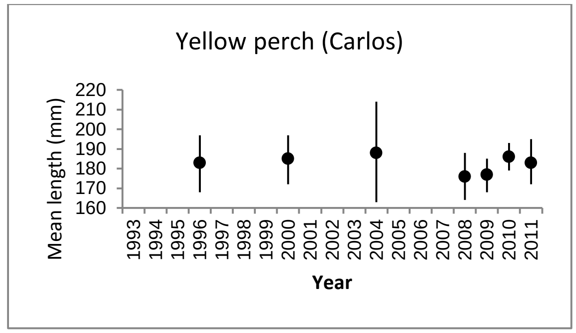


Figure 8. Mean (+ 95% confidence limits) length of northern pike, white sucker, rock bass, bluegill, largemouth bass, black crappie, walleye, and yellow perch in gill net catches at Carlos and Belle lakes from 1993 through 2011.

(Figure 8 continued on next page.)





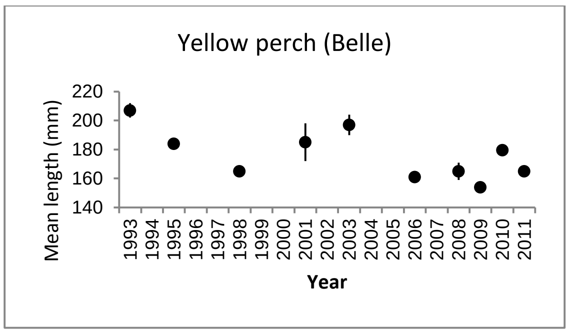


Figure 8. (continued)

Trap Netting

At least three estimates of trap net CPUE and mean TL were made for at least one target species in all sentinel lakes. Sampling dates were consistent in most lakes, usually within the same week- to 10-day period each year in 18 lakes; sample dates were less consistent at Elephant, Echo, Ten Mile, Portage, South Center, and St. James lakes (Table 3). Netting efforts generally followed LSM guidelines, but deviated from the recommendations on occasion.

Trap netting caught Bluegill and Black Crappie in all lakes where they occur, but they usually or often failed to capture White Sucker, Rock Bass, and Yellow Perch. Mean CPUE of Bluegill ranged from <1 to 106 and mean CPUE of Black Crappie ranged from < 1 to 35 among sentinel lakes. Mean CPUE of White Sucker, Rock Bass, and Yellow Perch ranged from 0 to 4 (Table 10).

Coefficients of variation of trap net catch of Bluegill and Black Crappie generally exceeded CV of gill net catch, and CV of trap net catch appeared to be affected by magnitude of catch, frequency distributions of trap net CPUE, and location of net sets within lakes. When CPUE < 1 per lift was excluded for both species the average sample CV of trap net catch exceeded 100% (Table 5). These analyses were not done for White Sucker, Rock Bass, or Yellow Perch because of consistently low CPUE (< 5 per lift) among lakes. Coefficients of variation of trap net catch per assessment decreased non-linearly with increasing trap net CPUE for both Bluegill and Black Crappie. However this was unlinked to the number of net sets within and among lakes (Figure 9; Table 6). Frequency distributions of trap net catches of Bluegill within lakes with high mean CPUE were not skewed but also lacked clear modes. Despite high mean CPUE, strongly right-skewed frequency distributions were observed for net catches of Black Crappie at Belle Lake. However, these distributions at St. Olaf Lake appeared somewhat normal (Figure 10). Trap net catches of Bluegill at varied by location on some lakes. For example, site 12 in White Iron Lake was consistently high whereas trap nets set at locations 6,7,9,14,15, and 21 seldom captured Bluegill (F = 3.91; df = 14; P = 0.0003 for location effects; F = 4.06; df = 3; P = 0.0127 for year effect). Net location did not affect trap net catch of Bluegill in most other lakes. Trap net catch of Black Crappie appeared unaffected by location of sets in all sentinel lakes.

Trap net CPUE did not appear to reflect density of Bluegill in several lakes but could for older or longer Black Crappie; data were unavailable to test if trap net CPUE of Rock Bass or Yellow Perch reflected density of those species. Only at Cedar and Madison lakes did CPUE of a strong year-class of Bluegill decline among consecutive years (Figure 11). However, CPUE of age 2 or younger Black Crappies were excluded from analysis, CPUE declined among consecutive years in all lakes except Artichoke (Figure 11).

Annual variation of CPUE of Bluegill at South Center Lake and of CPUE of Black Crappie at Belle Lake appeared high during 2008 through 2011; this was similar to variation in CPUE from assessments conducted prior to 2008 (Figure 12; t = -0.22; n = 6; P = 0.8354 for Bluegill at South Center; t = 0.88; n = 7; P =0.4119 for Black Crappie at Belle). CPUE of Bluegill at St. Olaf Lake appeared stable during 2008 through 2011, but somewhat lower than prior assessments (Figure 10; t = -2.16; n = 6; P = 0.0834). Conversely, annual variation in CPUE of Black Crappie at St. Olaf Lake during 2008 through 2011 exceeded that observed in prior assessments (Figure 10; t = 2.58; n = 6; P = 0.0493). Therefore, variation in CPUE of Bluegill at South Center and of Black Crappie at Belle Lake among assessments between 1993 and 2011 could be viewed as normal variation. However, the 2008 through 2011 period probably best reflect normal variation of Bluegill CPUE at St. Olaf Lake. Trap net CPUE of Black Crappie at St. Olaf Lake appeared to be trending upward between 2008 through 2011 as well as between 1993 and 2011; thus, no conclusion about variation can be made for this species at this lake.

Due to sufficient sample size and normal length distributions, trap netting has potential to provide mean length estimates for Rock Bass, Bluegill, Black Crappie, and Yellow Perch in most lakes. Average sample sizes of Rock Bass ranged from 0 to 49 among lakes, and sample sizes averaged from 1 to 952 for Bluegill, 1 to 400 for Black Crappie, and 0 to 40 Yellow Perch among lakes (Table 11). Average length frequency distributions appear normal for Rock Bass, Bluegill, and Black Crappie and but not for Yellow Perch (Figure 12). Trap netting failed to provide sufficient samples (< 10) of White Sucker for estimating mean length. Mean lengths of each species differed among lakes (Table 12).

Coefficients of variation of observed fish lengths per assessment appears to be a function of the number of individuals measured and mean total length; however, effects of these variables on CV of mean length differed among species. Based on plots of sample CV of fish length as a function of the number measured, sample CV of fish length does not stabilize until at least 20 Yellow Perch, 30 Rock bass, and 100 Black Crappies are measured (Figure 14). Coefficient of variation in fish length of Rock Bass declined with increasing mean total length suggesting similar dispersion across a wide range of mean lengths. Conversely, sample CV of fish length of Black Crappie declined with increasing sample size and mean length. However, the CV of Yellow Perch lengths appeared unaffected by sample size or mean length (Table 9). For Bluegill, sample CV of lengths did not stabilize until at least 145 individuals were measured and when mean lengths reached 148 mm TL, suggested by the strong sample size*mean length interaction (Table 9).

With few exceptions, estimates of mean total length of Bluegill and Black crappie appeared stable from 2008 to 2011 (Table 12). Exceptions for Bluegill include Echo, St. James, and Shaokotan lakes, all three of which are mixed shallow lakes with relatively low catches of this species. Similarly, high standard errors for mean length estimates of

Black Crappie occurred at Echo, South Twin, Red Sand and St. James lakes, again because of low catch. However, high CPUE did not always correspond with low S.E.; for example, standard errors for mean length estimates of Black Crappie at Artichoke Lake was high even though catch was also usually high (Tables 11 and 12). Annual variation in mean lengths of Rock Bass in Ten Mile and Elk lakes, Bluegill in South Center and St. Olaf lakes, Black Crappie in Belle and St. Olaf lakes, and Yellow Perch in Trout and White Iron lakes during 2008 through 2011 were similar to annual variation in the same metrics in surveys conducted prior to 2008 (Figure 15). Thus, the period between 1993 through 2011 could be viewed as normal variation of this metric in these lakes.

Recommendations:

Unless needed for other fish-based metrics, e.g., to maintain continuity with the state-wide lake survey program, it is recommended that summer trap netting be discontinued because precision and accuracy of CPUE metrics for bluegill and black crappie (the only two species effectively caught with this gear) are poor and length-based metrics are strongly affected by spawning. Cross et al. (1995) showed that trap net CPUE and size structure estimates of Bluegill changed throughout the summer in three Minnesota lakes, and these changes coincided with gonadal development. Water temperatures in May and June appeared warmer in 2009 than in 2008, 2010, or 2011; thus, timing of gonadal development and initiation of spawning probably differed between years and affected catchability in trap nets. Additionally, trap net CPUE of Black Crappie ≥ 200 mm TL in June and July did not increase with increasing population density among seven small (18 to 168 ha) south-central Minnesota lakes; however, CPUE in August did (MNDNR unpublished data). Trap net catchability of Black Crappie < 200 mm TL is lower than that of longer Black Crappies in spring and fall (McInerny and Cross 2006); thus, this size-selectivity mechanism could also be occurring during summer.

Trap netting in fall (water temperatures between 12 and 21 °C) or in spring after water temperatures reach 10 °C but before these species initiate spawning should be considered if reliable CPUE metrics for Black Crappie are desired. Trap net CPUE of Black Crappie ≥ 200 mm TL in April, May, and September among small lakes in south central Minnesota increased with increasing population density (McInerny and Cross 2006); thus, trap netting during fall or spring should provide a useful CPUE metric. It is hypothesized the same would occur for CPUE of Bluegill and Rock Bass because the same factors (spawning times, aquatic plant densities, etc.) affecting catchability in Black Crappie during the open water season probably affect catchability of Rock Bass and Bluegill. However, this deviation from the standard lake survey protocol would need to be assessed thoroughly on the larger and more northerly lakes within the sentinel lakes program.

Regardless of time of year when trap netting occurs, sampling effort following guidelines in the LSM appear reasonable for estimating CPUE and mean length metrics. (One exception is Carrie Lake and this can be overcome by increasing netting effort from five to nine nets.) Because of non-normal catch distributions, precision would not improve much if netting effort was increased above recommended levels. Because the possibility of obtaining a non-normal distribution of lengths of black crappie due to sub-sampling is high, this practice should be discontinued. As per recommendations in the lake survey manual, a minimum of 25 randomly selected bluegills should be measured per trap net (MNDNR 1993).

Table 10. Mean (s.e.) number per trap net lift of White Sucker, Rock Bass, Bluegill, Black Crappie, and Yellow Perch among assessments in 24 sentinel lakes during the four-year pilot (2008 through 2011).

	Species				
Lake	White sucker	Rock bass	Bluegill	Black crappie	Yellow perch
Trout	0				3.2 (0.4)
Bear Head	0.5 (0.2)		21.8 (1.9)	2.1 (0.4)	0
Elephant	0.2 (0.2)		3.2 (1.4)	4.0 (0.9)	2.8 (0.8)
Tait	0.06 (0.03)		0.1 (0.1)		0.2 (0.1)
White Iron	0.7 (0.2)	2.1 (0.5)	2.1 (0.7)	1.8 (0.5)	2.7 (0.6)
Echo	0.5 (0.1)	0.1 (0.04)	0.4 (0.3)	4.2 (1.1)	0.4 (0.1)
Ten Mile	0	3.3 (0.5)	18.0 (2.7)	0.6 (0.1)	0.2 (0.03)
Elk	0	1.9 (0.3)	39.7 (11.0)		3.2 (0.4)
Hill	0.1 (0.04)	0.6 (0.2)	7.4 (2.1)	0.9 (0.3)	2.0 (0.6)
South Twin	0.06 (0.06)	0.3 (0.1)	19.2 (7.5)	0.6 (0.2)	0.1 (0.03)
Red Sand			3.2 (0.7)	2.5 (1.1)	0.7 (0.5)
Portage	0.2 (0.1)	0	18.0 (5.9)	5.4 (1.5)	0.2 (0.1)
Cedar	0	0.5 (0.1)	38.2 (10.7)	0.03 (0.03)	0.7 (0.4)
Carlos	0.06 (0.05)	0.4 (0.1)	18.2 (3.1)	0.8 (0.3)	0.1 (0.05)
South Center	0.3 (0.1)		44.8 (11.0)	5.2 (1.6)	0.02 (0.02)
Pearl	0.5 (0.2)		16.3 (2.0)	2.7 (0.5)	0.2 (0.1)
Belle	0.1 (0.05)		3.2 (1.2)	33.3 (18.6)	0.5 (0.3)
Peltier	0.4 (0.3)		7.8 (1.9)	6.1 (1.2)	1.8 (0.5)
Carrie	0		13.1 (2.0)	25.0 (12.8)	0.1 (0.1)
St. Olaf	0.03 (0.03)		105.8 (18.2)	35.5 (10.0)	0.5 (0.4)
Madison	0.3 (0.2)		31.5 (1.6)	3.7 (1.0)	0.1 (0.1)
St. James			7.5 (1.2)	1.0 (0.7)	0.4 (0.3)
Shaokotan	0.2 (0.05)		0.2 (0.1)		0.5 (0.2)
Artichoke	0.02 (0.02)		0.9 (0.2)	8.3 (4.0)	0.03 (0.03)

Table 11. Mean (s.e.) number of White Sucker (WTS), Rock Bass (RKB), Bluegill (BLG), Black Crappie (BLC), and Yellow Perch (YEP) sampled with trap nets per assessment in 24 sentinel lakes from 2008 through 2011.

	Species				
Lake	White sucker	Rock bass	Bluegill	Black crappie	Yellow perch
Trout	0				38 (4)
Bear Head	6 (2)		261 (22)	25 (5)	0
Elephant	2 (2)		38 (17)	48 (10)	33 (9)
Tait	< 1		1 (1)		2 (1)
White Iron	10 (2)	32 (7)	31 (10)	27 (7)	40 (9)
Echo	6 (1)	2 (1)	5 (3)	51 (13)	4 (1)
Ten Mile	0	49 (8)	270 (41)	9 (2)	3 (< 1)
Elk	0	17 (3)	348 (104)		28 (4)
Hill	1 (< 1)	7 (2)	81 (23)	10 (3)	22 (7)
South Twin	1 (1)	4 (2)	274 (137)	8 (4)	2 (< 1)
Red Sand			29 (6)	23 (10)	6 (5)
Portage	2 (1)	0	167 (74)	39 (14)	2 (1)
Cedar	0	5 (1)	344 (96)	< 1 (<1)	6 (4)
Carlos	1 (< 1)	5 (2)	273 (47)	12 (5)	2 (1)
South Center	3 (1)		535 (134)	62 (19)	< 1
Pearl	6 (2)		196 (24)	33 (6)	2 (1)
Belle	1 (< 1)		38 (14)	400 (223)	6 (4)
Peltier	4 (3)		68 (16)	53 (11)	16 (5)
Carrie	0		66 (10)	124 (64)	< 1
St. Olaf	< 1		952 (164)	354 (124)	5 (4)
Madison	3 (1)		337 (22)	64 (26)	2 (1)
St. James			66 (12)	10 (5)	7 (2)
Shaokotan	2 (1)		2 (1)		6 (2)
Artichoke	< 1		14 (2)	124 (60)	< 1

Table 12. Mean (s.e.) total length of White Sucker, Rock Bass, Bluegill, Black Crappie, and Yellow Perch among trap net assessments in 24 sentinel lakes during the four-year pilot (2008 through 2011).

	Species				
Lake	White sucker	Rock bass	Bluegill	Black crappie	Yellow perch
Trout					174 (4)
Bear Head	494 (7)		151 (4)	251 (5)	
Elephant	513 (27)		138 (7)	209 (23)	171 (4)
Tait	490 (14)		88		234 (78)
White Iron	482 (9)	195 (3)	194 (4)	240 (7)	192 (8)
Echo	444 (28)	202 (15)	167 (28)	243 (5)	175 (5)
Ten Mile		183 (4)	142 (4)	228 (9)	163 (14)
Elk		179 (11)	134 (5)		170 (10)
Hill	337 (140)	174 (10)	130 (3)	198 (12)	155 (2)
South Twin	512	221 (28)	126 (7)	198 (32)	226 (7)
Red Sand			160 (8)	184 (14)	159 (18)
Portage	501 (3)		150 (5)	205 (9)	146 (8)
Cedar		157 (2)	130 (5)	130	179 (3)
Carlos	449 (26)	191 (13)	151 (5)	232 (9)	168 (13)
South Center	517 (12)		155 (2)	197 (3)	197
Pearl	499 (13)		147 (4)	213 (7)	142 (4)
Belle	496 (18)		145 (5)	177 (5)	154 (14)
Peltier	464 (55)		156 (3)	205 (5)	150 (7)
Carrie			141 (5)	153 (3)	163
St. Olaf	493		162 (2)	185 (3)	161 (18)
Madison	490 (5)		163 (2)	204 (7)	177 (24)
St. James			148 (12)	178 (29)	184 (7)
Shaokotan	512 (13)		153 (32)		227 (26)
Artichoke	496		163 (15)	195 (35)	174

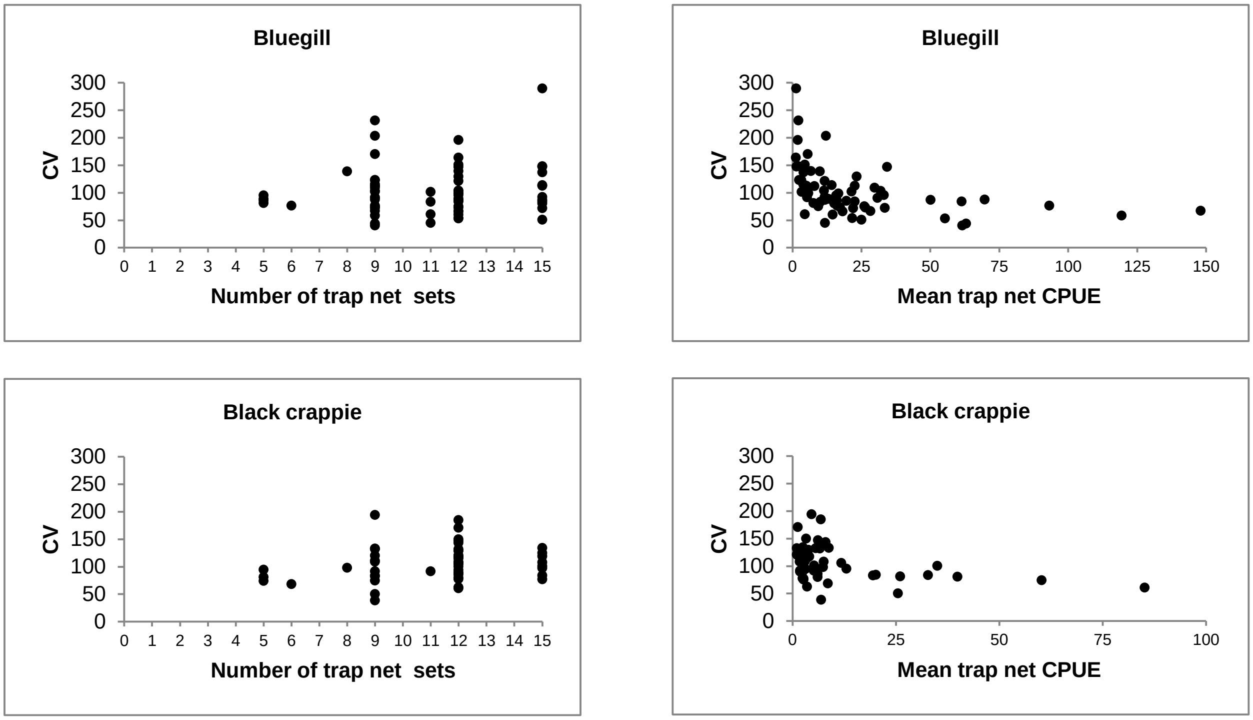


Figure 9. Coefficient of variation of trap net catch as a function of the number of net sets within lakes and as a function of mean (≥ 1 per lift) trap net CPUE of Bluegill and Black Crappie among sentinel lakes and all years between 2008 and 2011.

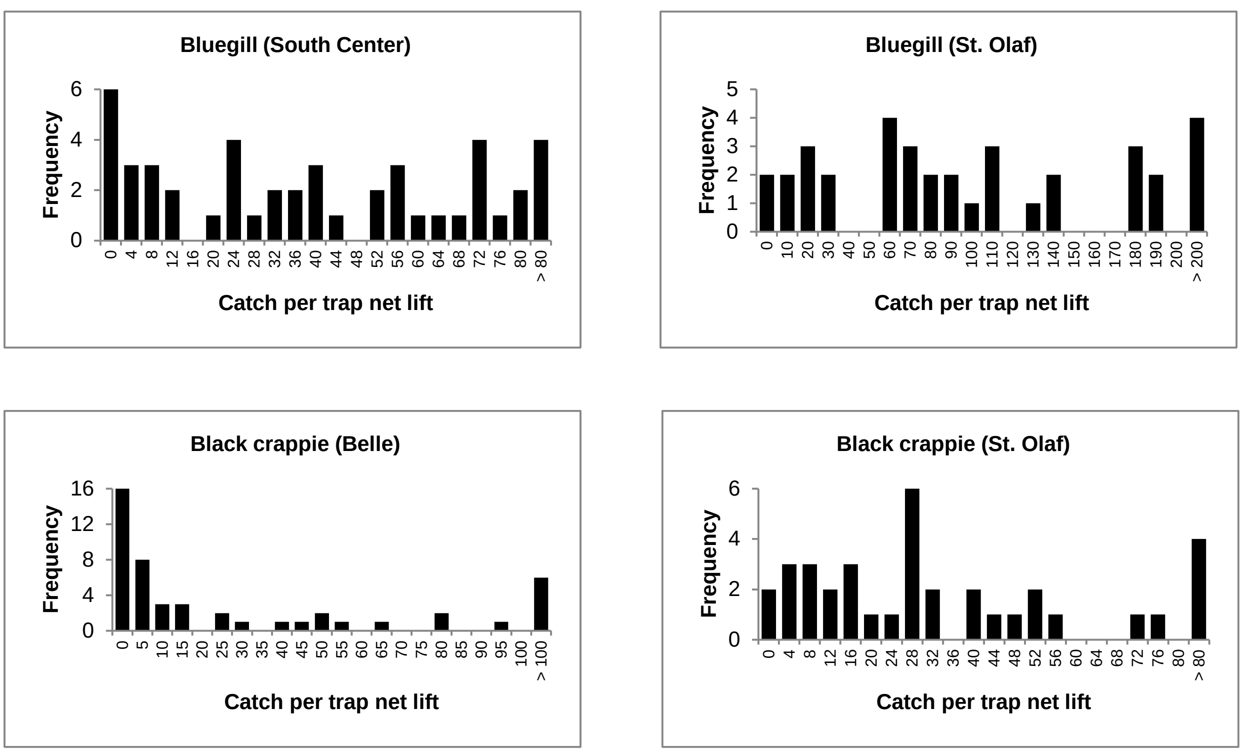
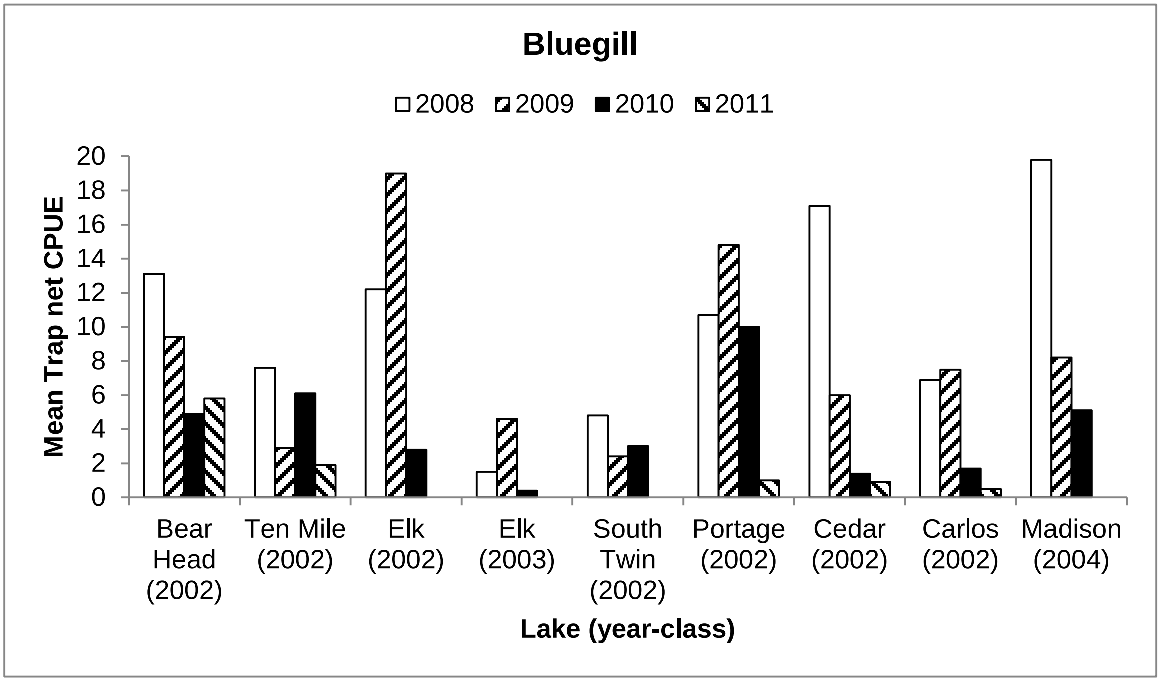


Figure 10. Frequency distributions of trap net catches of Bluegill and Black Crappie in two sentinel lakes with high gill net CPUE coupled with a minimum of 30 net sets per species from 2008 through 2011.



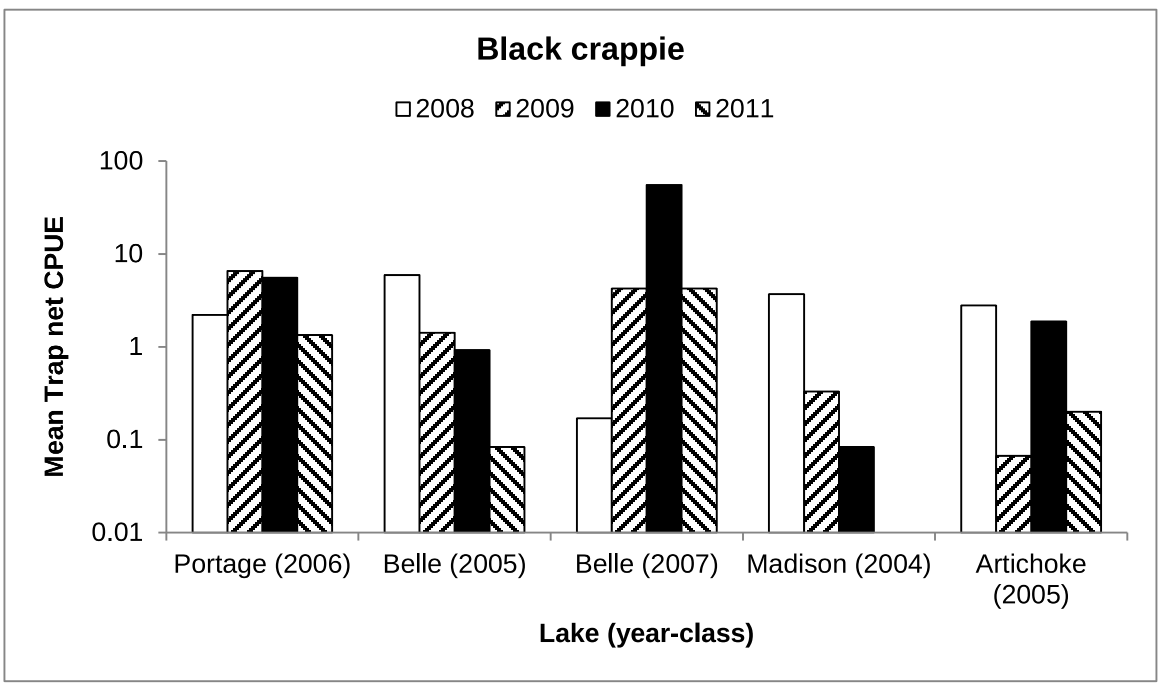


Figure 11. Mean trap net catch per lift of relatively strong year-classes of Bluegill and Black Crappie caught in consecutive years (2008, 2009, 2010, and 2011) in Bear Head, Ten Mile, Elk, South Twin, Portage, Cedar, Carlos, Madison, or Artichoke lakes.

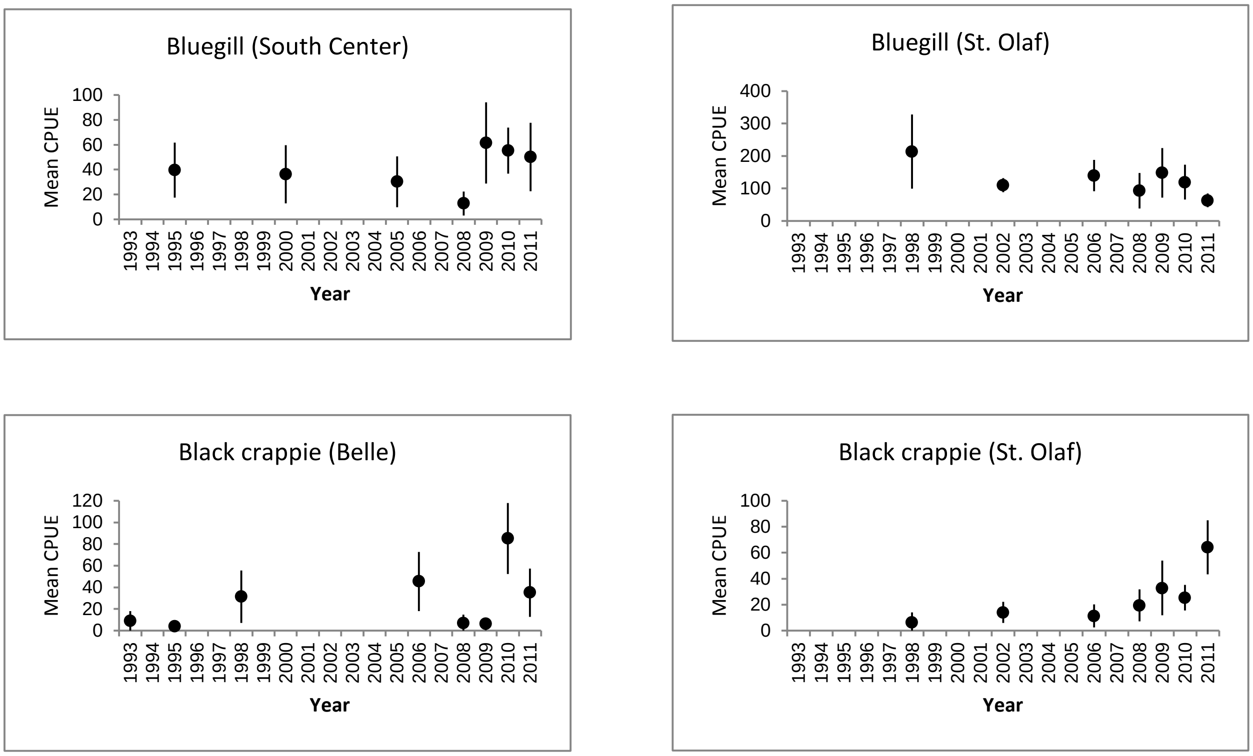
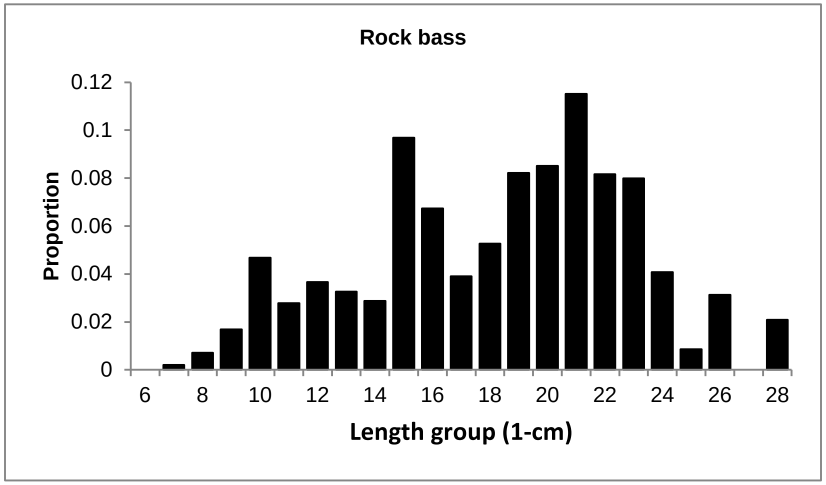
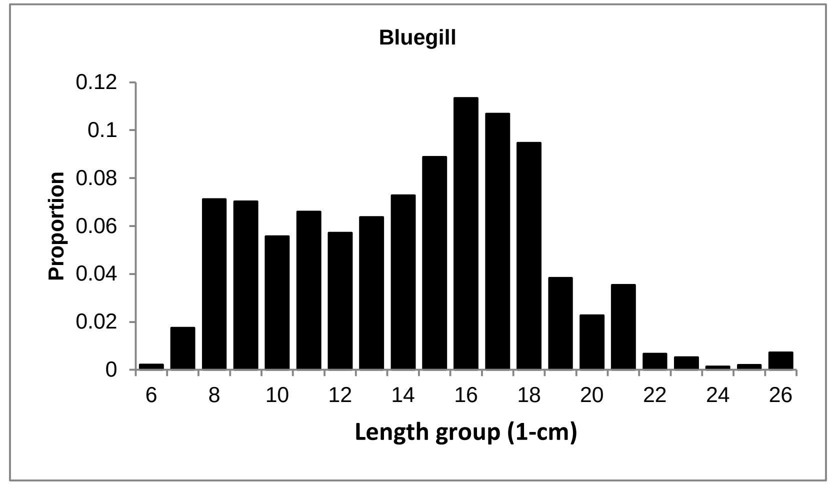
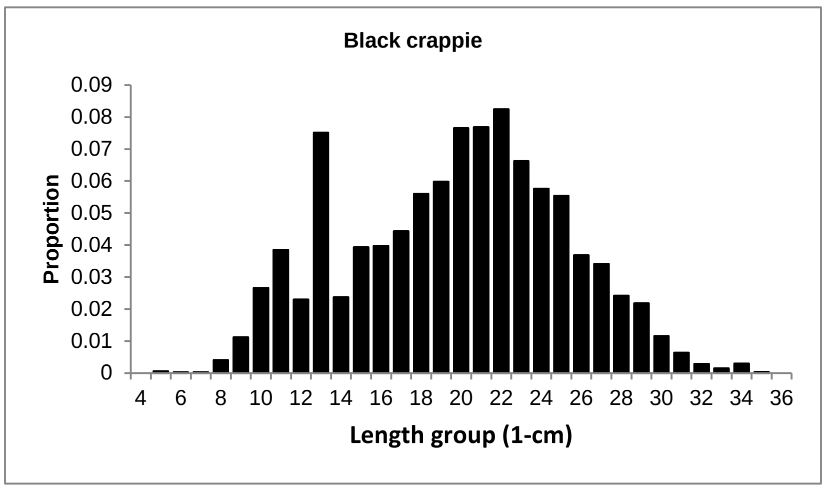


Figure 12. Mean (± 95% confidence limits) catch per trap net lift (CPUE) of Bluegill and Black Crappie in South Center, Belle or St. Olaf lakes from 1993 through 2011.







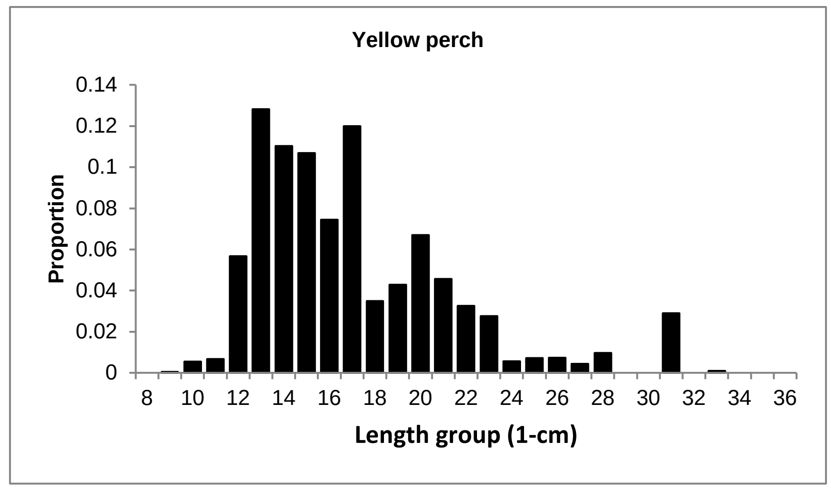


Figure 13. Proportion by length of Rock Bass, Bluegill, Black Crappie, and Yellow Perch caught in standard trap nets (all lakes and years combined).

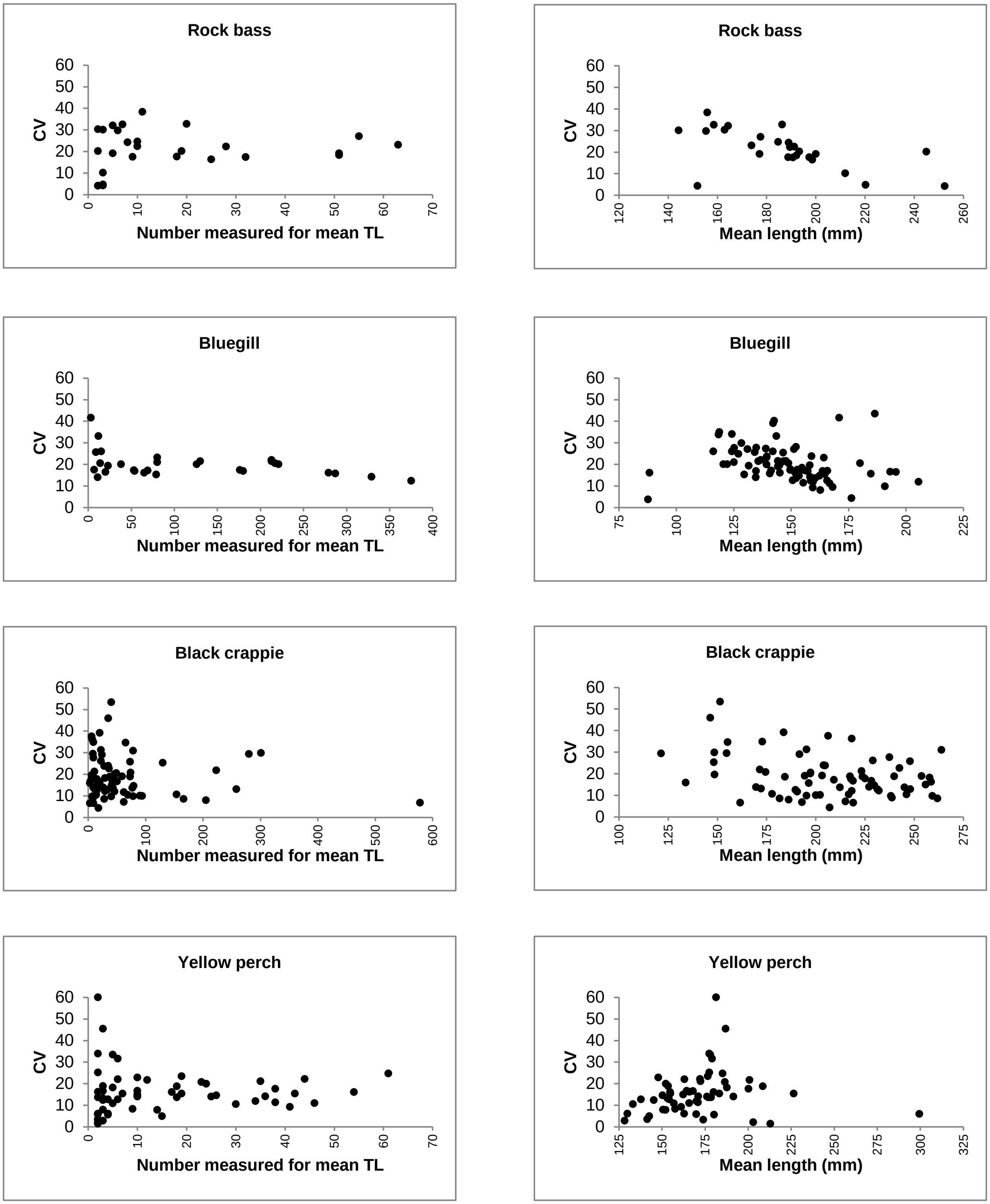


Figure 14. Coefficient of variation (CV) of fish length as a function of sample size and mean total length of Rock Bass, Bluegill, Black Crappie, and Yellow Perch captured with standard trap netting in 24 sentinel lakes from 2008 through 2011.

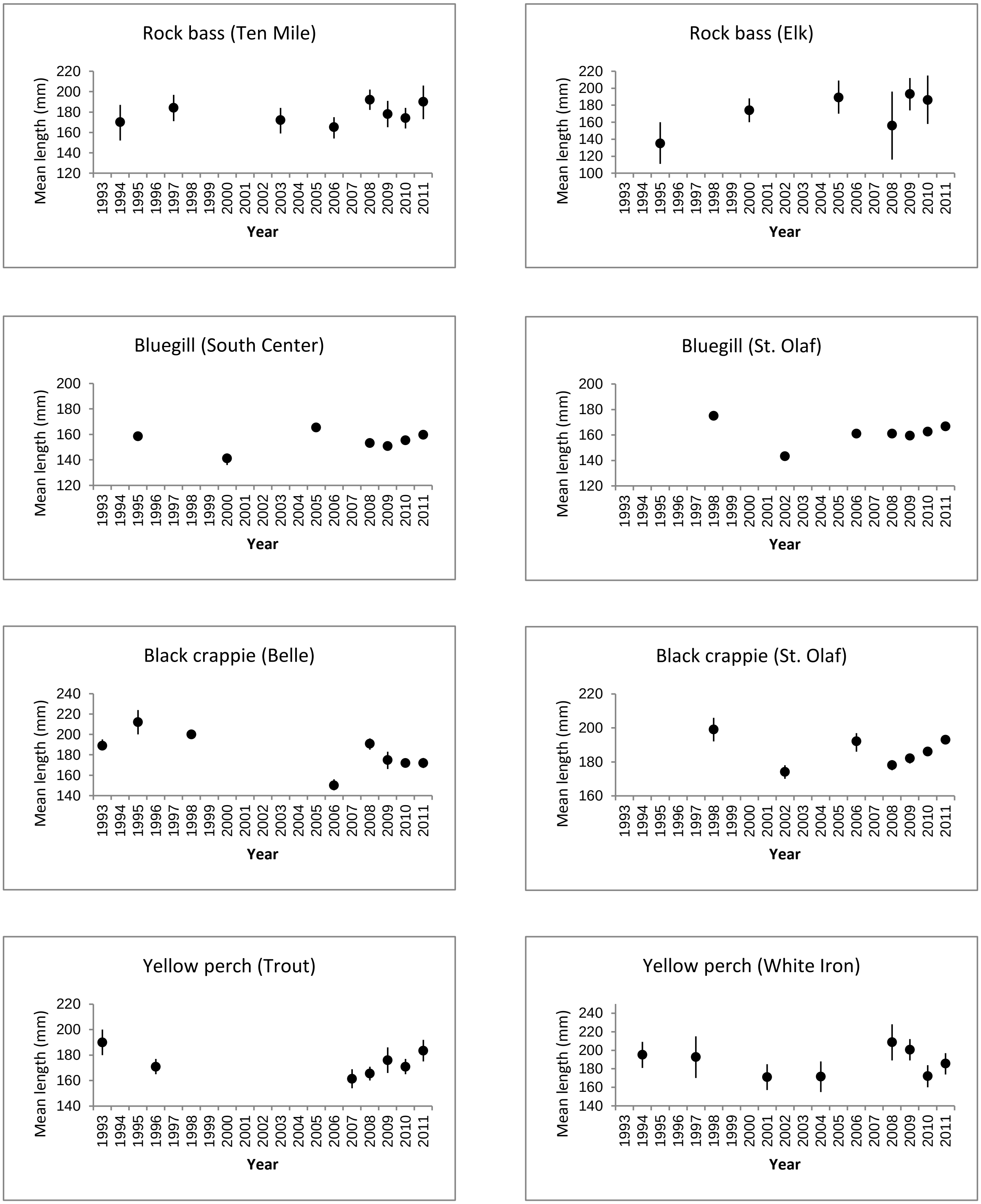


Figure 15. Mean (± 95% confidence limits) length of Rock Bass, Bluegill, Black Crappie, and Yellow Perch in trap net catches in two lakes with higher sample sizes of the appropriate species from 1993 through 2011.

Mean length metrics of lake trout and northern pike from ice-out trap netting

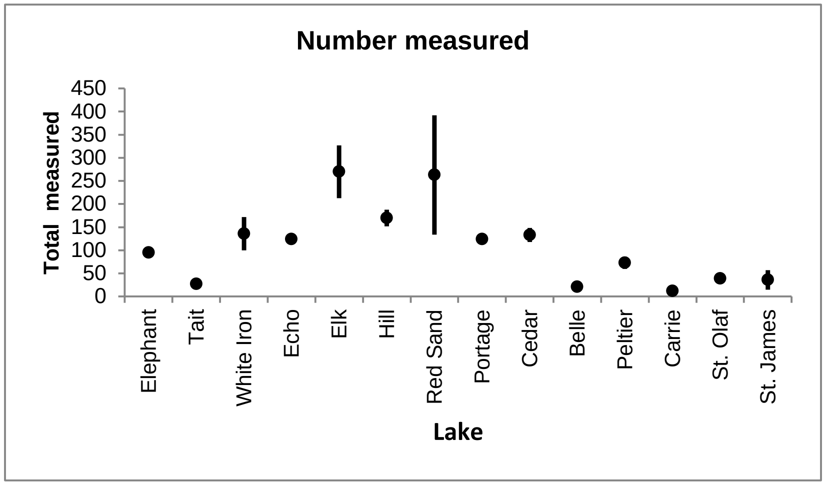
Ice-out trap netting appears useful for capturing Northern Pike in many lakes to estimate mean and maximum lengths. It is not useful for assessing Lake Trout in Trout Lake. Ice-out trap netting failed to capture the target sample size of 100 northern pike in six of the 14 lakes after 5 days of effort (Figure 16). Single-frame trap nets set in five lakes sampled a narrower range (20 to 92 cm in single-frame; 20 to 110 cm in double-frame) of Northern Pike than double frame trap nets set in nine different lakes after ice out (Figure 16). Modal length in the single-frame nets was also shorter. Males usually outnumbered females and proportions of females to males appeared consistent among years within each lake (Figure 16).

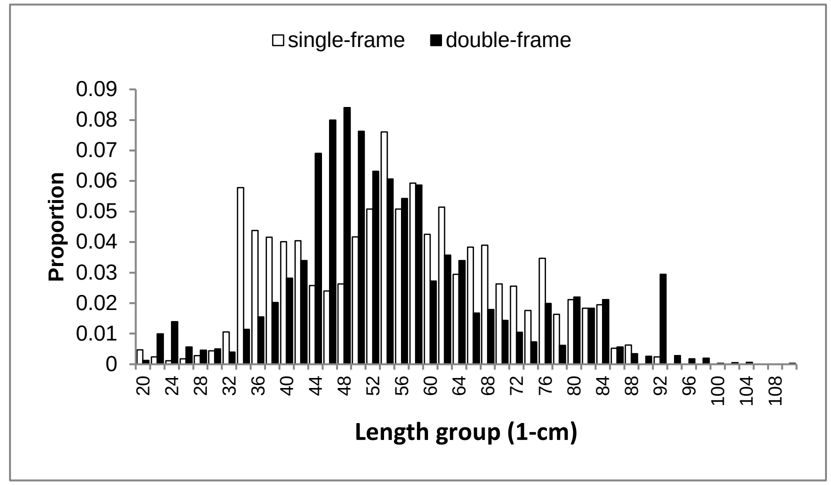
Precision of mean length estimates of Northern Pike improved if segregated by sex. In lakes where sex was determined, CV of mean length of all (both sexes plus unknown) Northern Pike measured per assessment averaged 21%; these exceeded average CV for females (18%), which in turn exceeded CV for males (14%). This result likely occurred because mean length estimates of all Northern Pike include immature individuals and that lengths of females exceeded lengths of males. Coefficients of variation of mean length estimated from all measured Northern Pike and all measured males did not appear affected linearly by mean length or sample size (Table 9; Figure 17). However, CV of mean lengths of females increased after mean lengths reached 615 mm TL and sample size exceeded 45; suggested by a significant sample size*mean length interaction (Table 9; Figure 17). If Northern Pike were not sexed, CV of mean length per assessment did not stabilize until sample sizes reached about 200, but if sexed, CV stabilized when sample sizes reached about 80 per sex (Figure 17). No Lake Trout or Northern Pike were captured with ice-out trap netting at Trout Lake in 2008 and 2009; thus, ice-out trap netting was discontinued.

As a metric, maximum length is less useful than the mean length because it does not reflect mean length well, and may change little temporally even when changes in mean lengths were occurring. Changes in maximum lengths did not correspond to changes in mean length among lakes (Figure 18). At St. Olaf Lake, the only lake with a long history of ice-out trap netting, maximum lengths appeared less sensitive than mean lengths from 1996 and 2011. Mean lengths increased by about 200 mm, but maximum length changed only 63 mm during the same time span (Figure 18).

Recommendations:

Length data of Northern Pike collected with trap nets at ice out appears to be a good surrogate to data collected with gill netting, if there are concerns regarding excessive mortality associated with gill netting. The mean length metric collected with ice-out trap netting appears sensitive for detecting changes in size structure of Northern Pike; for example, the increased mean lengths of Northern Pike observed at St. Olaf Lake could be a response to a minimum length limit (76 cm) implemented in 1998. Use of a maximum length metric should be dropped because one cannot be assured that ice-out netting will capture one of the larger Northern Pike. Target sample sizes should be 200 if sex is not determined; 70 to 80 per sex if sex is determined. If ice-out trap netting is to be expanded, within-lake comparison should be made between single- and double-frame trap nets prior to implementation. Ice-out trap netting for Lake Trout should be discontinued.





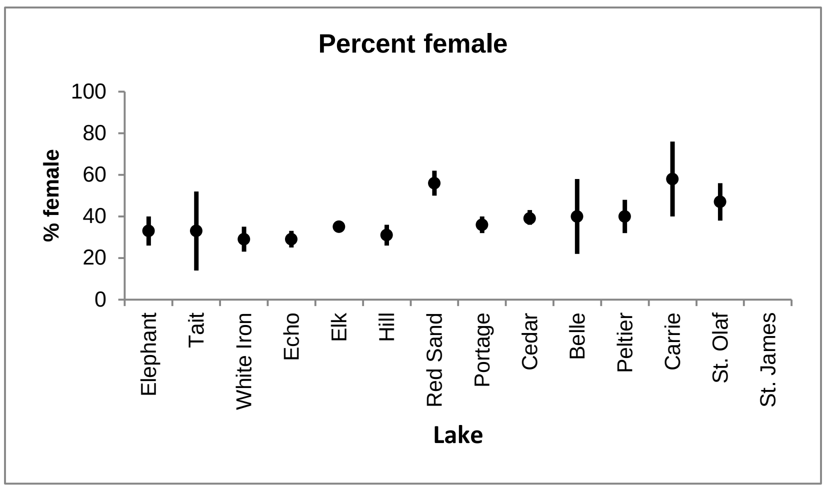


Figure 16. Mean (± s.e.) number of northern pike measured for total length estimates, mean proportion of catch by 2-cm length groups of northern pike caught in single-frame trap nets set in five lakes and in double-frame trap nets set in nine lakes, and mean (± s.e.) percent female of all sexed northern pike caught with ice-out trap netting in 14 sentinel lakes from 2008 through 2011.

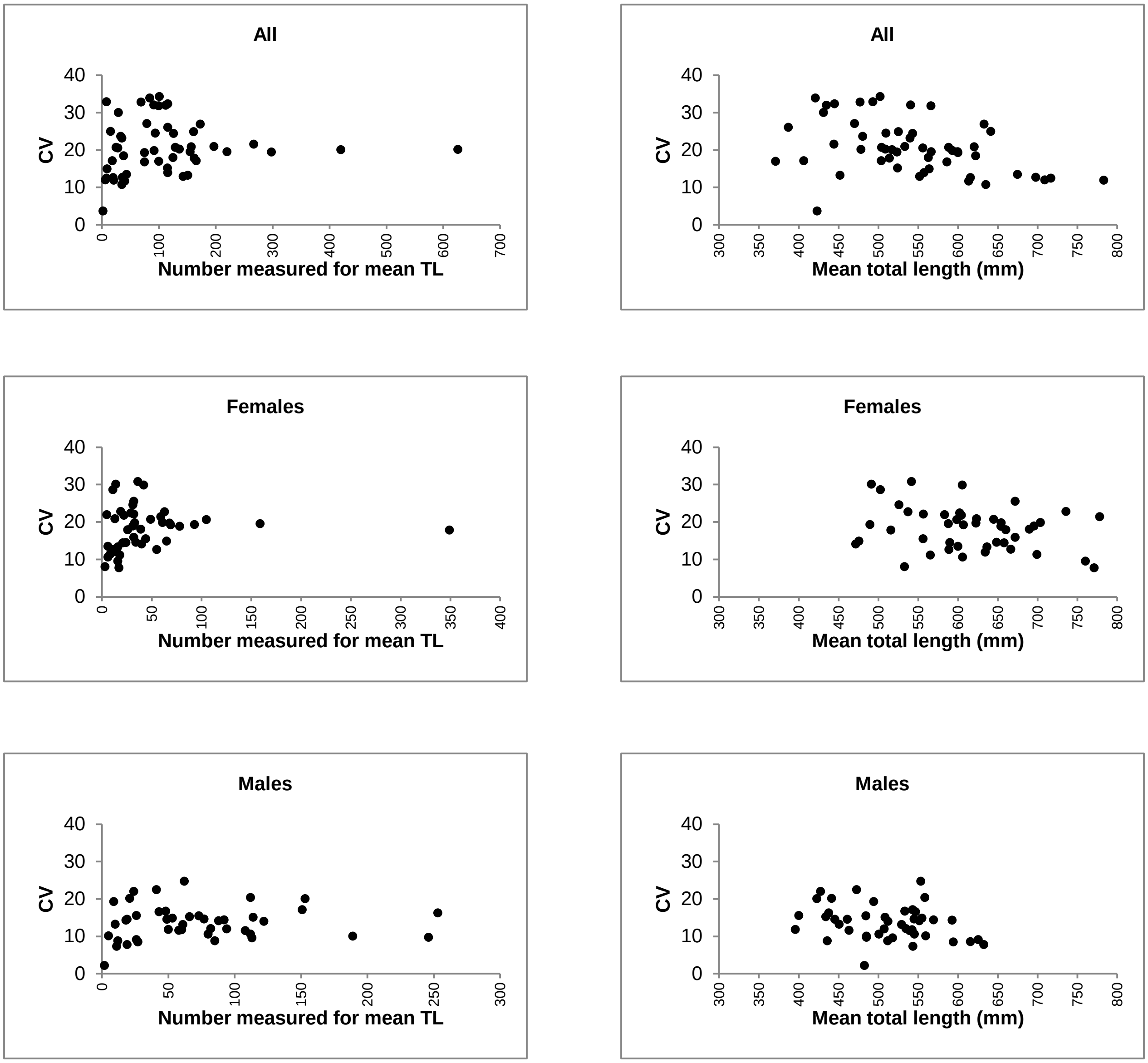
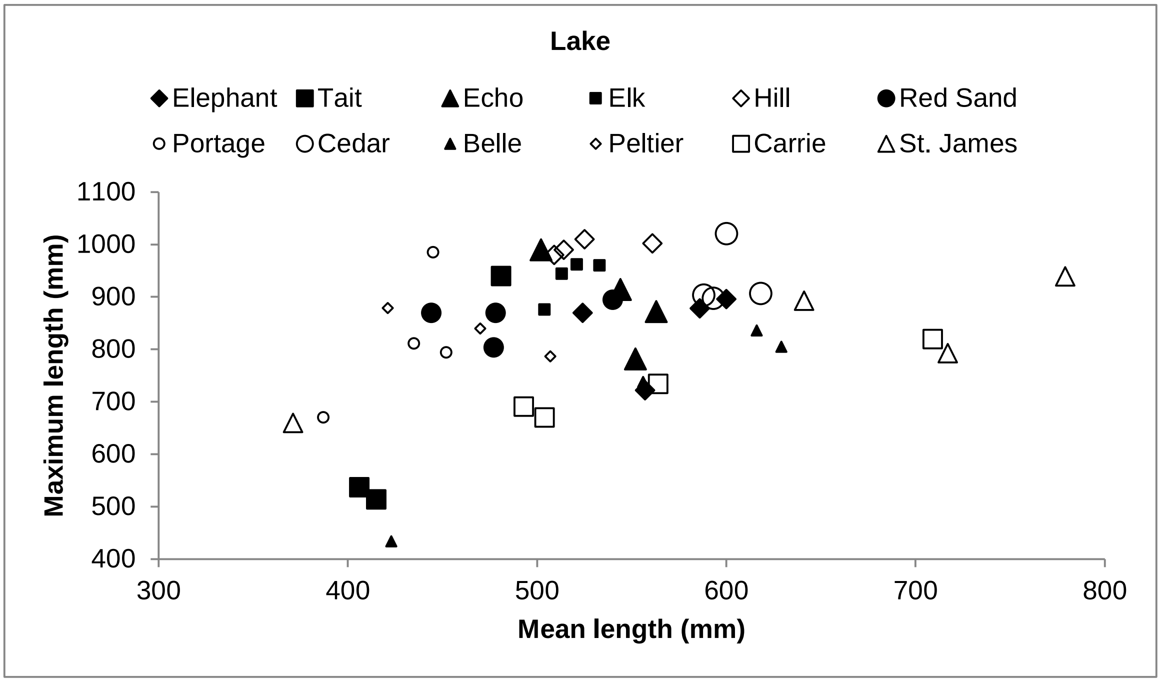


Figure 17. Coefficient of variation (CV) of mean total length (TL) per assessment as a function of sample size and mean total length of all, female, and male northern pike captured with ice-out trap netting in 14 sentinel lakes from 2008 through 2011.



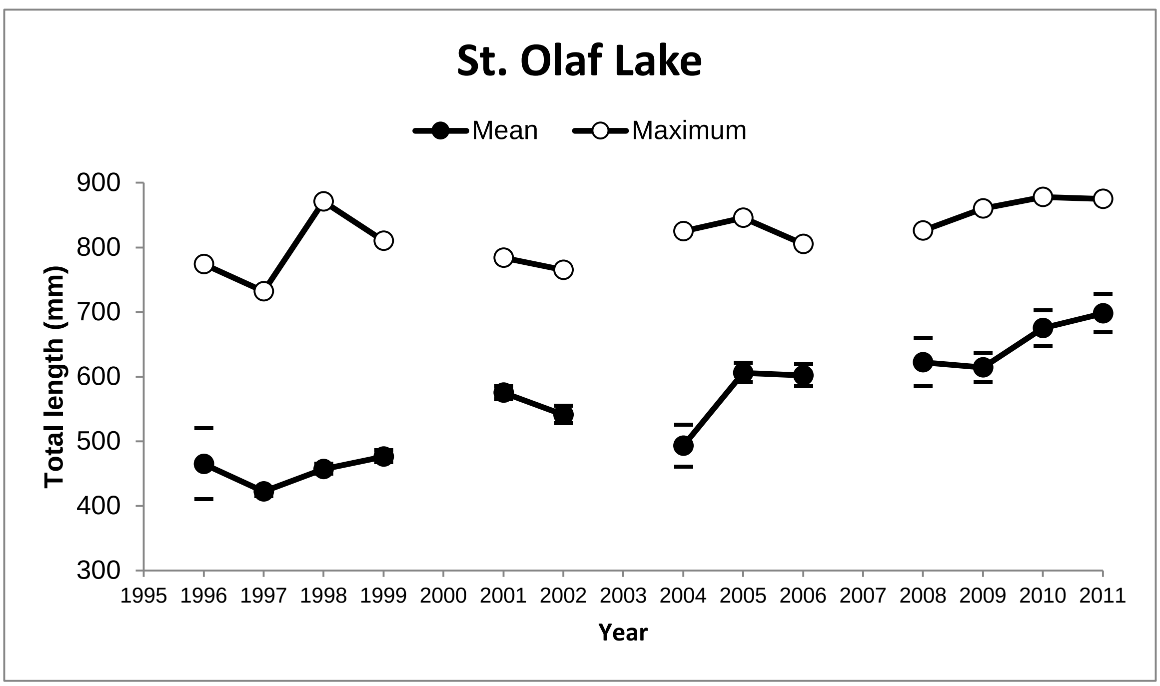


Figure 18. Maximum length as a function of mean length of northern pike captured in ice-out trap nets during 2008 through 2011 in 12 sentinel lakes (White Iron excluded because sampling occurred in only two of the four years), and maximum and mean ($\pm$ 95% confidence limits; horizontal bars above and below black dots) total length of northern pike caught with ice-out trap netting at St. Olaf Lake between 1996 and 2011.

Electrofishing

Evaluation of electrofishing efforts revealed inconsistencies in the amount of sampling effort, sampling dates, water temperatures, anode configurations, and number of netters within and among lakes. Total sampling effort ranged from 0.6 to 2.5 hours of effort, sampling dates ranged from the same week of the year to 30 days difference, water temperatures ranged from 12 to 24 ºC, four different anode configurations were used, and one, two, or one to two netters dipped stunned bass (Table 13). Examination of aerial photographs with sampling locations suggested that effort was well distributed throughout most lakes. Conversely, sampling efforts on Ten Mile, Cedar, Carlos, and Pearl lakes were not well distributed throughout the lakes; therefore data from these four lakes were excluded from further analyses.

Electrofishing captured each bass species in all lakes known to support them, and mean CPH and CV of mean CPH differed among lakes. Spring electrofishing CPH of Smallmouth Bass averaged 124 in Elephant Lake but only 11 at Echo Lake (Figure 19). Spring CPH of Largemouth Bass ranged from 1 at Belle to over 100 at South Twin Lake (Figure 19); fall CPH averaged about 10 at White Iron Lake. No black bass were sampled in Trout, Tait, or Shaokotan lakes; thus, a benchmark of zero CPH was established in these lakes. Among 36 electrofishing assessments in 13 lakes, the CV of mean CPH per assessment of Largemouth Bass ranged from 10 to 245 and averaged 73%. Coefficient of variation of mean CPH per assessment declined curvilinearly with increasing mean CPH but was not clearly linked with segment length only (Figure 20). Based on a strong segment length*mean CPH interaction (Table 14), CV of mean CPH stabilized after mean CPH of largemouth bass exceeded 38 and segment length exceeded 1170 seconds.

Location effects on CPH were much more common with electrofishing than with either type of netting. Electrofishing CPH of Smallmouth Bass differed among locations in Elephant Lake (F = 15.84; df = 3; P = 0.0010 for location effect; F = 3.74; df = 3; P = 0.0602 for year effect). Electrofishing CPH of Smallmouth Bass at location 4 consistently exceeded CPH at the other three locations in Elephant Lake. Similarly, electrofishing CPH of Largemouth Bass differed among sampling locations at South Twin (F = 3.67; df = 5; P = 0.0228 for location effect; F = 3.17; df = 3; P = 0.0554 for year effect) , South Center (F = 6.48; df = 3; P =0.0125 for location effect; F = 3.11; df = 3; P = 0.0815 for year effect), Peltier (F = 5.55; df = 3; P = 0.0196 for location effect; F = 5.30; df = 3; P = 0.0223 for year effect) and Artichoke (F = 3.82; df =5; P = 0.0196 for location effect; F = 0.60; df = 3; P = 0.6222 for year effect) lakes. Catch per hour at locations 5 and 6 in South Twin Lake consistently exceed CPH at location 1, CPH at location 3 consistently exceeded CPH at location 1 at South Center Lake, CPH at location 1 at Lake Peltier was consistently low compared to locations 2 and 3, and Largemouth Bass were caught only at locations 1 and 12 in Artichoke Lake. Frequency distributions of CPH at Hill and South Center lakes, the two lakes with the most segments sampled and with relatively high CPH, were relatively normal (Figure 20).

Examination of CPH of stronger year-classes among consecutive years suggested that CPH obtained with current methods reflect density in some lakes, but not others. Electrofishing CPH of stronger year-classes of Largemouth Bass declined at South Center, Carrie, and Madison lakes, but did not at Hill, Portage, Peltier, or St. Olaf lakes (Figure 21).

Annual variation in CPH of Smallmouth Bass at Elephant Lake appeared high compared to that in Echo Lake from 2008 through 2011 (Figure 19). For Largemouth Bass annual CPH appeared relatively stable during this study except at Hill, South Center, and St. James lakes. Annual variation of CPH of Largemouth Bass at South Center Lake appeared high among all assessments done between 1995 and 2011 (Figure 20; t = -0.91; P = 0.3744 for year effect; F = 7.82; df = 3; P = 0.0013 for location (fixed) effects). However, the absence of a year-effect suggests that the period between 1995 through 2011 can be viewed as normal background noise in electrofishing CPH at South Center Lake.

Historical electrofishing data in the sentinel lakes are lacking; thus, only one comparison could be made between annual variation in CPH during 2008 through 2011 and prior electrofishing samples. Pre-2005 electrofishing surveys using boats with the same or similar anode configurations, the same sampling stations, and the same power settings exist only at South Center, Belle, and Carrie lakes, and the latter two lakes support sparse densities of Largemouth Bass. Historical data on electrofishing CPH at Bear Head, Elephant, St. Olaf, and Madison lakes cannot be used because of changes in anode configurations (sphere to two spider arrays) and changes in power settings. No pre-2008 electrofishing data exist for South Twin, Hill, Portage, Peltier, and Artichoke lakes.

Sample sizes for estimating mean lengths for spring electrofishing varied between or among lakes for both species, and overall distributions of length frequencies appeared normal. Sample sizes of Smallmouth Bass averaged 194 (s.e. = 33) per assessment at Elephant Lake and 20 (s.e. = 5) at Echo Lake. Mean sample sizes of Largemouth Bass ranged from 1 (Belle) to 95 (Hill). The mean length estimates of each species differed considerably among lakes (Figure 22). Length distributions of Smallmouth Bass (Elephant and Echo lakes) and Largemouth Bass appear normal; modal lengths of Smallmouth Bass were shorter than Largemouth Bass (Figure 23). Therefore, mean length estimates appear to be a reasonable metric representing size structure of these species.

High catches of Largemouth Bass seldom occurred in lakes selected for evaluation during this study; thus, estimating sample sizes to achieve the lowest CV of mean length could not be determined with confidence. Coefficients of variation of mean length estimates of Smallmouth Bass per assessment was unaffected by sample size or mean length, but only eight estimates of mean length were made (Table 9; Figure 24). Coefficients of variation of mean length estimates of Largemouth Bass per assessment was unaffected by the number of fish measured but declined with increasing mean length (Table 7; Figure 24).

Annual variation in mean length estimates of Smallmouth Bass and Largemouth Bass during 2008 through 2011 showed relatively high variation at Echo Lake, as well as for Largemouth Bass at Red Sand Lake (Figure 22). Annual variation of mean length of Smallmouth Bass at Elephant Lake during 2008 through 2011 exceeded mean length estimated in earlier assessments (Figure 24). Thus, background variation in mean lengths is unknown for this species in this lake. Conversely, annual variation of mean lengths of largemouth bass from 2008 through 2011 and before this time period appear relatively stable at South Center Lake (Figure 24); thus, the entire period from 1995 through 2011 could be viewed as normal background variation.

<u>Recommendations</u>:

To increase the odds that electrofishing will provide precise and accurate metrics on relative abundance and size structure of Largemouth Bass changes in effort and sampling methodology need to be made in most lakes. Anode configurations on boats should either be the same or side-by-side comparisons of CPH and size structure sampled with different anode configurations need to be made in order to develop conversion factors to compensate for differences in catchability. Except for those lakes where entire shorelines are sampled, a total of two hours of electrofishing effort should be expended. This effort should produce sufficient number (N > 150) of Largemouth Bass in Bear Head, South Twin, Portage, South Center, Madison, and St. James lakes for mean length estimates (Gilliland 1986). Increased effort in the other lakes currently sampled with less than two hours of effort will benefit mean length estimates, but the total number of bass will remain insufficient for ideal precision of mean length estimates because of low abundance. Because crew size and experience affects catchability of black bass, the same crew size must be deployed (choose between one or two netters), and it is preferable that crews be experienced with electrofishing. Additionally, when conditions permit electrofishing for both species should be done at night. All bass observed regardless of size should be collected. Water temperatures should be 12 to 20 ^{o}C as CPH estimated at these temperatures reflect population density (McInerny and Cross 2000). Sampling dates should be similar because first nest times appear similar over time within lakes (J.R. Reed, MNDNR, personal observation). Power must be set at levels to induce an electroshock response whereby netters can effectively net largemouth bass, and power must be applied continuously, not intermittently. Calm conditions are also preferable.

New randomly selected sampling stations should be established at Ten Mile, Cedar, Carlos, and Pearl lakes, and existing sampling stations in the other sentinel lakes (except Elk, Carrie, and St. Olaf lakes where the entire shoreline is sampled) need to be evaluated to ensure that sampling stations were not selected based on perceived bass catch as suggested by the LSM. Once selected, sampling stations should be at least 20 minutes long; doing so increases the odds that some bass will be collected per station and reduces station-to-station variation in CPH caused by patchy distribution patterns of bass (Miranda et al. 1996).

Table 13. Mean (s.e.) effort in hours, start dates in each sample year, range of water temperatures (°C), type of control box (either Coffelt VVP-15, VVP-2E or XXII or Smith-Root GPP 5.0 or GPP 7.5), number and configuration of anodes, and number of netters during boom electrofishing at night for largemouth bass or smallmouth bass in 24 sentinel lakes from 2008 through 2011 (* entire shoreline sampled).

		Start dates							
Lake	Effort (s.e.)	2008	2009	2010	2011	Water temperatures	Control box	Anode configuration (Number of anodes)	Number of netters
Trout	2.2 (0.1)		23 June	22 June		20	VVP-2E	spider array (1)	1-2
Bear Head	1.3 (0.2)	23 June		24 May		19-22	VVP-2E	x-ring (1)	1
Elephant	1.6 (0.1)	2 June	2 June	21 May	7 June	14-20	GPP5.0	spider array (2)	2
Tait	2.5 (0.05)		24 June	23 June		20-23	VVP-2E	spider-array (1)	1-2
White Iron	1.5 (0.2)	16 September		7 October	3 October	12-16	VVP-2E	x ring (1) or sphere (1)	1
Echo	1.9 (0.1)	10 June	1 June	20 May	8 June	17-23	GPP5.0	spider-array (2)	1-2
Ten Mile	1.5 (0.06)	9 June	27 May	25 May	1 June	13-18	GPP5.0	spider array (2)	1
Elk*	2.3 (0.3)	10 June	11 June	2 June			VVP-15	sphere (1)	1
Hill	1.9 (0.1)	9 June	28 May	26 May	1 June	13-18	GPP5.0	spider array (2)	1-2
South Twin	0.9 (0.1)	9 June	10 June	2 June	16 June	16-20	XXII; GPP5.0	spider array (1-2)	1-2
Red Sand	1.6 (0.04)	28 May	19 May	24 May	23 May	18-24	GPP5.0	spider-array (2)	1-2
Portage	1.3 (0.04)	2 June	17 June	15 June	6 June	17-20	GPP5.0	spider-array (2)	1
Cedar	0.6 (0.02)	27 May	19 May	19 May	25 May	14-18	GPP5.0	spider-array (2)	2
Carlos	1.3 (0.1)	28 May	1 June	28 May	16 June	12-17	GPP5.0	spider-array (2)	1
South Center	1.0 (0.2)	4 June	10 June	20 May	16 June	17-23	GPP5.0	spider-array (2)	1
Pearl	1.2 (0.1)	20 May	18 May	18 May	26 May	15-20	GPP5.0	spider-array (2)	1-2
Belle	1.7 (0)	22 May	22 May	18 May	26 May	15-19	GPP5.0	spider-array (1)	1
Peltier	1.8 (0.2)	27 May	3 June	26 May	26 May	16-21	GPP7.5	spider-array (2)	2
Carrie*	0.8 (0.06)	21 May	7 May	17 May	23 May	16-19	GPP5.0	sphere (1)	1
St. Olaf*	1.1 (0.1)	28 May	11 June		1 June	16-18	GPP5.0	spider-array (2)	1-2
Madison	1.1 (0.1)	27 May	3 June		6 June	16-20	GPP5.0	spider-array (2)	2
St. James	1.0 (0.01)	17 June		7 June	8 June	22-24	GPP7.5	spider-array (2)	1-2
Shaokotan	1.4 (0.1)	16 September	19 October	28 September		6-19	GPP7.5	spider-array (2)	1-2
Artichoke	1.0 (0)	4 June	3 June	25 May	6 June	17-24	VVP-15	spider-array (2)	1-2

Table 14. Sample size, *t*-ratios, probabilities that *t* ratio = 0 for full factorial ANOVAs testing the effects of segment length (seconds of on-time) and mean catch per hour (CPH; CPH ≥ 1) on coefficients of variation of spring electrofishing CPH of smallmouth bass and largemouth bass (all samples within and among sentinel lakes combined).

		Independent variables					
		Segment length		CPH		Segment length*CPH	
Species	N	*t*-ratio	*P*	*t*-ratio	*P*	*t*-ratio	*P*
Smallmouth bass	8	-2.38	0.0759	-3.94	0.0170	1.98	0.1187
Largemouth bass	36	-4.36	<0.0001	-6.13	<0.0001	-2.19	0.0356

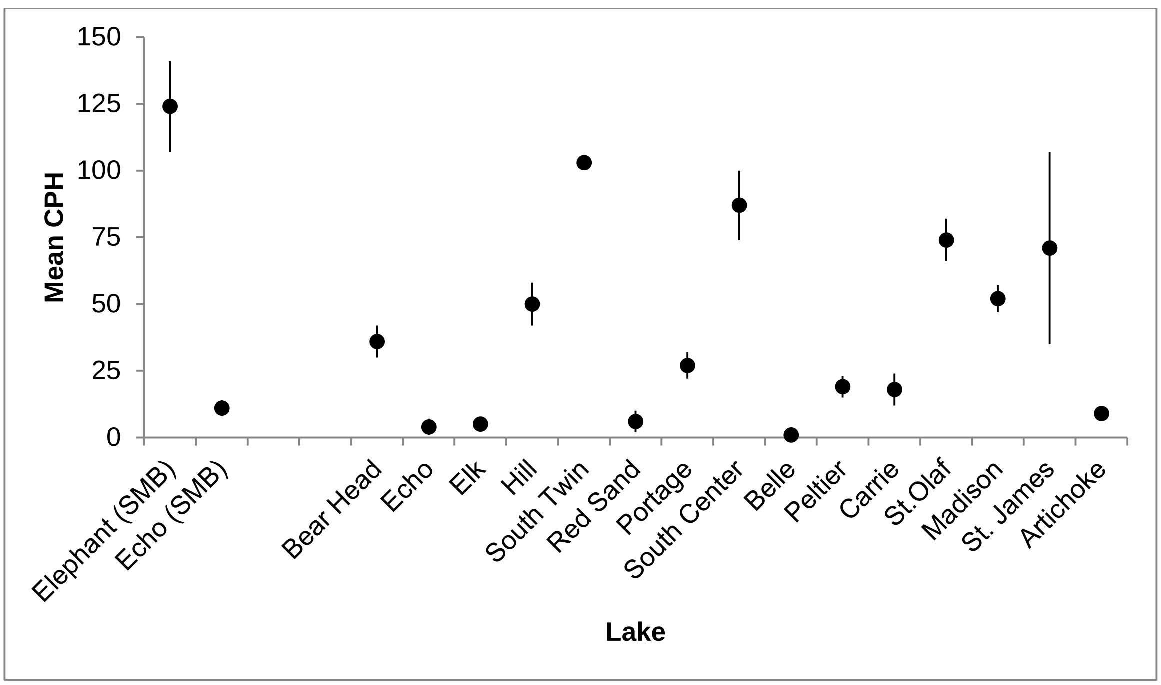


Figure 19. Mean (s.e.) electrofishing catch per hour (CPH) of smallmouth bass (SMB) and largemouth bass during spring at each sentinel lake sampled from 2008 through 2011.

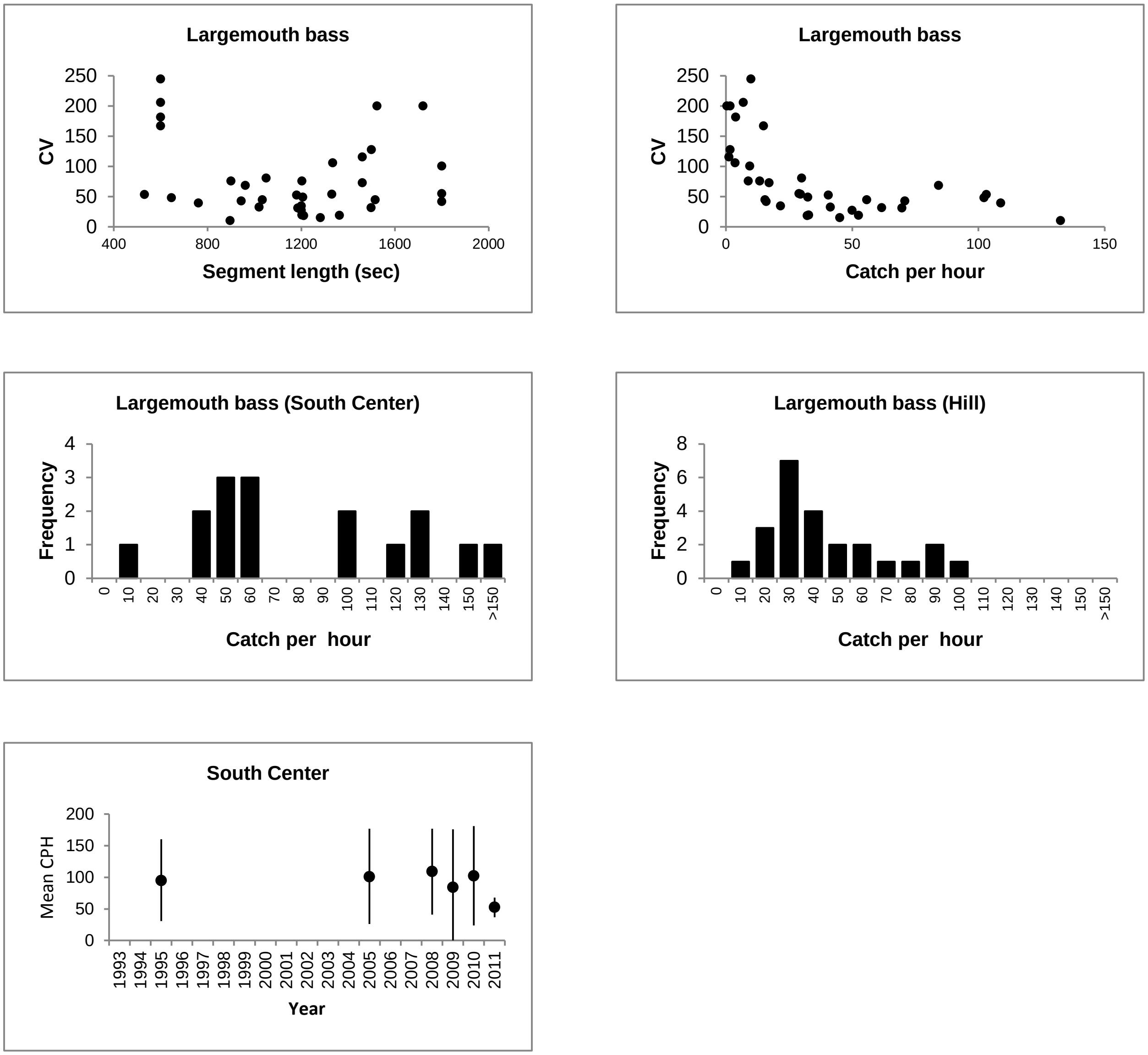


Figure 20. Coefficients of variation (CV) of mean electrofishing catch per hour (CPH) of largemouth bass per assessment during spring as a function of segment length (seconds) and CPH per assessment (all lakes and years combined), frequency of CPH in 10-bass/hr. bins at Hill and South Center lakes during 2008 through 2011 (all years combined), and mean (± 95% confidence intervals) CPH of largemouth bass among assessments at South Center Lake between 1993 and 2011).

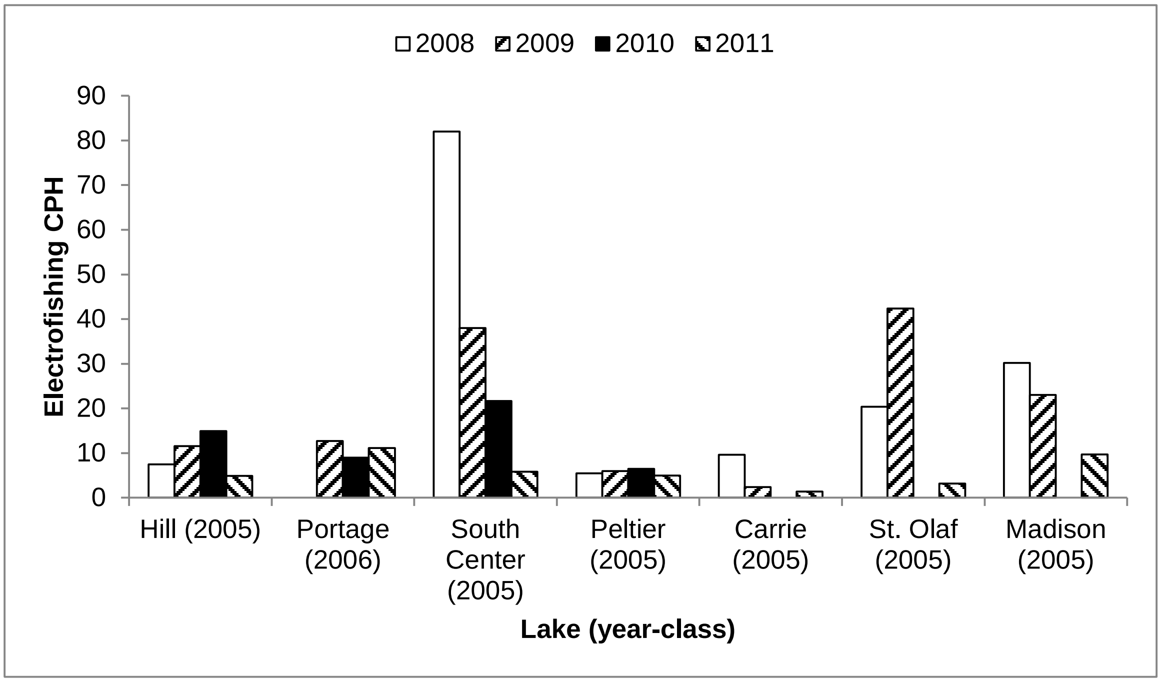
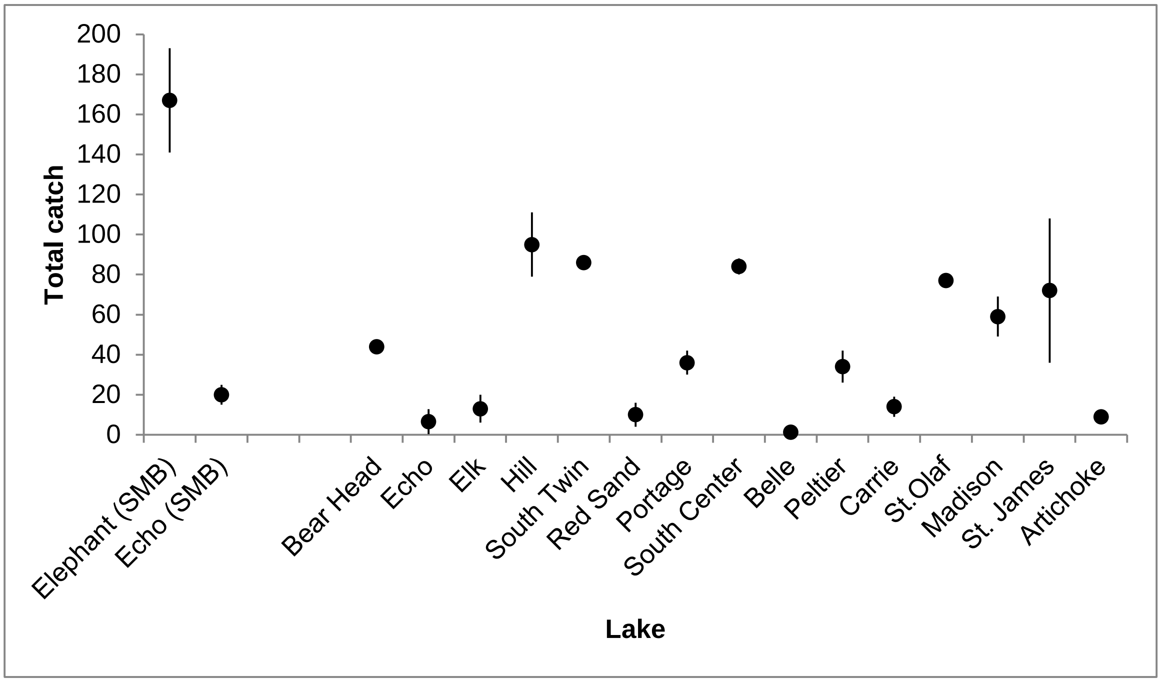


Figure 21. Mean electrofishing catch per hour of stronger year-classes of largemouth bass caught in consecutive years (2008, 2009, 2010, and 2011) in Hill, Portage, South Center, Peltier, Carrie, St. Olaf, and Madison lakes (electrofishing was not done at St. Olaf and Madison lakes in 2010).



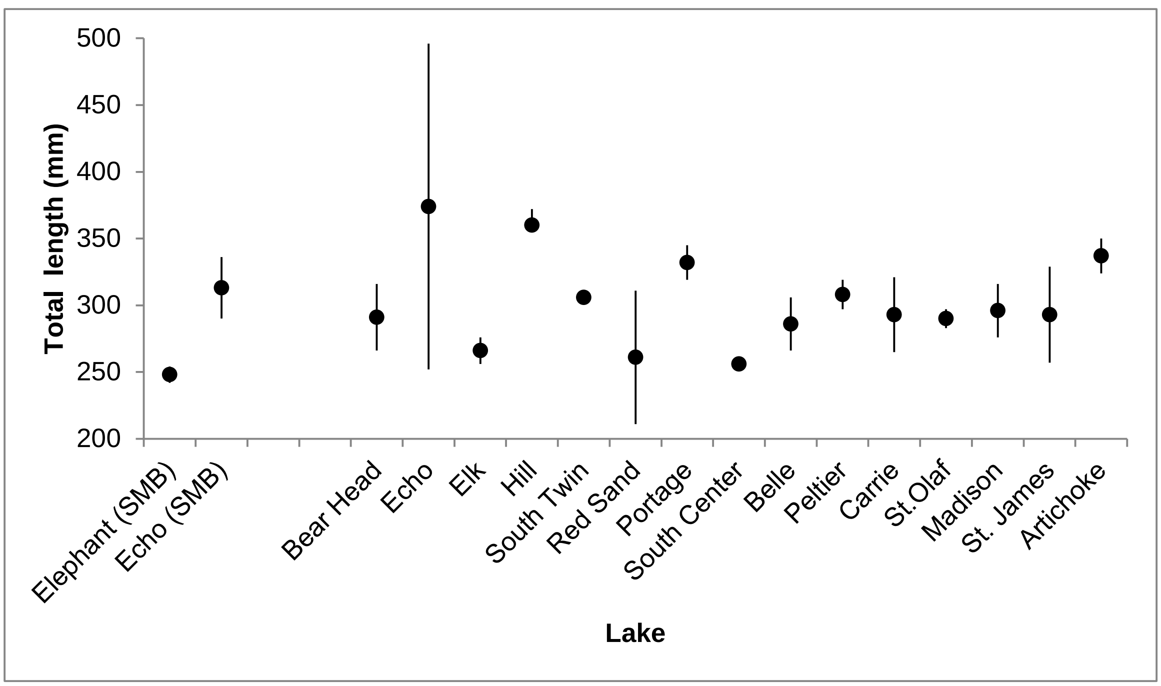
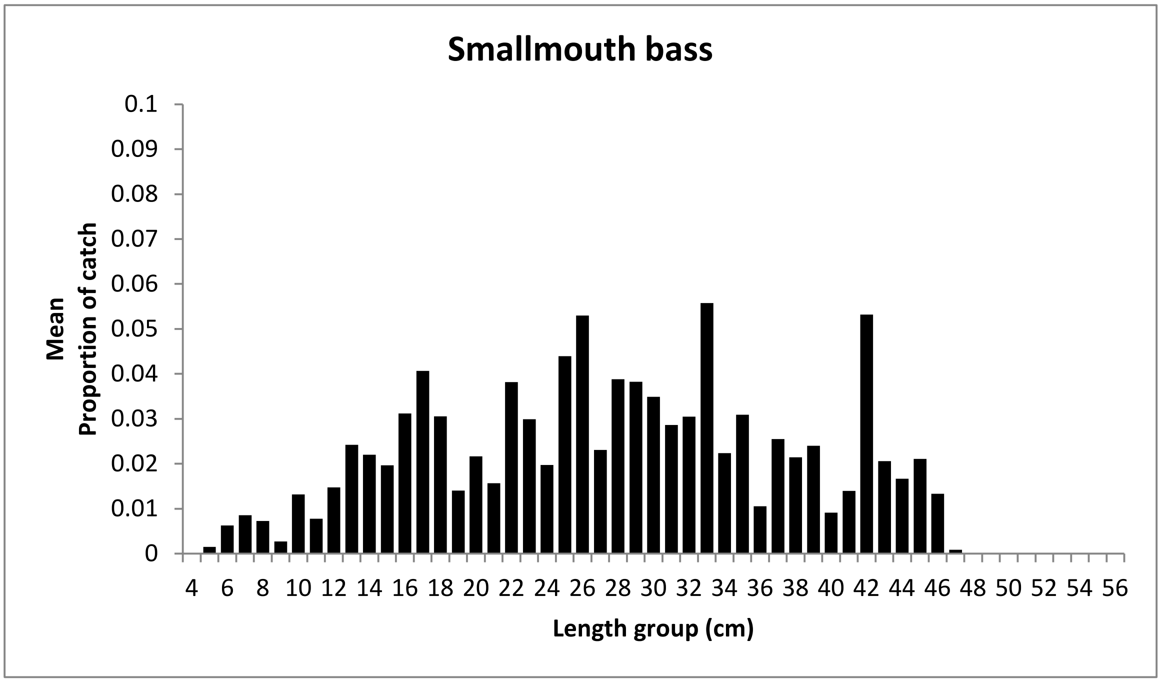


Figure 22. Mean (± s.e.) total catch and mean (± s.e.) total length estimates of smallmouth bass (SMB) and largemouth bass captured with boom electrofishing during spring in 16 sentinel lakes from 2008 through 2011.



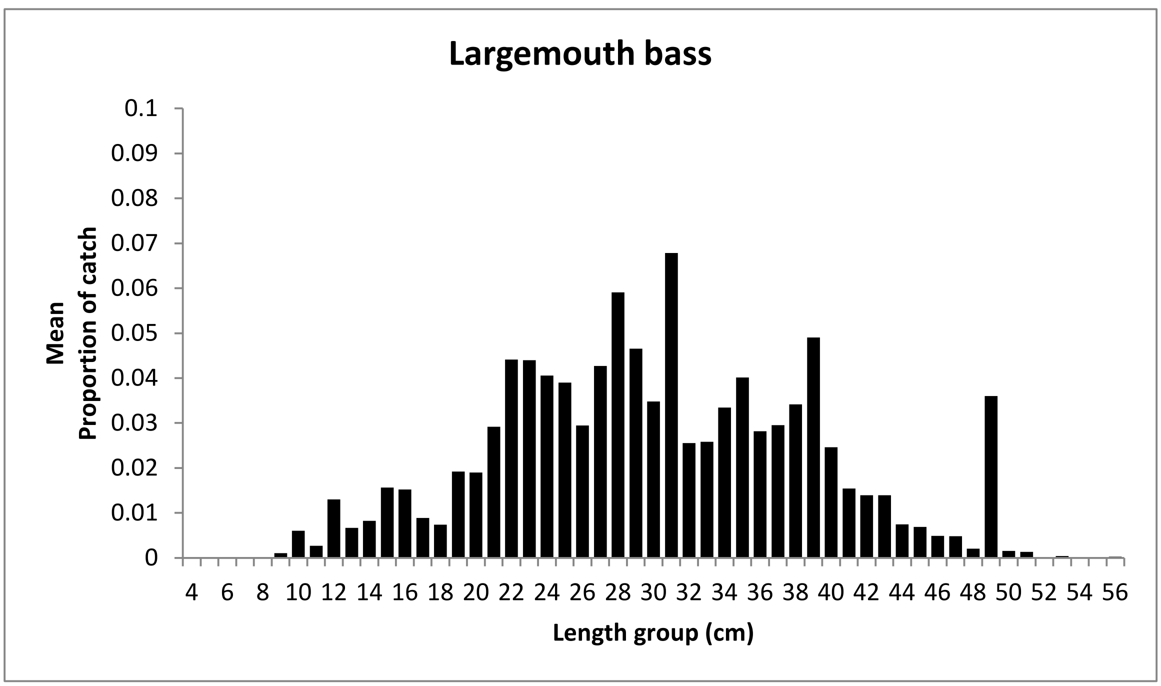


Figure 23. Mean (all lakes and years combined) proportion of spring electrofishing catches of smallmouth bass (Elephant and Echo lakes) and largemouth bass (15 sentinel lakes) by 1-cm length groups.

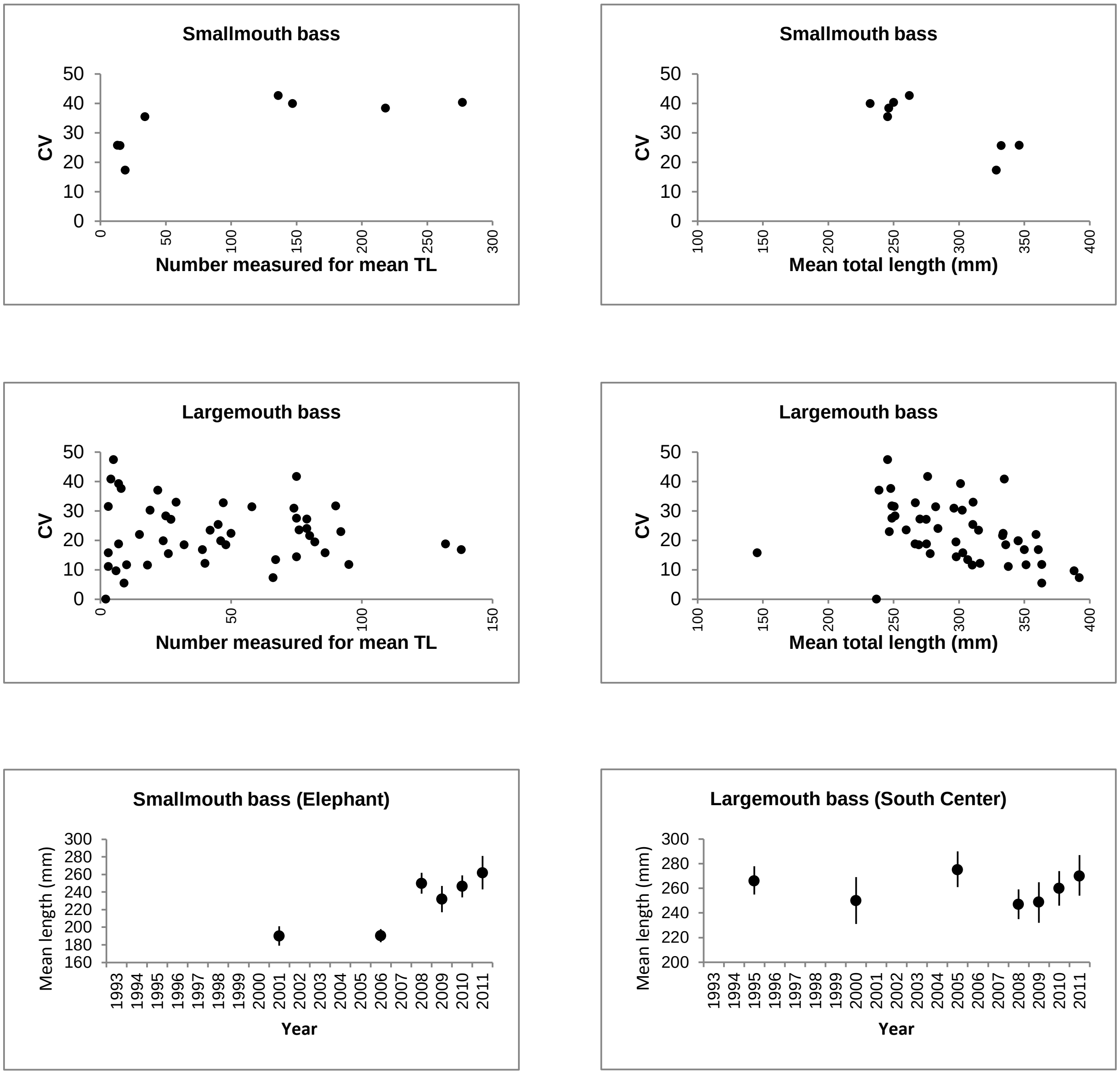


Figure 24. Coefficients of variation (CV) of mean length estimates per assessment of smallmouth bass and largemouth bass as a function of the total number of individuals measured and mean total length per assessment (all lakes and years combined), and mean (+ 95% confidence limits) total length of smallmouth bass at Elephant Lake and of largemouth bass at South Center Lake from 1993 through 2011.

Length at capture and at age

Sample sizes of centrarchids where aging structures were removed differed between species and among lakes. Except for Ten Mile and Carlos lakes aging structures were collected from relatively few (< 50) Rock Bass per assessment (Figure 25). Aging structures were removed from an average of 1 to 137 Bluegills per assessment, 2 to 110 Largemouth Bass, and 1 to 153 Black Crappies (Figure 25). Random subsampling (aging structures collected from all or up to 25 individuals per net) provided high samples of Bluegill at Elk and Carlos lakes, but few Bluegills were collected with this method at Elephant and Echo lakes (Figure 25). Scale samples were removed from an average of 122 Smallmouth Bass per assessment at Elephant Lake and from 20 at Echo Lake.

Estimates of scale age generally agreed with estimates of otolith age up to otolith ages 6 to 8 for most species and lakes. Scale and otolith samples were collected from Rock Bass, Bluegill, and Black Crappie at each lake at least once except at Carrie and Artichoke lakes. Scales and otoliths from Smallmouth Bass were collected from Echo and Ten Mile lakes, and from Largemouth Bass caught in Bear Head, Echo, Ten Mile, Cedar, Carlos, Peltier, Madison, and Artichoke lakes. Scale-age estimates of Rock Bass showed no bias with respect to otolith age through otolith age 9 (Figure.26), and for most lakes, scale age matched otolith age estimates of Bluegill through age 8 (Figure 27). However, scales underestimated otolith age of Bluegill by age 5 at South Center Lake, and by age 6 at Pearl, Madison, St. Olaf, and St. James lakes (Figure 27). Ages estimated with scales of Smallmouth Bass and Largemouth Bass tended to become biased low after age 6 (Figure 26). For Black Crappie scale ages were similar to otolith ages through age 8 for all lakes where otoliths were collected, expect at South Center, Carrie, and St. Olaf lakes were scales ages underestimated age relative to otolith age starting age 5 (Figure 26).

Sex ratios varied and lengths at age at the time of capture often differed between sexes of centrarchids; however, these two effects either did not affect or affected very little precision of mean length at capture by age of Rock Bass, Bluegill, Largemouth Bass or Black Crappie. Percent female per assessment among 34 age classes of Rock Bass caught with gill netting averaged 53% and ranged from 22 to 89%; however, percent female among 85 age classes of bluegill ranged from 10 to 92% but averaged 44% (Figure 28). Data were sparse for Black Crappie; percent female averaged 48% while ranging from 18 to 88% among 15 age classes. Median percent female equaled 50% among age classes of Largemouth Bass caught with spring electrofishing (Figure 28); however, median percent female in gill nets equaled 43% (data not shown). Conversely, failure to determine sex in Yellow Perch will probably affect growth metrics for this species. Females composed most Yellow Perch among 1-cm length groups caught with gill nets in Ten Mile, Hill, Carlos, and Belle lakes (Figure 28).

Mean lengths at capture of older Rock Bass and Bluegill often differed between sexes (male lengths usually exceeded female lengths), but mean length at capture of Smallmouth Bass, Largemouth Bass, and Black Crappie did not differ consistently between sexes regardless of age. At Ten Mile and Carlos lakes, lengths at capture of Rock Bass males exceeded lengths at capture of females in nearly all age classes older than four years (Figure 29; Table 15). Male lengths at capture of Bluegill captured at White Iron, Belle or Artichoke lakes did not differ between sex at any age (Figure 30 and Table 15). However, mean lengths at capture of many older age classes of Bluegill in the other lakes differed between sexes. Except for St. James Lake, male lengths exceeded female lengths (Figure 30; Table 15). In most lakes, lengths at capture of Largemouth Bass and Black Crappie did not differ consistently between sexes (Figure 29). Lengths of age 5 male Black Crappies in White Iron Lake trap nets exceeded lengths of females of the same age. However, gill nets at Belle Lake caught longer age 2 and 3 male Black Crappies than females of the same ages, but trap nets caught longer age 4 females (Figure 29; Table 15). When segregated by sex, CV of mean lengths at capture per assessment of Rock Bass and Bluegill were usually lower than CV of mean lengths at capture for the same age classes when not sexed. However, differences were slight (Figure 31). When controlling for sample size and mean length, CV of mean lengths of age classes of Rock Bass (F = 0.4207; df = 2; P = 0.4207) or Bluegill (F = 0.05; df = 2; P = 0.9463) did not differ between sexes.

Coefficients of variation of mean length at capture per assessment showed similar patterns with respect to increasing mean length and sample size regardless of species or gear except for Bluegill caught in trap nets. As mean length estimates of age classes increased, CV of mean length at capture of Rock Bass in gill nets and trap nets, Black Crappie in gill nets and trap nets, Bluegill in gill nets, and Largemouth Bass in electrofishing declined (Table 9; Figure 32). These CV's were also not linearly related to sample size. However, CV of mean length at capture of Bluegill age classes in trap nets decreased with increasing mean lengths after exceeding 154 mm and after sample sizes exceeded 32. Coefficients of variation of mean lengths at capture per assessment began stabilizing (usually < 10%) after sample sizes of age classes reached 30 Rock Bass, 35 Bluegills, and 35 Black Crappies caught in gill nets, 30 Smallmouth Bass and 30 Largemouth Bass caught with electrofishing, and 60 Black Crappies caught in trap nets (Figure 32).

Unlike mean lengths at capture, mean back-calculated lengths at age of Rock Bass and Bluegill seldom differed between sexes. Mean back-calculated lengths at age 5 Rock Bass differed between sexes in White Iron, Elk, Hill, and Carlos lakes where random subsampling for aging structures occurred; males were longer than females (Figure 33; $F = 6.30$; df = 148; $P = 0.0132$). This is the only occasion that back-calculated lengths at age differed between sexes. Mean lengths at ages 1 through 4 Rock Bass did not differ between females and males (Figure 33; $F = 1.50$ to 2.89; df = 155 to 179; $P =$ 0.0914 to 0.2211 for ages 1 through 4). Although lengths at age differed, CV of mean back-calculated lengths at age 5 (per assessment) segregated by sex did not differ from CV of mean back-calculated length when sexes were combined (Figure 33; $F =$ 0.35; df = 29; $P = 0.7084$). Conversely, mean back-calculated lengths of age 1 through 5 Bluegill did not differ ($t = 0.11$ to 1.52; df = 230 to 424; $P = 0.1294$ to 0.9116 for ages 1 through 5) between sexes in Elk and Carlos lakes where random subsampling occurred and sample sizes of bluegills were sufficient for these analyses.

Coefficients of variation of mean back-calculated lengths at age per assessment of Rock Bass, Bluegill, and Largemouth Bass appeared affected by sample size and mean back-calculated lengths. Among aging samples collected with random subsampling, CV of mean back-calculated lengths at ages 1 through 5 were estimated for 20 age classes of Rock Bass from two lakes, 22 age classes of Bluegill from four lakes, and 131 age classes of Largemouth Bass from 16 lakes. For Rock Bass sampled with gill nets, CV of mean back-calculated lengths at age 1 per assessment and age group was not linearly related to either sample size or mean length; however, the range of sample sizes was low (Figure 34; Table 9). Coefficient of variation of mean back-calculated lengths at age 1 of Rock Bass appeared to stabilize at around 5% after sample size reached 10 to 15. For Bluegill sampled with trap nets, CV of mean back-calculated lengths at age 1 for each age group and assessment averaged 7% and stabilized after sample sizes exceeded 21 and mean lengths exceeded 34 mm (suggested by a strong sample size*mean length interaction; Table 9; Figure 34). For Largemouth Bass, CV of mean back-calculated lengths at age 1 per age group and assessment dropped after sample size exceeded 9 and mean length exceeded 86 mm; CV ranged from 20 to 25% when sample size exceeded 10 (Table 9; Figure 34). Plots of CV of mean back-calculated lengths at ages 2, 3, and 4 per age group and assessment as functions of mean back-calculated lengths at age and sample size of Rock Bass, Bluegill, and Largemouth Bass appeared similar as those for lengths at age 1; thus, these plots are not shown.

The standard fixed-subsampling method for collecting aging structures (5-fish per 1-cm length group) appears reasonable for estimating age and growth metrics for some centrarchid populations in some lakes but not in others. The number of age-classes of Bluegill collected per assessment did not increase in Bear Head, Hill, Red Sand, Belle, Peltier, St. Olaf or Madison lakes after using the 10-fish per 1-cm length group method (Figure 35). However, an additional 1 to 2 year-classes were collected at South Twin, Portage, Cedar, and South Center lakes after doubling the sampling size criterion. The number of age classes of Black Crappie did not increase at Portage Lake after switching from a 5-fish to a 10-fish per 1-cm sampling protocol; however, increases in the numbers of age classes occurred at Belle and Madison lakes (Figure 35). More age classes of Largemouth Bass were observed if scales were removed from all individuals captured during electrofishing at Carlos and Madison lakes,but not so at Hill Lake (Figure 35). The standard 5-fish method is inadequate for estimating age structure in several centrarchid populations because five or more age classes of Rock Bass, Bluegill, Black Crappie, and Largemouth Bass were sampled in many 1-cm length groups in many lakes (Figure 36).

Rosa Lee's phenomenon occurred for many year-classes of Rock Bass, Bluegill, Largemouth Bass, and Black Crappie in lakes where aging structures were collected annually (Tables 16, 17, 18, and 19), and causes for this phenomenon include sampling of faster growing cohorts of younger fish, inconsistent relationships between scale radius and body length, and better survival of slow-growing individuals of older cohorts. Lee's phenomenon probably occurs for Smallmouth Bass, but data were lacking to confirm this hypothesis. Standard intercepts were used and age estimations appear reasonably accurate based on age-bias plots; thus, effects from these two factors on Lee's phenomenon appear negligible.

Faster growing cohorts of young age classes of centrarchids appear vulnerable to capture in gill nets, trap nets, or electrofishing. Ages when Bluegill appear fully vulnerable to gill netting and trap netting ranged from 2 to 5 among lakes, whereas age 2 to 3 Largemouth Bass and age 2 Black Crappie appear fully vulnerable their respective sampling gears (Figure 37). In all cases except for Bluegill at Madison Lake, one to two younger age classes of each species, likely faster growing cohorts, were captured with their respective gears (data not shown). At Madison Lake, no age 1 Bluegills were caught with gill nets. Annual age data were not collected for Rock Bass collected with gill netting; thus, age when this species becomes vulnerable to this gear could not be estimated.

Inconsistent relationships between scale radii and body length appear variable and could contribute to Lee's phenomenon. Overall relationships for Bluegill, Smallmouth Bass, and Black Crappie appear mostly linear; however, those for Rock Bass and Largemouth Bass appear more curvilinear (Figure 38). However, slopes and intercepts of these relationships often differed among years within lakes and relationships also differed among lakes, suggested by significant lake or lake-year interactions (Table 20). Reasons for these differences include scale removals coming from different regions of the fish, differing ranges of body lengths, and differences in growth rates among populations. For example, the scale radii to body length relationship for Rock Bass at Hill Lake differed from those same relationships developed for Rock Bass from White Iron, Elk, Ten Mile, Carlos, and Cedar lakes. The same individual removed Rock Bass scales from all except Hill Lake; thus, scale removals from different regions of the body could explain this finding.

Growth rates and growth patterns differ between centrarchid species within and among lakes. Rock Bass grew fastest at White Iron Lake and slowest at Cedar, and none of the Rock Bass populations exhibit von Bertalanffy growth patterns (Figure 39). Bluegill growth varied greatly among lakes; two populations (St. Olaf and Carrie) show clear von Bertalanffy growth patterns but Gompertz or logistic growth better explains growth patterns in the other populations (Figure 39). Smallmouth Bass grew slowest at Elephant Lake, but only the White Iron population exhibits von Bertalanffy growth. Growth of Largemouth Bass was fastest at Artichoke Lake and slowest at Ten Mile, South Twin, Cedar, and Carlos lakes (Figure 39). All Largemouth Bass populations except at Ten Mile, Cedar, South Center, Carrie and St. James lakes exhibit either Gompertz or logistic growth patterns. Lastly, Black Crappie growth also varied among lakes; eight of the 19 populations exhibit von Bertalanffy growth and three of these populations (South Center, Carrie, and St. Olaf) appeared stunted.

<u>Potential growth metrics</u>:

The number and type of potentially useful growth metrics differed among species because of differing vulnerability to gear, relationships between scale radii and body length, and mortality rates. The best solution to limit bias in back-calculated lengths at age caused by Lee's phenomenon is to estimate metrics from the youngest individual age class vulnerable to capture in all lakes.

Metrics based on back-calculated lengths at age estimated with the Fraser-Lee method appear relatively limited for Rock Bass because of curvilinearity in scale radii and body length; thus, only data from individuals less than 200 mm caught with gill nets should be used (Table 21). Mean length at capture of age 5 Rock Bass could be a useful growth metric because this age was usually captured in all lakes, and it is assumed that all lengths of rock bass at this age are fully vulnerable. However, the age at which all lengths are fully vulnerable to capture gear was not determined for this species; thus, metrics from age 4 Rock Bass should be also evaluated.

For Bluegills captured with summer gill netting or trap netting, mean length of age 5 at capture and mean back-calculated length at ages 1 through 5 calculated from 5-year olds were the best bluegill growth metrics because this was the youngest age consistently sampled among lakes (Table 21). However, sample sizes of age 5 bluegills in lakes with fast growing populations will oftentimes be low, possibly because of high annual mortality in these lakes. Composite mean back-calculated lengths at age estimated from all age classes in which age was accurately estimated could also be useful. This composite estimate assumes that positive bias caused by inclusion of faster growing cohorts of younger age classes offsets negative bias caused by inclusion of slow growing cohorts of older age classes. Furthermore, the overall relationship between scale radii and body length appears mostly linear, thus bias of this composite estimate from this source should be small.

Growth metrics for Largemouth Bass should be based on age 3, 4, or 5 individuals captured with electrofishing (Table 21), as age 3 Largemouth Bass are fully vulnerable to electrofishing and age 5 Largemouth Bass should exist in all sentinel lakes. However, the only mean back-calculated lengths at age metrics should be those calculated from 3-year old Largemouth Bass. Besides being vulnerable to capture in all lakes, age 3 is the youngest age at which individuals from most lakes (exceptions are St. James and Artichoke lakes) will be less than 300 mm TL, the approximate inflection point in the overall scale radii-body length relationship. At this point in time, it is assumed that the same metrics would be useful for Smallmouth Bass.

Mean lengths at capture and mean back-calculated lengths at age metrics of Black Crappies based on age 2, 3, 4, or 5 describe the growth of this species (Table 21). All length groups of age 2 Black Crappies occur equally in trap netting and gill netting and the overall scale radii-body length relationships was approximately linear. However, high mortality in faster growing populations may limit the value of metrics estimated from 4- and 5-year old Black Crappies because sample size will often be too low.

The proportion of the age sample exhibiting each of the three growth curves is a potential growth metric for Black Crappies, but at this time it is not known if this metric will be useful for the other four centrarchids. After examining a statewide data base of back-calculated lengths at age, variation in growth patterns occurs within populations of Black Crappies (MNDNR unpublished data). However, growth patterns within populations of Rock Bass, Bluegill, Smallmouth Bass, or Largemouth Bass have not been examined.

Growth metrics of each species showed inconsistent annual variability during this study; however, because accurate age data were not available before 2008, it is not known if variation within this study represents normal variation of these metrics. Standard errors of mean lengths of age 5 Rock Bass and Bluegill, mean lengths at ages 3 through 5 Smallmouth Bass and Largemouth Bass, and mean lengths at ages 2 through 5 Black Crappie were relatively low but differed among lakes (Tables 22, 23, and 24). Similarly, mean back-calculated lengths at ages 1 through 5 Rock Bass and Bluegill estimated from 5-year olds showed variable standard errors among lakes and standard errors increased with increasing age (Table 25). Standard errors of mean back-calculated lengths at ages 1 through 3 of Smallmouth Bass, Largemouth Bass, and Black Crappie also increased with increasing age (Table 26).

<u>Recommendations</u>:

Assuming links between growth metrics and environmental stressors are found, growth metrics based on mean length at capture by age and mean back-calculated lengths at age should be estimated because they are more precise than fish-based metrics describing relative abundance or size structure. However, several shortcomings should be addressed before estimating these metrics. These include developing quality control measures that ensure age estimates are reasonably accurate and applying consistent sampling procedures for collecting age structures. Quality control measures include training of readers and second reads of age estimates. Improved sampling procedures include consistent and optimal sampling times, sampling wide ranges of lengths so that structures are collected from both young and old individuals of a population, collecting a sufficient sample size, using consistent methods for age structure removal from fish, and representative sampling. Although age estimates made by counting annuli on scales can be accurate with sufficient training, otoliths should be also removed whenever possible.

It is recommended that age structures be collected during the same time of year, preferably before early June or after mid-August to ensure that the last annulus on a given structure can be distinguished from the edge of the aging structure. Furthermore collections during these periods ensure the least noisy estimates of growth calculated with length at capture data. Annuli on younger individuals form earlier in the growing season than on older individuals of the same species. For example, annuli on Yellow Perch age 4 and younger in South Dakota lakes usually formed in early June, but annuli in older Yellow Perch did not form until July or August (Blackwell and Kaufman 2012). Most of the annual growth of Black Crappie in south central Minnesota lakes occurs between mid-June and mid-August (M.C. McInerny, MNDNR, personal observation), thus, inconsistent sampling dates among years will add more error to growth estimates made with length at capture data collected during summer than in spring or fall.

It is recommended that gears sampling a wider size range of Rock Bass and Bluegill be added to the suite of sampling gears for long-term monitoring if growth metrics are to be estimated for these two species. Gill netting and trap netting capture these species relatively late in their lives, making it more difficult to understand mechanisms allowing these species to reach the age and size when caught. Furthermore, any temporal change in Bluegill growth should cause temporal changes in age of vulnerability in gill netting and trap netting. Thus, general remedies for reducing effects of Lee's phenomenon on back-calculated lengths at age among populations appear limited, as vulnerability to capture will change when growth conditions change. Conversely, electrofishing captures wide length ranges (3 to 17 cm in six south central Minnesota lakes; McInerny and Cross 2004); thus, samples collected with this gear should be more are more robust for detecting changes in growth because more age-classes should be vulnerable to capture. Smaller- (0.6-cm bar) mesh trap nets also capture wide length ranges of Bluegill that include smaller individuals, but overall catchability appears low (MNDNR unpublished data; Jackson and Bauer 2000). These small mesh trap nets have been used sparingly in Minnesota; thus, it could be useful to evaluate this gear for sampling small Bluegills.

It is assumed that any fish sampled for age structures is representative of the entire population regardless of where caught in a given lake; however, this assumption needs to be tested. For example, spatial differences in growth rates occurred for Walleye within Leech Lake (45,000 ha) and for Black Crappie within a large (4,900 ha) reservoir even though barriers preventing lake-wide movements did not exist (Schupp 1978; McInerny and Degan 1991). Therefore, the above assumption could be false, especially in larger lakes such Ten Mile (1,890 ha), White Iron (1,300 ha), and Carlos (1,040 ha).

Aging structures should be separated by gear (as suggested in the LSM (MNDNR 1993), scales should be removed from the same region of the body, and the same transect should be used for measuring radii and annuli. Length-selectivity of Rock Bass, Bluegill, and Black Crappie differed between gill netting and trap netting, and these differences will add additional noise to growth metrics if gears are combined. One explanation for differing scale radii-body length relationships for Rock Bass among within and among lakes appear related to where on the body scales were removed. Furthermore, sensitivity of the Weisberg linear growth model, which is used to test for environmental effects on growth, improves if scales come from the same region of the body (Weisberg and Frie 1987). Also, although differences appear minor when transects differ, measuring scale radii and annuli along the same transect should improve precision of back-calculated lengths at age (Hurley et al. 1997).

Sample sizes for estimating age structure metrics (i.e. mean age at capture; not estimated in this study because of insufficient data) should be increased. Because up to seven age classes of Rock Bass, Bluegill, and Black Crappie could be sampled per 1-cm length group in many lakes, the recommended subsampling guidelines (5 to 10 per 1-cm length group) in the LSM will not effectively sample enough age classes with few individuals from a given population (MNDNR 1993). Thus, it is recommended that sample size for a given lake be equal to the product of 3 or 4 times the total number of age classes sampled per 1-cm. The number of age classes per species would be determined from annual sampling in each lake; and these ages should be estimated with otoliths. Consequently, populations with few age classes would require fewer aging samples than those populations with many age classes.

Finally, adjustments in sampling protocol should be made to correct for bias in precision of back-calculated lengths at age when aging structures are collected with fixed subsampling. Although estimates of means will differ little between a fixed versus a random subsampling of aging structures, odds increase that all measurements of dispersion will be biased high if fixed subsampling occurs (Bettoli and Miranda 2001). At least two solutions could be applied to eliminate bias caused by fixed subsampling. One approach is to remove structures from all fish collected from the same subsample of fish to be measured from each net or electrofishing run; this is usually 25 fish per net or electrofishing run (MNDNR 1993). The other approach still uses the fixed subsampling strategy but assigns not only an age to un-aged fish, but also randomly assigns a set of scale measurements from same aged fish within the same length category.

Table 15. Sample size, *F* statistics and probabilities (*P*) that mean length at capture by age group did not differ between female and male rock bass, bluegill, smallmouth bass, largemouth bass, and black crappie captured with gill nets, trap nets, or spring electrofishing among sentinel lakes; statistics are from full-factorial ANOVA testing effects of gender, age, and sample year on mean length.

		Effect					
		Gender		Gender*age		Gender*year	
Lake	N	*F*	*P*	*F*	*P*	*F*	*P*
			Rock bass in gill nets				
Ten Mile	273	23.74	<0.0001	1.86	0.0878		
South Twin	5	1.44	0.3173				
Carlos	125	40.06	<0.0001	0.50	0.8340	2.29	0.1333
			Rock bass in trap nets				
Ten Mile	55	8.83	0.0047	0.75	0.5651		
Elk	9	1.75	0.1398			1.71	0.1480
			Bluegill in gill nets				
Ten Mile	28	0.00	0.9975	0.33	0.7456		
South Twin	12	0.06	0.9522				
Carlos	31	0.27	0.7919	0.12	0.9017	1.01	0.3211
			Bluegill in trap nets				
Bear Head	210	5.38	0.0214	3.02	0.0191		
White Iron	9	1.95	0.0924				
Ten Mile	310	28.40	<0.0001	12.10	<0.0001		
Elk	728	19.29	<0.0001	4.85	<0.0001	1.31	0.2703
South Twin	306	5.87	0.0160	3.77	0.0012	0.25	0.6162
Portage	24	2.10	0.0489	1.44	0.1662		
Cedar	337	3.46	0.0637	2.67	0.0321	0.65	0.4215
Carlos	733	19.22	<0.0001	5.00	<0.0001	9.85	<0.0001
Pearl	252	6.84	0.0095	2.33	0.0435		
Belle	49	0.84	0.3645	0.08	0.9271		
Peltier	84	2.08	0.0408	0.89	0.3774	0.29	0.7718
St. James	63	1.26	0.2666	2.86	0.0454		
Artichoke	20	0.82	0.4256	0.89	0.3872	0.53	0.6039
			Smallmouth bass in spring electrofishing				
Echo	27	0.16	0.8760	0.50	0.6200		
			Largemouth bass in spring electrofishing				
Bear Head	40	0.92	0.3459	0.34	0.7971		
Echo	24	0.84	0.4120	1.26	0.2210		
Peltier	13	1.04	0.3252	0.49	0.6365		
Madison	43	1.23	0.2272	0.82	0.4165		
Artichoke	7	0.83	0.4422				
			Largemouth bass in gill nets				
Ten Mile	23	1.91	0.1845	1.07	0.3637		
Carlos	97	0.68	0.4128	0.81	0.5217	0.68	0.4126
			Black crappie in gill nets				
Ten Mile	7	1.20	0.2848				
Belle	18	2.26	0.0402	0.34	0.7387		
Artichoke	410	0.59	0.4443	2.59	0.0523	2.18	0.0897
			Black crappie in trap nets				
Bear Head	23	0.33	0.7444				
White Iron	15	2.32	0.0372				
Portage	12	0.09	0.9307				
Pearl	30	0.04	0.8514	0.67	0.5210		
Belle	222	4.49	0.0352	1.59	0.1930		
Peltier	18	0.65	0.5233	1.06	0.3064		
Artichoke	122	0.10	0.7488	0.21	0.9330	0.52	0.4706

Table 16. Mean (s.e.) back-calculated lengths at ages 1 through 5 of year-classes of rock bass sampled for three to four consecutive years (trap nets and gill nets combined) at Ten Mile and Elk lakes from 2008 through 2011.

		Age				
Lake (year-class)	Year	1	2	3	4	5
Ten Mile (2002)	2008	40 (1)	53 (1)	67 (2)	91 (2)	123 (3)
	2009	42 (1)	58 (2)	81 (4)	112 (4)	148 (5)
	2010	41 (<1)	55 (1)	70 (2)	98 (3)	128 (3)
	2011	44 (1)	59 (2)	76 (5)	105 (5)	135 (6)
Ten Mile (2005)	2008	44 (1)	63 (1)	94 (3)		
	2009	43 (<1)	60 (2)	85 (3)	119 (4)	
	2010	43 (<1)	61 (1)	86 (2)	118 (2)	148 (2)
	2011	41 (1)	55 (1)	71 (2)	97 (4)	131 (6)
Ten Mile (2006)	2009	44 (1)	59 (2)	85 (3)		
	2010	43 (<1)	57 (1)	79 (1)	113 (2)	
	2011	42 (1)	58 (1)	80 (5)	114 (7)	141 (10)
Elk (2002)	2008	44 (1)	63 (1)	87 (3)	121 (8)	155 (1)
	2009	42 (1)	61 (3)	86 (3)	114 (5)	154 (9)
	2010	41 (1)	61 (1)	76 (3)	102 (<1)	141 (13)
Elk (2003)	2008	40 (1)	57 (3)	89 (3)	131 (11)	168 (6)
	2009	43 (3)	57 (2)	84 (6)	125 (7)	173 (8)
	2010	43 (1)	59 (4)	83 (1)	116 (10)	169 (18)
Elk (2005)	2008	41 (1)	63 (2)	98 (3)		
	2009	41 (<1)	63 (5)	99 (5)	131 (8)	
	2010	40 (1)	57 (2)	90 (5)	119 (7)	161 (7)

Table 17. Mean (s.e.) back-calculated lengths at ages 1 through 5 of year-classes of bluegill sampled with trap nets or gill nets for three to four consecutive years at 17 sentinel lakes from 2008 through 2011.

		Age				
Lake (year-class)	Year	1	2	3	4	5
Bear Head (2003)	2008	37 (1)	51 (1)	68 (1)	86 (2)	108 (2)
	2009	35 (1)	49 (1)	67 (1)	89 (2)	113 (3)
	2010	34 (1)	48 (2)	65 (3)	85 (4)	107 (4)
	2011	33 (1)	48 (2)	65 (3)	83 (5)	102 (5)
Bear Head (2005)	2009	36 (<1)	59 (1)	81 (1)	106 (3)	
	2010	34 (<1)	54 (1)	72 (1)	91 (2)	114 (3)
	2011	34 (<1)	53 (1)	72 (1)	90 (2)	112 (2)
Elephant (2006)	2008	42 (2)	83 (3)			
	2009	40 (1)	82 (3)	113 (3)		
	2010	37 (4)	66 (8)	93 (8)	123 (2)	
	2011	39 (3)	73 (6)	110 (1)	147 (2)	172 (1)
White Iron (2005)	2008	41 (1)	101 (3)	161 (3)		
	2009	38 (1)	89 (4)	146 (4)	185 (3)	
	2010	39 (2)	95 (5)	149 (7)	183 (6)	197 (5)
	2011	34 (1)	82 (8)	131 (15)	163 (16)	187 (12)
Ten Mile (2003)	2008	36 (1)	47 (1)	59 (1)	77 (1)	100 (2)
	2009	34 (1)	47 (4)	58 (5)	73 (5)	91 (4)
	2010	38 (1)	54 (2)	68 (3)	86 (3)	109 (3)
	2011	35 (1)	45 (3)	58 (3)	73 (2)	92 (2)
Ten Mile (2005)	2008	36 (1)	56 (2)	77 (3)		
	2009	37 (1)	56 (1)	74 (1)	92 (2)	
	2010	36 (<1)	53 (1)	71 (1)	89 (1)	110 (1)
	2011	36 (<1)	53 (1)	68 (1)	84 (1)	105 (2)
Ten Mile (2006)	2009	40 (1)	57 (1)	74 (3)		
	2010	37 (1)	52 (1)	66 (1)	82 (2)	
	2011	38 (1)	53 (1)	67 (1)	84 (1)	101 (2)
Elk (2003)	2008	32 (1)	45 (1)	63 (2)	83 (2)	115 (3)
	2009	32 (1)	45 (1)	63 (2)	84 (2)	114 (3)
	2010	32 (1)	52 (8)	74 (10)	98 (10)	128 (11)
Elk (2005)	2008	36 (1)	57 (1)	85 (2)		
	2009	35 (<1)	50 (1)	72 (1)	96 (1)	
	2010	33 (<1)	48 (1)	71 (1)	96 (2)	128 (2)
Hill (2005)	2008	38 (<1)	63 (1)	100 (2)		
	2009	34 (2)	61 (3)	97 (5)	135 (7)	
	2010	38 (1)	61 (1)	92 (3)	133 (4)	164 (4)
	2011	38 (2)	62 (2)	100 (8)	141 (6)	172 (5)
Hill (2006)	2008	38 (1)	70 (2)			
	2009	38 (2)	67 (4)	100 (6)		
	2010	35 (1)	54 (1)	74 (2)	102 (3)	
	2011	33 (1)	53 (2)	80 (3)	120 (4)	158 (4)
South Twin (2003)	2008	33 (1)	42 (1)	55 (2)	75 (3)	103 (5)
	2009	33 (1)	40 (1)	50 (2)	70 (3)	95 (4)
	2010	33 (1)	40 (1)	50 (1)	68 (2)	89 (2)
South Twin (2005)	2008	36 (2)	50 (1)	69 (4)		
	2009	34 (1)	49 (1)	64 (2)	86 (3)	
	2010	36 (1)	50 (2)	65 (3)	85 (4)	115 (4)
Red Sand (2005)	2008	54 (5)	93 (5)	123 (4)		
	2009	47 (1)	80 (2)	112 (1)	173 (2)	
	2010	47 (2)	78 (2)	107 (3)	170 (6)	205 (5)
	2011	40 (1)	55 (1)	67 (2)	86 (3)	120 (7)
Portage (2005)	2008	38 (1)	58 (1)	82 (1)		
	2009	36 (1)	56 (2)	82 (2)	110 (2)	
	2010	37 (1)	56 (1)	78 (1)	107 (2)	143 (2)
	2011	37 (2)	56 (3)	78 (3)	106 (4)	146 (5)
Portage (2006)	2008	37 (1)	58 (1)			
	2009	37 (1)	58 (2)	85 (2)		
	2010	35 (<1)	53 (1)	78 (1)	113 (2)	
	2011	37 (1)	57 (1)	84 (4)	115 (4)	149 (6)

(Table 17 continued on next page.)

Table 17. (continued).

Lake (year-class)	Year	Age 1	2	3	4	5
Cedar (2005)	2008	40 (1)	54 (1)	77 (2)		
	2009	37 (1)	50 (1)	67 (2)	90 (3)	
	2010	36 (<1)	47 (1)	62 (1)	81 (2)	106 (3)
	2011	34 (1)	44 (1)	57 (1)	76 (2)	102 (3)
Carlos (2002)	2008	33 (<1)	43 (1)	56 (1)	72 (2)	94 (3)
	2009	34 (<1)	44 (1)	57 (3)	72 (4)	91 (5)
	2010	31 (1)	40 (1)	52 (1)	69 (2)	89 (3)
	2011	33 (1)	43 (2)	52 (3)	65 (4)	83 (6)
Carlos (2003)	2008	34 (<1)	44 (1)	56 (2)	77 (3)	103 (4)
	2009	34 (1)	42 (1)	53 (1)	70 (3)	91 (5)
	2010	33 (<1)	41 (1)	51 (1)	67 (2)	87 (3)
	2011	32 (1)	40 (1)	48 (2)	67 (3)	88 (5)
Carlos (2005)	2009	36 (1)	50 (1)	67 (2)	90 (3)	
	2010	33 (<1)	43 (<1)	56 (1)	73 (1)	98 (2)
	2011	34 (<1)	45 (1)	59 (1)	79 (2)	106 (3)
South Center (2006)	2008	40 (1)	71 (2)			
	2009	39 (1)	74 (3)	109 (3)		
	2010	38 (1)	72 (2)	106 (3)	134 (3)	
	2011	37 (1)	70 (4)	107 (6)	135 (5)	154 (6)
South Center (2007)	2009	38 (1)	69 (2)			
	2010	37 (1)	66 (2)	102 (2)		
	2011	36 (1)	61 (1)	101 (3)	130 (4)	
Belle (2006)	2008	57 (1)	117 (5)			
	2009	47 (8)	94 (13)	150 (4)		
	2010	48 (2)	86 (6)	126 (7)	157(6)	
	2011	42 (2)	73 (3)	114 (6)	141(6)	165 (6)
Belle (2007)	2009	44 (1)	108 (4)			
	2010	45 (2)	94 (6)	144 (8)		
	2011	40 (1)	73 (6)	115 (11)	171 (9)	
Carrie (2007)	2009	42 (1)	81 (2)			
	2010	40 (1)	73 (3)	108 (4)		
	2011	41 (1)	81 (4)	125 (9)	173 (6)	
Carrie (2008)	2009	54 (1)				
	2010	46 (1)	97 (10)			
	2011	44 (1)	81 (3)	139 (2)		
St. Olaf (2005)	2008	45 (1)	69 (2)	104 (2)		
	2009	46 (1)	70 (1)	108 (2)	131 (3)	
	2010	49 (1)	74 (2)	110 (3)	134 (3)	155 (4)
	2011	45 (1)	69 (1)	103 (2)	129 (2)	152 (2)
Madison (2004)	2008	38 (1)	81 (3)	124 (4)	159 (3)	
	2009	36 (1)	80 (5)	127 (6)	160 (5)	
	2010	36 (2)	71 (4)	113 (4)	150 (6)	170 (3)
	2011	35 (2)	68 (5)	108 (6)	143 (5)	175 (4)
Madison (2005)	2008	40 (1)	73 (2)	119 (1)		
	2009	45 (2)	81 (5)	128 (4)	162 (4)	
	2010	39 (1)	69 (2)	112 (3)	143 (2)	171 (3)
	2011	44 (1)	77 (2)	122 (1)	150 (3)	175 (4)
Madison (2006)	2008	39 (2)	73 (8)			
	2009	44 (3)	87 (4)	128 (4)		
	2010	35 (4)	69 (<1)	115 (7)	155 (<1)	
	2011	44 (4)	83 (7)	122 (6)	161 (6)	183 (3)
Madison (2007)	2009	44 (2)	85 (3)			
	2010	39 (2)	74 (3)	124 (3)		
	2011	38 (1)	72 (2)	122 (2)	158 (2)	
Artichoke (2007)	2009	35 (1)	82 (5)			
	2010	43 (3)	104 (6)	165 (5)		
	2011	39 (2)	88 (6)	148 (8)	194 (5)	

Table 18. Mean (s.e.) back-calculated lengths at ages 1 through 5 of year-classes of largemouth bass sampled with spring electrofishing for three to four consecutive years at four sentinel lakes from 2008 through 2011.

		Age				
Lake (year-class)	Year	1	2	3	4	5
Hill (2005)	2008	76 (3)	170 (5)	258 (5)		
	2009	79 (3)	168 (6)	258 (6)	310 (5)	
	2010	79 (4)	165 (7)	247 (7)	302 (6)	329 (5)
	2011	74 (4)	178 (6)	267 (4)	321 (5)	357 (4)
Hill (2006)	2008	80 (4)	171 (4)			
	2009	87 (4)	182 (4)	254 (3)		
	2010	74 (6)	166 (6)	243 (7)	300 (8)	
	2011	85 (4)	188 (5)	266 (6)	322 (5)	357 (4)
Portage (2006)	2008	96 (4)	209 (7)			
	2009	76 (4)	182 (6)	253 (5)		
	2010	66 (2)	167 (4)	245 (4)	301 (3)	
	2011	71 (3)	173 (6)	255 (3)	305 (3)	345 (3)
South Center (2005)	2008	95 (3)	169 (3)	226 (2)		
	2009	92 (4)	159 (4)	209 (4)	241 (3)	
	2010	76 (9)	142 (11)	204 (8)	247 (6)	277 (7)
	2011	73 (5)	153 (6)	217 (8)	261 (9)	291 (8)
South Center (2006)	2008	95 (9)	185 (4)			
	2009	81 (4)	162 (5)	211 (6)		
	2010	84 (5)	149 (6)	207 (3)	253 (4)	
	2011	88 (10)	157 (9)	215 (7)	257 (6)	286 (6)
South Center (2007)	2009	102 (3)	171 (3)			
	2010	93 (3)	163 (3)	207 (3)		
	2011	94 (4)	164 (4)	220 (6)	266 (8)	
South Center (2008)	2009	104 (6)				
	2010	104 (4)	178 (3)			
	2011	81 (4)	158 (4)	227 (4)		
Peltier (2005)	2008	91 (3)	164 (8)	241 (4)		
	2009	92 (4)	147 (5)	237 (3)	304 (3)	
	2010	90 (3)	164 (10)	249 (7)	318 (6)	357 (6)
	2011	87 (4)	172 (15)	255 (13)	316 (10)	349 (10)
Peltier (2007)	2009	101 (4)	221 (6)			
	2010	100 (7)	204 (6)	285 (6)		
	2011	97 (6)	197 (17)	279 (14)	335 (15)	
Peltier (2008)	2009	121 (10)				
	2010	102 (3)	204 (4)			
	2011	95 (7)	206 (7)	291 (6)		

Table 19. Mean (s.e) back-calculated lengths at ages 1 through 5 of year-classes of black crappie sampled for three to four consecutive years at 11 sentinel lakes from 2008 through 2011.

Lake (year-class)	Year of capture	Annulus 1	2	3	4	5
Bear Head (2006)	2009	65 (3)	100 (4)	155 (6)		
	2010	62 (2)	94 (5)	135 (7)	179 (8)	
	2011	62 (1)	99 (2)	142 (3)	187 (3)	229 (3)
Elephant (2005)	2008	58 (1)	122 (4)	199 (4)		
	2009	57 (1)	121 (5)	197 (4)	233 (4)	
	2010	55 (1)	117 (5)	195 (5)	233 (4)	255 (3)
White Iron (2005)	2008	71 (3)	151 (2)	221 (3)		
	2009	69 (2)	148 (4)	213 (4)	248 (3)	
	2010	70 (3)	144 (3)	205 (4)	238 (4)	256 (5)
	2011	71 (10)	155 (10)	224 (8)	254 (9)	274 (7)
White Iron (2006)	2008	77 (3)	139 (9)			
	2009	74 (2)	140 (3)	194 (3)		
	2010	73 (3)	133 (3)	185 (4)	222 (4)	
	2011	65 (2)	129 (4)	185 (4)	226 (4)	255 (4)
Red Sand (2005)	2008	66 (1)	93 (3)	116 (5)		
	2009	67 (1)	99 (5)	127 (7)	186 (9)	
	2010	66 (1)	97 (3)	129 (5)	193 (5)	227 (5)
	2011	67 (1)	95 (3)	125 (5)	183 (5)	218 (4)
Hill (2006)	2008	63 (5)	137 (8)			
	2009	62 (1)	128 (3)	193 (3)		
	2010	59 (1)	125 (2)	190 (5)	236 (11)	
	2011	63 (1)	129 (7)	186 (13)	229 (16)	255 (18)
Portage (2006)	2008	67 (1)	112 (2)			
	2009	66 (1)	110 (2)	158 (2)		
	2010	65 (1)	105 (1)	153 (2)	193 (3)	
	2011	65 (1)	107 (2)	156 (3)	199 (3)	229 (3)
Belle (2005)	2008	75 (2)	143 (3)	195 (3)		
	2009	78 (1)	139 (3)	189 (5)	226 (5)	
	2010	79 (1)	161 (12)	220 (12)	247 (5)	268 (3)
Belle (2006)	2008	80 (2)	157 (2)			
	2009	84 (2)	153 (5)	204 (6)		
	2010	72 (3)	121 (12)	160 (27)	206 (18)	
Belle (2007)	2008	87 (4)				
	2009	77 (2)	150 (3)			
	2010	71 (1)	136 (2)	191 (4)		
	2011	68 (1)	127 (2)	179 (3)	216 (5)	
Belle (2008)	2009	94 (2)				
	2010	71 (2)	140 (3)			
	2011	67 (1)	133 (2)	189 (4)		

(Table 19 continued on next page.)

Table 19. (continued).

Lake (year-class)	Year of capture	Annulus				
		1	2	3	4	5
South Center (2007)	2009	63 (2)	122 (3)			
	2010	72 (1)	127 (3)	164 (4)		
	2011	69 (2)	127 (5)	168 (5)	191 (5)	
St. Olaf (2007)	2008	76 (2)				
	2009	69 (2)	142 (5)			
	2010	73 (1)	131 (4)	171 (4)		
	2011	69 (1)	127 (2)	164 (2)	190 (2)	
Madison (2005)	2008	73 (1)	120 (2)	182 (2)		
	2009	73 (4)	128 (3)	187 (3)	225 (4)	
	2010	79 (4)	137 (7)	201 (5)	238 (4)	261 (5)
	2011	74 (3)	127 (5)	190 (3)	224 (3)	252 (2)
Madison (2006)	2008	74 (2)	142 (3)			
	2009	73 (1)	144 (2)	188 (3)		
	2010	74 (2)	143 (3)	190 (4)	227 (3)	
	2011	73 (1)	141 (3)	194 (2)	234 (2)	261 (2)
Madison (2007)	2008	87 (3)				
	2009	76 (1)	142 (2)			
	2010	77 (2)	134 (3)	195 (3)		
	2011	76 (2)	136 (3)	202 (4)	242 (3)	
Madison (2008)	2009	82 (2)				
	2010	75 (2)	142 (3)			
	2011	71 (1)	140 (2)	206 (3)		
Artichoke (2007)	2008	90 (2)				
	2009	77 (4)	187 (8)			
	2010	95 (2)	208 (3)	267 (3)		
	2011	88 (3)	193 (6)	253 (5)	300 (4)	
Artichoke (2008)	2009	81 (1)				
	2010	80 (3)	170 (4)			
	2011	72 (2)	158 (2)	248 (3)		

Table 20. Degrees of freedom (df), *F* statistics, and probabilities that scale radii of rock bass, bluegill, smallmouth bass, largemouth bass, and black crappie were affected by lake or lake and year (lake+year), body length (length), and the body length*lake (or lake-year) interaction; scale radii were measured with either a digitizing pad or ruler.

		ANOVA statistics			
Species	Measure method	Effect	df	*F*	*P*
Rock bass	Digitizing tablet	Lake	4	5.57	0.0002
		Length	1	1,978	<0.0001
		Lake*length	4	0.54	0.7009
Bluegill	Ruler	Lake-year	41	16.56	<0.0001
		Length	1	8,841	<0.0001
		Lake-year*length	41	4.68	<0.0001
Bluegill	Digitizing tablet	Lake-year	29	26.68	<0.0001
		Length	1	18,962	<0.0001
		Lake-year*length	29	4.64	<0.0001
Smallmouth bass	Ruler	Lake	1	0.91	0.3697
		Length	1	3,916	<0.0001
		Lake*length	1	2.59	0.0100
Smallmouth bass	Digitizing tablet	Lake	1	5.37	<0.0001
		Length	1	598	<0.0001
		Lake*length	1	0.75	0.4549
Largemouth bass	Ruler	Lake-year	12	18.35	<0.0001
		Length	1	4,421	<0.0001
		Lake-year*length	12	12.57	<0.0001
Largemouth bass	Digitizing tablet	Lake-year	30	33.99	<0.0001
		Length	1	5,236	<0.0001
		Lake-year*length	30	7.76	<0.0001
Black crappie	Ruler	Lake	13	22.2	<0.0001
		Length	1	6,353	<0.0001
		Lake*length	13	7.59	<0.0001
Black crappie	Digitizing tablet	Lake-year	24	13.03	<0.0001
		Length	1	6,248	<0.0001
		Lake-year*length	24	5.26	<0.0001

Table 21. List of growth metrics that can be estimated with minimal bias for rock bass, bluegill, and black crappie sampled with summer trap netting and gill netting, and for largemouth bass sampled with spring electrofishing (V = von Bertalanffy, G = Gompertz, and L = logistic growth pattern).

Species	Metrics
Rock bass	Back-calculated lengths at age 1 through 4 from 4-year olds Back-calculated lengths at age 1 through 5 from 5-year olds Proportion of V, G, and L growth among age 5 individuals Length at capture of age 4 and 5
Bluegill	Back-calculated lengths at age 1 through 5 from 5-year olds Back-calculated lengths at age 1 through 5 from all ages in sample Proportion of V, G, and L growth among age 5 individuals Length at capture of age 5
Black crappie	Back-calculated lengths at age 1 and 2 from age 2 individuals Back-calculated lengths at age 1, 2, and 3 from age 3 individuals Back-calculated lengths at age 1,2, 3, and 4 from age 4 individuals Back-calculated lengths at age 1,2,3,4, and 5 from age 5 individuals Back-calculated lengths at age 1 through 5 from all ages in sample Lengths at capture of age 2, 3, 4 and 5 Proportion of V,G, and L growth among age 4 or age 5 individuals
Largemouth bass	Back-calculated lengths at age 1, 2, and 3 from 3-year olds Lengths at capture of age 2, 3, 4 and 5 Proportion of V,G, and L growth among age 5 individuals

Table 22. Mean (s.e.) length at capture of age 5 rock bass and age 5 bluegill in gill nets and trap nets in 23 sentinel lakes during 2008 through 2011.

	Rock bass		Bluegill	
Lake	Gill net	Trap net	Gill net	Trap net
Bear Head				114 (2)
Elephant				167 (5)
Tait				
White Iron	206	180 (7)		208 (6)
Echo				212
Ten Mile	159 (6)	159 (6)	125	122 (5)
Elk	166	180 (4)	100	131 (9)
Hill	175	177 (10)	171	168 (5)
South Twin			103 (2)	125 (6)
Red Sand				170 (19)
Portage				169 (7)
Cedar		197		121 (2)
Carlos	185 (3)	178	112 (8)	137 (2)
South Center			165 (4)	161 (1)
Pearl			159 (3)	159 (6)
Belle				157 (6)
Peltier				198 (8)
Carrie				164 (3)
St. Olaf			175	160 (2)
Madison			186 (3)	188 (2)
St. James				197 (3)
Shaokotan				
Artichoke				

Table 23. Mean (s.e.) length at capture of age 3, 4, and 5 smallmouth bass and age 3, 4, and 5 largemouth bass in spring electrofishing during the four-year pilot (2008 through 2011) in 20 sentinel lakes.

	Smallmouth bass			Largemouth bass		
Lake	Age 3	Age 4	Age 5	Age 3	Age 4	Age 5
Bear Head				215 (22)	272 (16)	315 (8)
Elephant	145 (13)	196 (16)	247 (12)			
Echo	232 (8)	304	313 (21)	298		
Ten Mile						
Elk				285	324	375
Hill				244 (12)	304 (2)	342 (6)
South Twin				204	262	298
Red Sand				234		378
Portage				259 (7)	318 (10)	342 (3)
Cedar						
Carlos						
South Center				220 (5)	261 (7)	288 (11)
Pearl						
Belle				340		
Peltier				278 (12)	303 (21)	356 (1)
Carrie				292 (21)	330 (14)	376
St. Olaf				253 (10)	302 (11)	352 (14)
Madison				260 (11)	309 (20)	365 (15)
St. James				313 (10)	340 (9)	363 (41)
Artichoke				364 (9)	407 (4)	429 (3)

Table 24. Mean (s.e.) length at capture of age 2, age 3, age 4, and age 5 black crappie in gill nets and trap nets during 2008 through 2011 in 20 sentinel lakes.

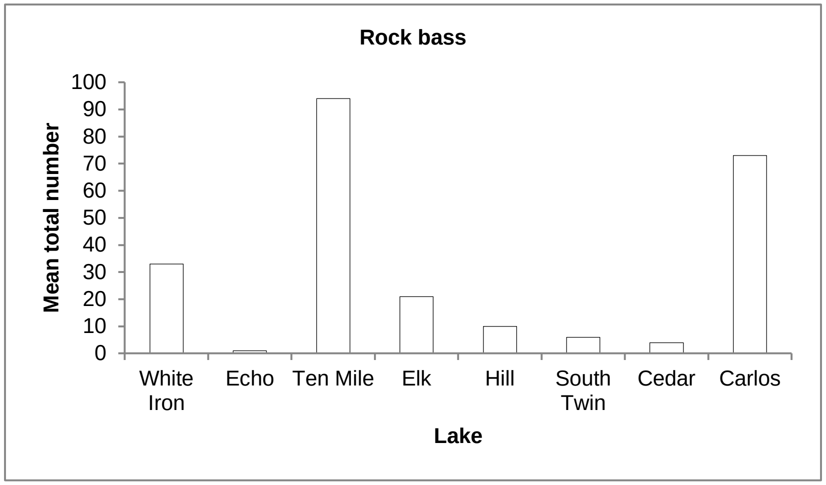
	Age 2		Age 3		Age 4		Age 5	
Lakes	Gill nets	Trap nets	Gill nets	Trap nets	Gill nets	Trap nets	Gill nets	Trap nets
Bear Head				155		201 (17)		230 (1)
Elephant		167		215 (3)		255		272 (8)
White Iron		149		210 (13)		237 (11)		259 (1)
Echo		155 (11)		196 (3)		242 (3)		263 (4)
Ten Mile	137		201 (13)	213 (4)	248	243	281 (1)	270 (1)
Hill	166	159 (7)	213	214 (5)	251 (3)	253 (4)	271 (<1)	262
South Twin		134	180	170 (6)		215 (6)		246 (10)
Red Sand		128 (7)		163 (14)		181 (8)		222 (9)
Portage	155	147 (6)	187	191 (2)	212	213 (2)		231 (9)
Cedar								
Carlos	142 (5)	147 (4)	201 (1)	209 (6)	238 (4)	241 (6)	258 (10)	254 (12)
South Center	153 (2)	159 (6)	184 (3)	189 (6)	223	200 (2)	210 (11)	214 (4)
Pearl	161 (12)	157	193 (12)	200 (9)	198 (29)	227 (1)	230 (19)	224 (11)
Belle	158 (2)	156 (3)	200 (8)	194 (4)	207 (9)	221 (8)	265	246 (25)
Peltier		194 (1)		228 (<1)		230		249
Carrie		134 (10)		182 (18)		196 (15)		199 (17)
St. Olaf		160		178 (5)	193	184 (4)		192 (5)
Madison	170 (2)	179 (3)	209 (5)	210 (6)	232 (4)	236 (4)	274 (13)	258 (6)
St. James		159		207				204
Artichoke	228 (9)	191 (3)	265	256 (11)	300	292 (5)	317	282 (21)

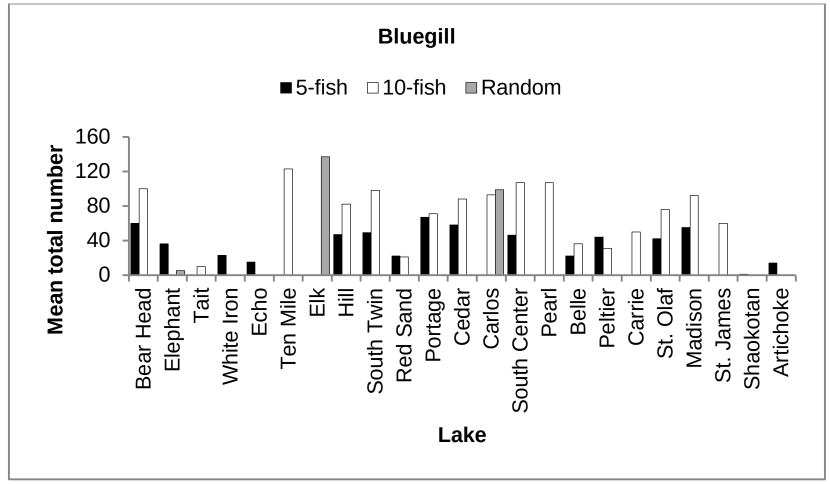
Table 25. Mean (s.e.) back-calculated lengths at ages 1 through 5 of rock bass and bluegill estimated with 5-year olds among sentinel lakes during 2008 through 2011.

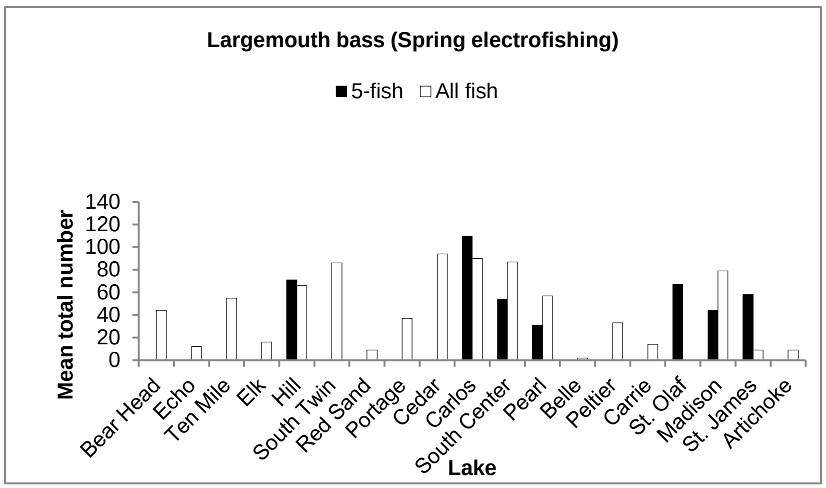
	Age				
Lake	1	2	3	4	5
			Rock bass		
White Iron	50	80	121	161	187
Ten Mile	42 (1)	57 (3)	79 (5)	114 (2)	141 (4)
Elk	40 (<1)	56 (<1)	93 (3)	127 (4)	165 (2)
Hill	42 (3)	61 (10)	93 (21)	120 (19)	158 (9)
Cedar	40	53	83	129	184
Carlos	42 (1)	58 (2)	94 (6)	131 (5)	166 (5)
			Bluegill		
Bear Head	34 (2)	51 (2)	69 (2)	89 (3)	111 (2)
Elephant	36 (2)	58 (6)	93 (7)	133 (12)	161 (9)
Tait					
White Iron	40 (3)	92 (3)	152 (6)	193 (9)	209 (8)
Echo	46	98	152	201	210
Ten Mile	36 (1)	51 (2)	66 (3)	83 (3)	104 (3)
Elk	32 (<1)	47 (1)	67 (4)	89 (7)	121 (7)
Hill	35 (2)	55 (3)	80 (7)	116 (11)	153 (8)
South Twin	34 (1)	45 (3)	58 (3)	78 (3)	107 (4)
Red Sand	42 (5)	65 (13)	88 (19)	134 (36)	171 (34)
Portage	38 (1)	58 (2)	84 (3)	112 (2)	141 (6)
Cedar	33 (1)	43 (2)	57 (3)	76 (3)	101 (4)
Carlos	34 (<1)	43 (<1)	56 (1)	77 (2)	104 (3)
South Center	38 (2)	67 (2)	107 (1)	137 (1)	156 (1)
Pearl	35 (1)	55 (1)	80 (1)	106 (2)	134 (5)
Belle	43 (3)	77 (11)	111 (17)	136 (14)	162 (4)
Peltier	43 (<1)	78 (2)	125 (5)	168 (5)	192 (11)
Carrie	41 (2)	80 (6)	104 (7)	132 (4)	159 (3)
St. Olaf	43 (3)	69 (3)	100 (5)	125 (5)	149 (3)
Madison	40 (2)	82 (5)	128 (8)	160 (7)	182 (4)
St. James	38 (2)	84 (13)	135 (23)	166 (12)	185 (5)
Shaokotan	38	133	205	232	248
Artichoke					

Table 26. Mean (s.e.) back-calculated lengths at ages 1 through 3 of smallmouth bass, largemouth bass, and black crappie estimated with 3-year olds among sentinel lakes during 2008 through 2011.

	Age		
Lake	1	2	3
	Smallmouth bass		
Elephant	78 (4)	119 (10)	148 (14)
White Iron	68	139	210
Echo	86 (7)	159 (9)	238 (4)
Ten Mile	80	171	262
	Largemouth bass		
Bear Head	61 (1)	148 (13)	211 (18)
White Iron			
Echo	88	215	298
Ten Mile	69 (3)	141 (7)	201 (5)
Elk	80 (3)	175 (16)	270 (16)
Hill	80 (4)	168 (9)	244 (12)
South Twin	58	127	204
Red Sand	79 (23)	169 (18)	232 (5)
Portage	74 (4)	176 (4)	258 (7)
Cedar	82 (2)	161 (2)	240 (5)
Carlos	72 (3)	148 (7)	214 (2)
South Center	88 (4)	163 (2)	218 (5)
Pearl	84 (12)	172 (15)	247 (1)
Belle			
Peltier	94 (2)	194 (10)	276 (12)
Carrie	102 (6)	203 (1)	292 (22)
St. Olaf	86 (8)	161 (16)	251 (11)
Madison	85 (2)	175 (11)	259 (10)
St. James	140 (5)	245 (17)	307 (14)
Artichoke	126 (3)	279 (5)	354 (1)
	Black crappie		
Bear Head	65	100	155
Elephant	71 (7)	133 (9)	188 (10)
White Iron	73 (1)	146 (6)	207 (13)
Echo	69	127	179
Ten Mile	59 (1)	110 (4)	179 (7)
Hill	64 (2)	124 (4)	191 (1)
South Twin	54 (1)	97 (8)	154 (11)
Red Sand	68 (1)	111 (10)	156 (15)
Portage	66 (2)	111 (3)	161 (3)
Cedar			
Carlos	56 (1)	101 (3)	173 (2)
South Center	71 (<1)	129 (2)	169 (5)
Pearl	63	108	161
Belle	74 (4)	141 (5)	195 (3)
Peltier	67 (8)	142 (1)	200 (<1)
Carrie	77 (4)	135 (14)	175 (19)
St. Olaf	69 (5)	129 (5)	167 (5)
Madison	73 (1)	135 (5)	193 (5)
St. James	63 (4)	145 (22)	216 (38)
Artichoke	84 (6)	181 (14)	247 (12)







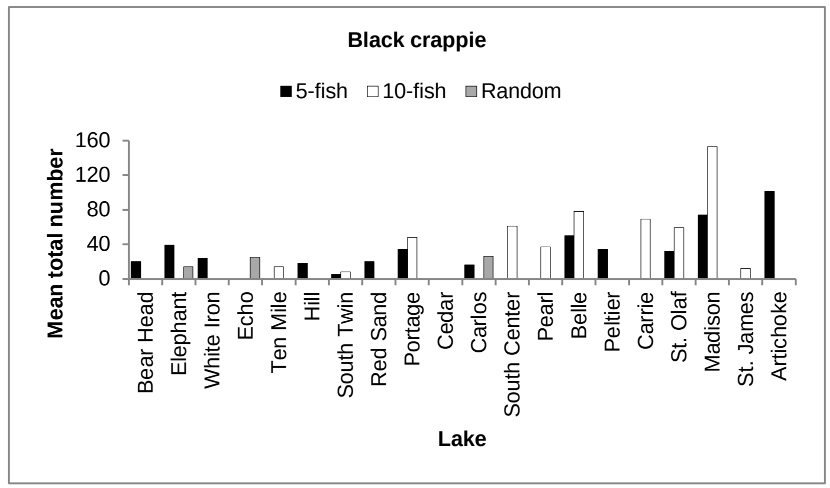


Figure 25. Mean number of rock bass sampled with gill netting and trap netting for age and growth estimates, mean number of bluegill and black crappies sampled with gill netting or trap netting for age and growth estimates using either 5-fish per 1-cm-fixed, 10-fish per 1-cm fixed-, or random-subsampling, and mean number of largemouth bass sampled with electrofishing for age and growth estimates using either 5-fish per 1-cm fixed subsampling or no subsampling (structures collected from all largemouth bass) in 23 sentinel lakes during 2008 through 2011.

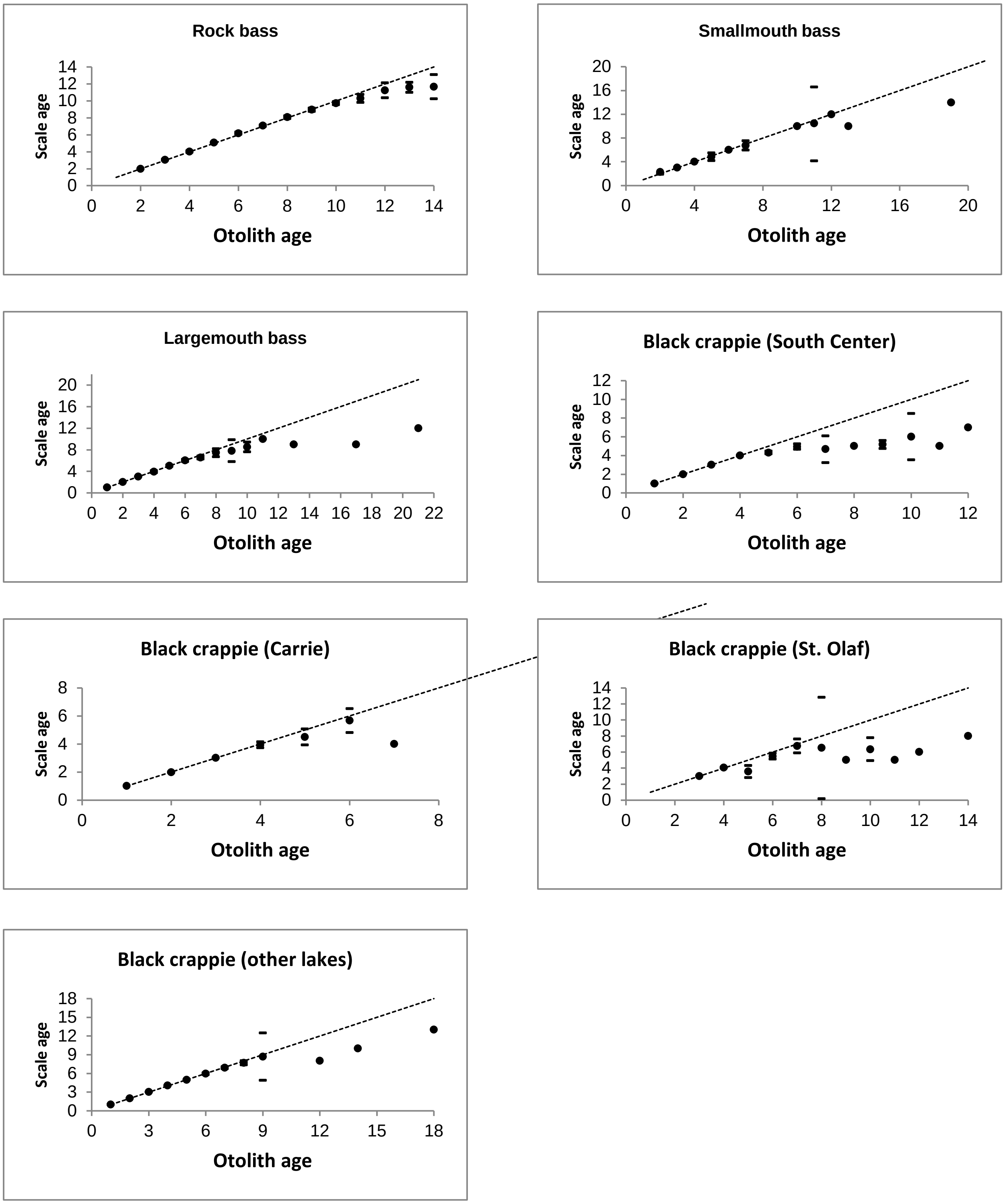


Figure 26. Age-bias plots of scale age estimates as a function of sectioned otolith age estimates of rock bass (all lakes and years combined), smallmouth bass (all lakes and years combined), largemouth bass (all lakes and years combined), black crappie in South Center, Carrie, and St. Olaf lakes, and black crappie in all other lakes and years combined (horizontal bars above and below points depict upper and lower 95% confidence limits).

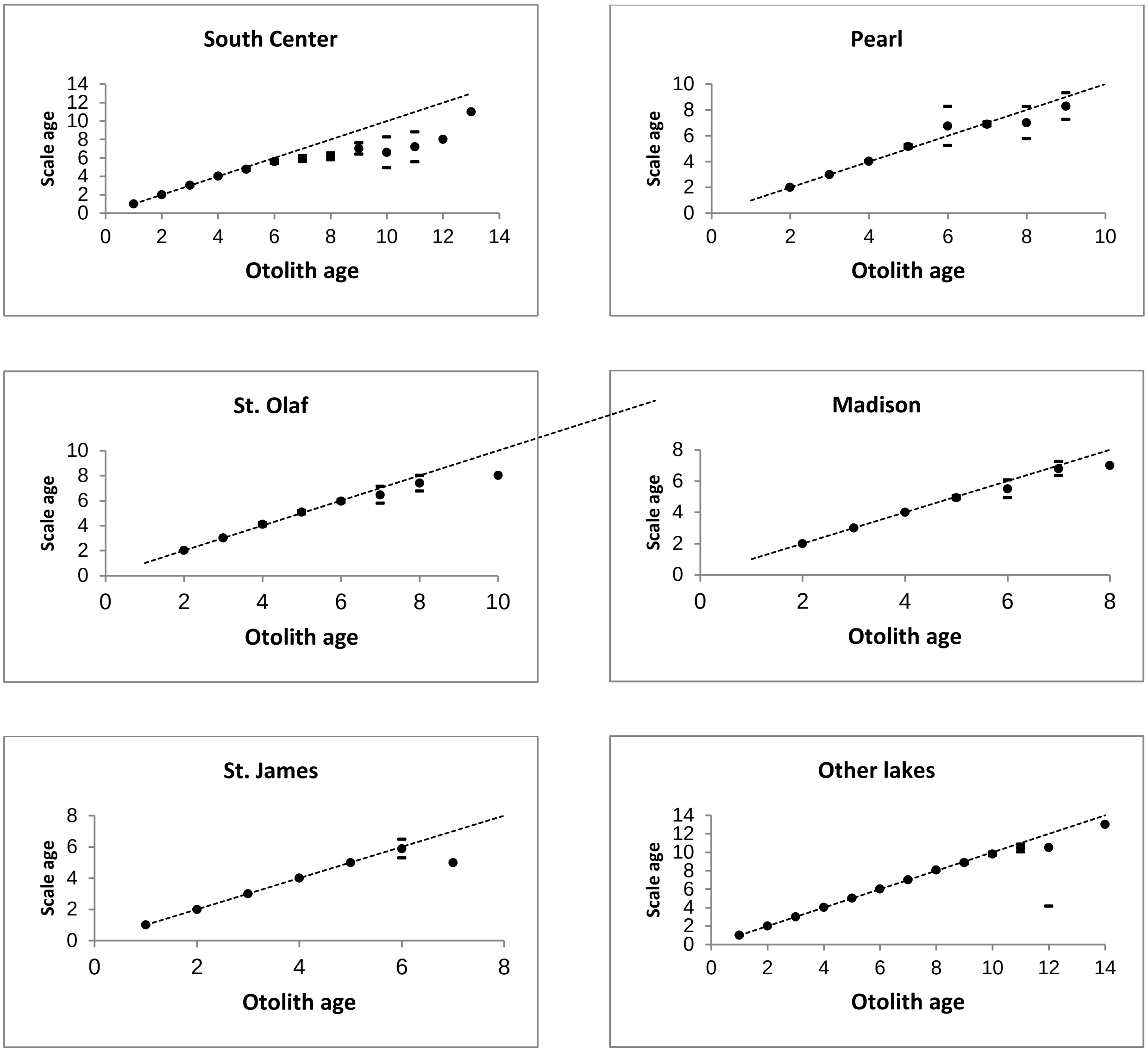


Figure 27. Age-bias plots of scale age estimates as a function of sectioned otolith age estimates of bluegill in South Center, Pearl, St. Olaf, Madison, and St. James lakes, and bluegill in all other lakes and years combined (horizontal bars above and below points depict upper and lower 95% confidence limits).

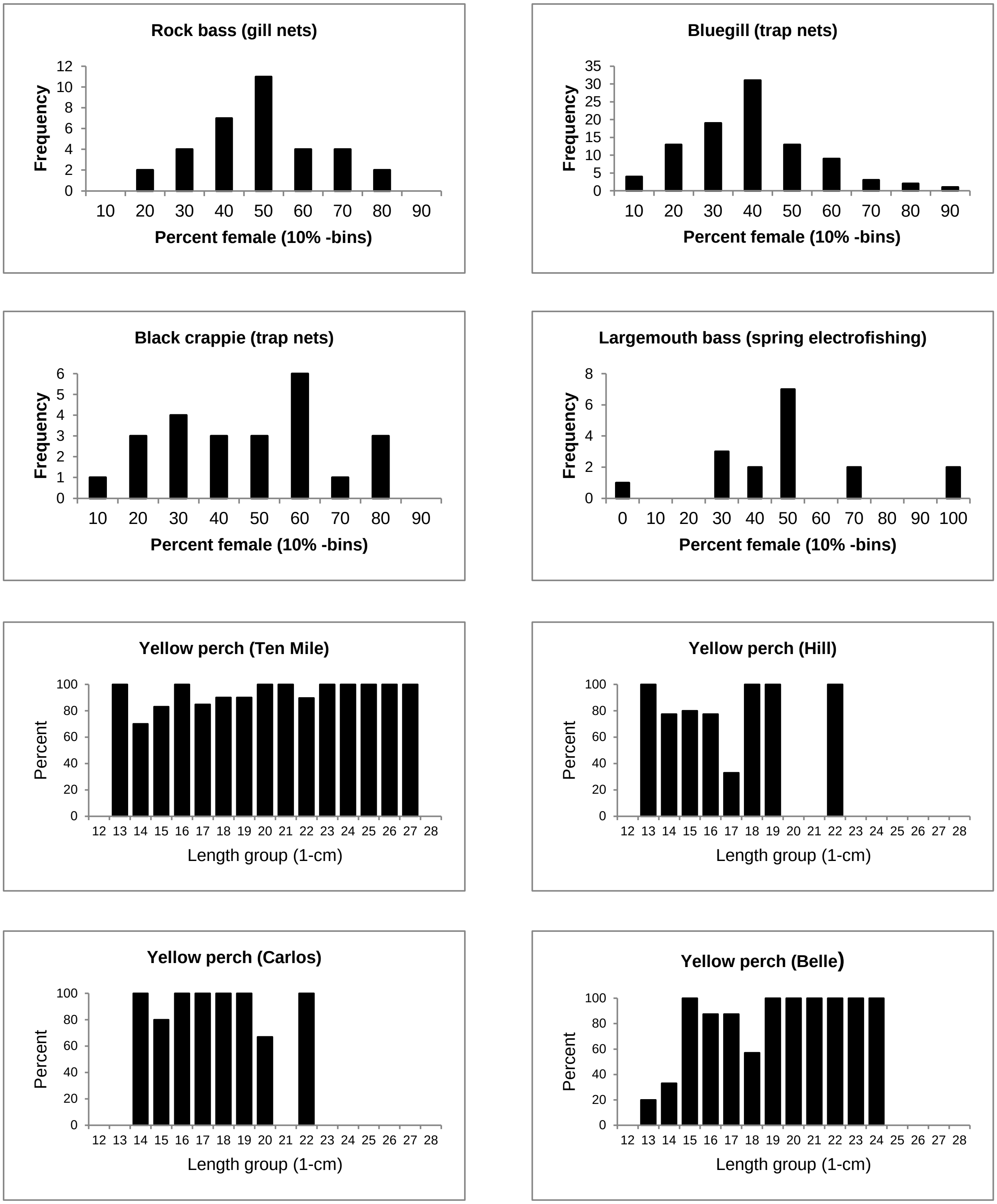


Figure 28. Frequency of age classes with differing percentages (in 10%-bins) of female rock bass caught with gill nets, bluegill and black crappie caught in trap nets, largemouth bass caught with spring electrofishing, and percent female yellow perch in 1-cm length groups in gill nets at Ten Mile, Hill, Carlos, and Belle lakes.

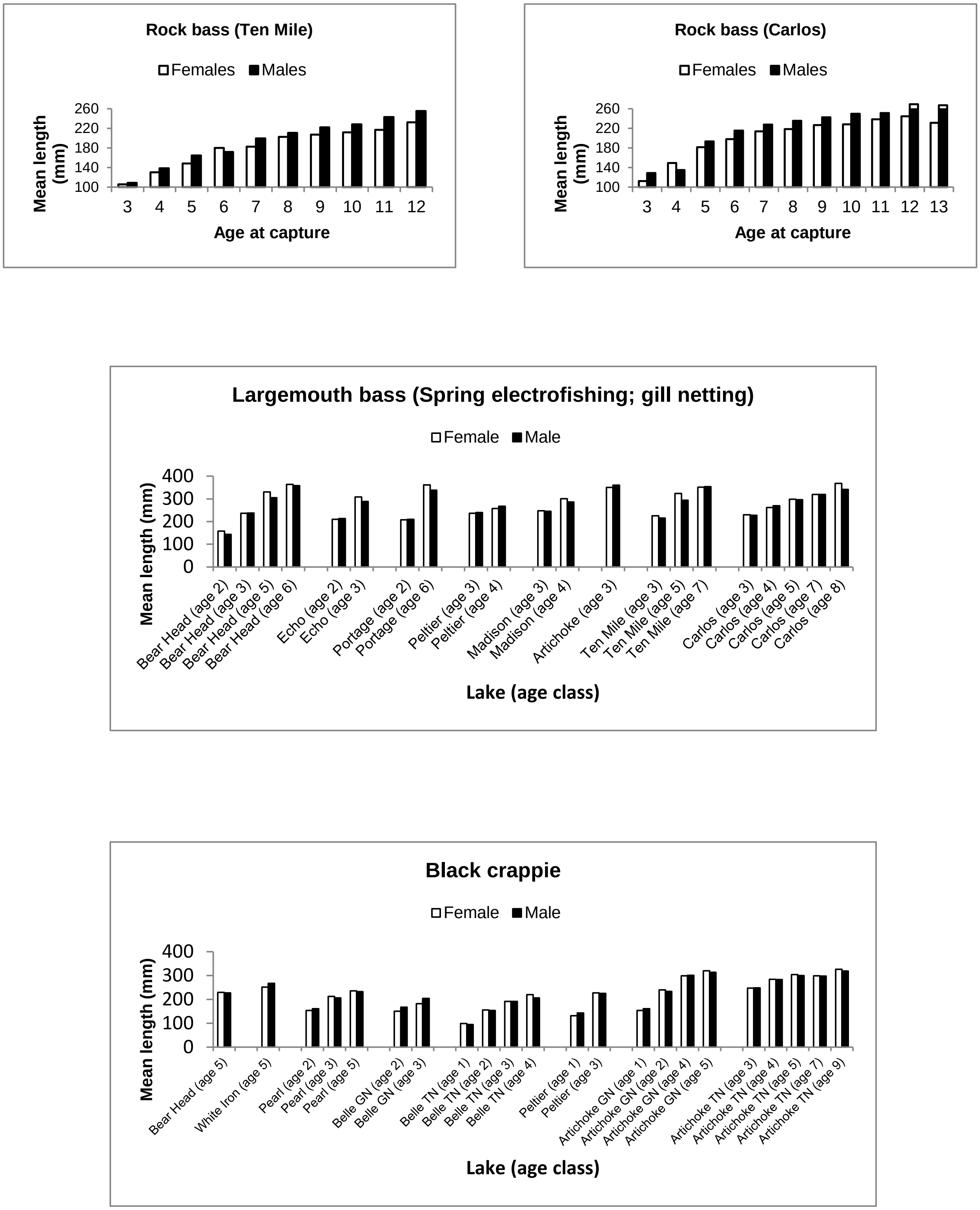


Figure 29. Mean length at capture by age class of male and female rock bass in gill nets at Ten Mile and Carlos lakes, largemouth bass in electrofishing catches in Bear Head, Echo, Portage, Peltier, Madison, and Artichoke lakes, largemouth bass in gill nets at Ten Mile and Carlos, and black crappie in gill nets (GN) and trap nets (TN) at Bear Head, White Iron, Pearl, Belle, Peltier, and Artichoke lakes.

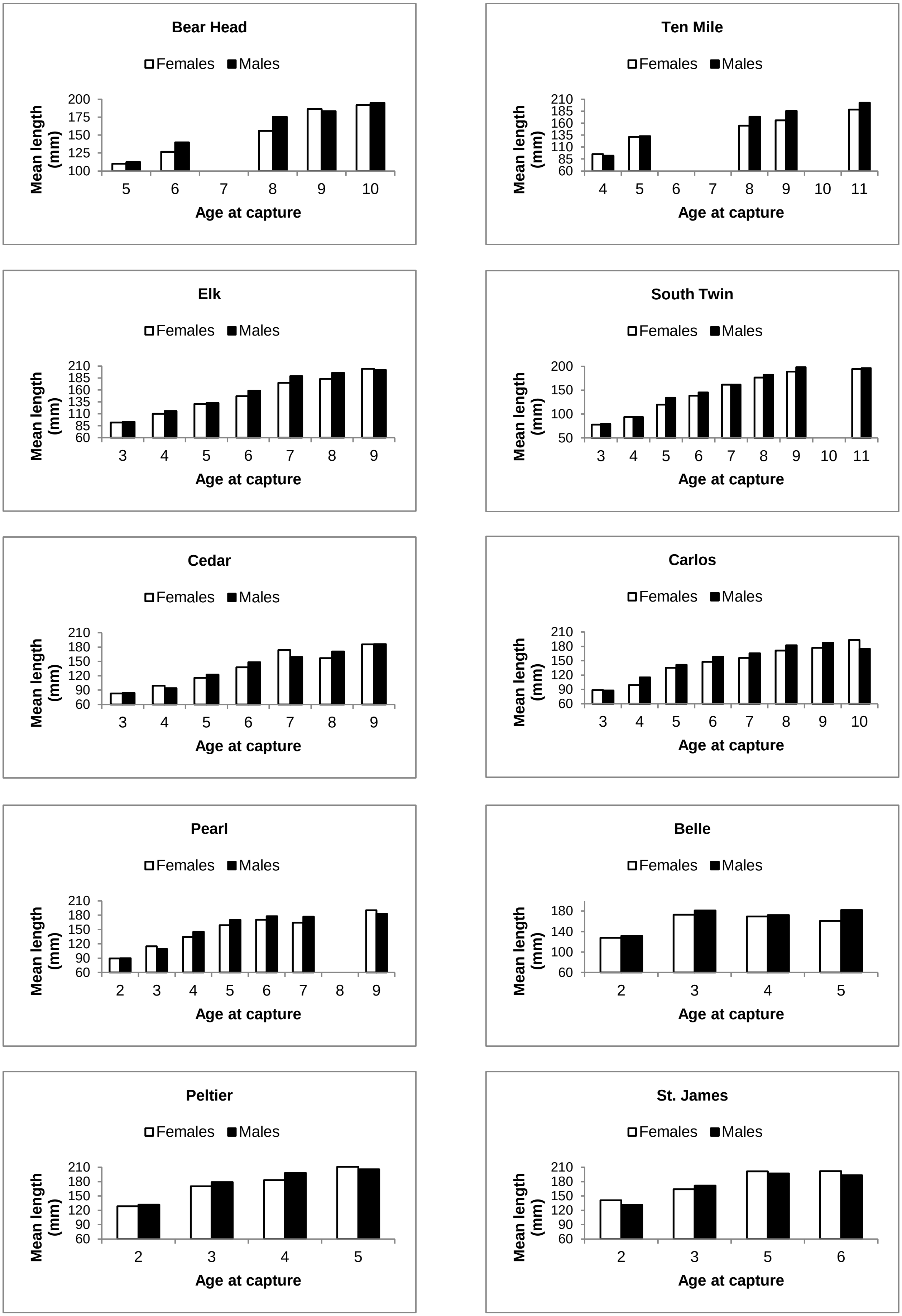
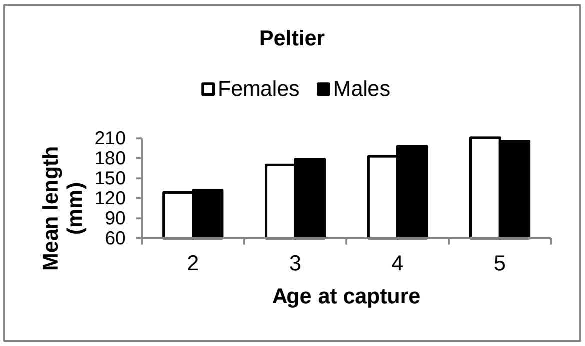


Figure 30. Mean length at capture by age class of male and female bluegill in trap nets at Bear Head, Ten Mile, Elk, South Twin, Cedar, Carlos, Pearl, Belle, Peltier, and St. James lakes. **(Figure 30 continued on next page.)**



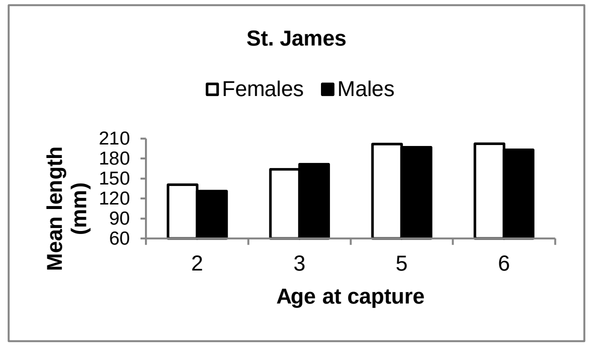
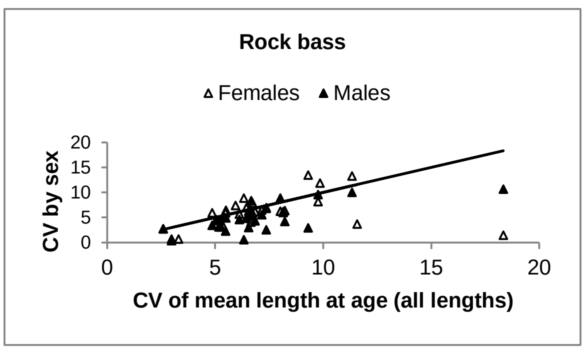


Figure 30. (continued).



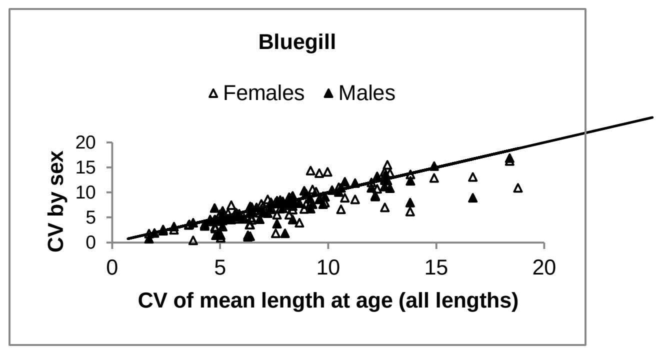


Figure 31. Coefficients of variation of mean length estimates within age classes of male and female rock bass and bluegill as a function of coefficient of variation of both sexes combined; solid diagonal line denotes coefficient of variation of both sexes combined.

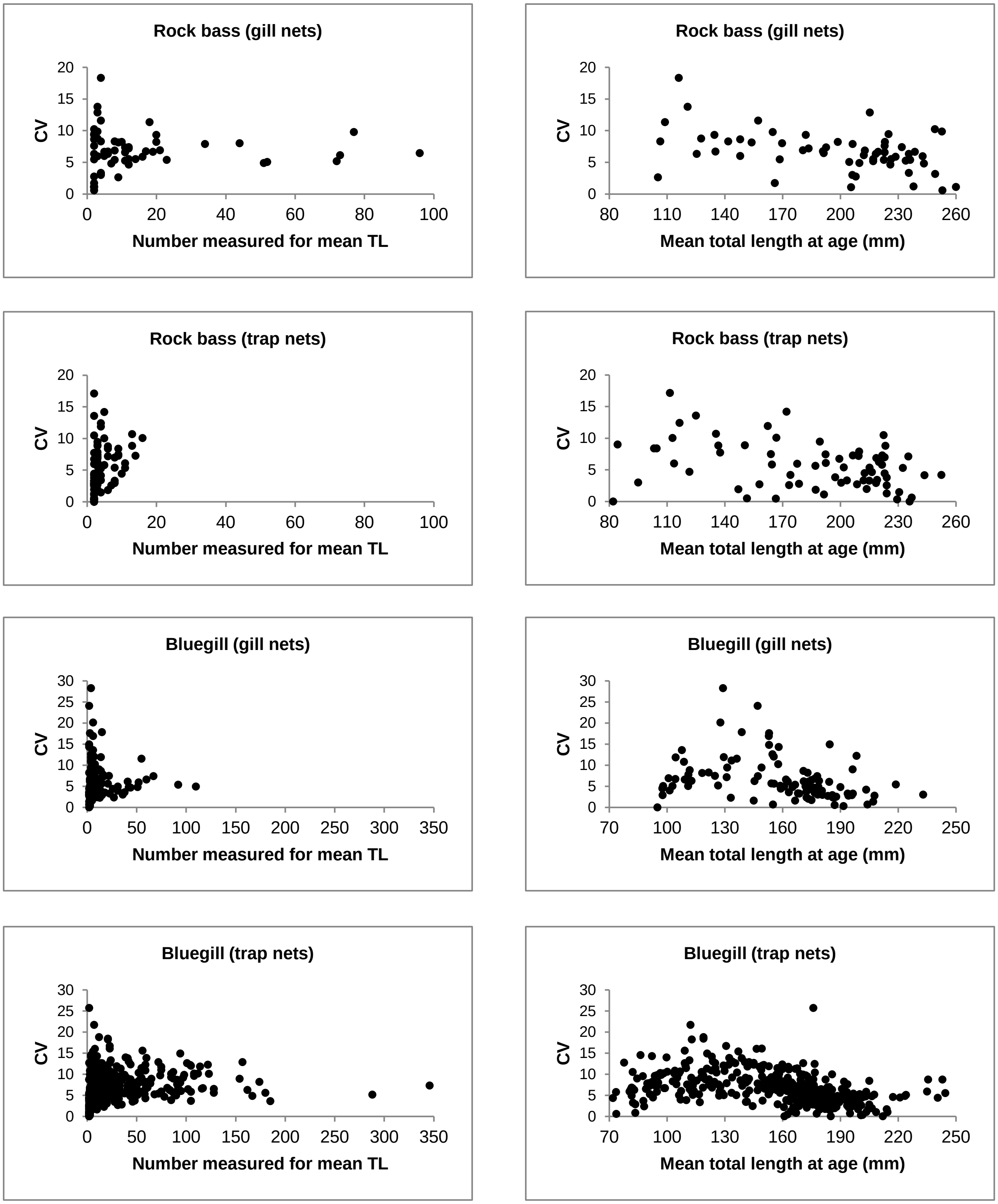


Figure 32. Coefficients of variation of mean total lengths at age at capture per assessment of rock bass, bluegill, black crappie caught with gill nets and trap nets , and smallmouth bass, and largemouth bass caught with spring electrofishing as a function of total number of fish measured and mean total length (all lakes and years combined).

(Figure 32 continued on next page.)

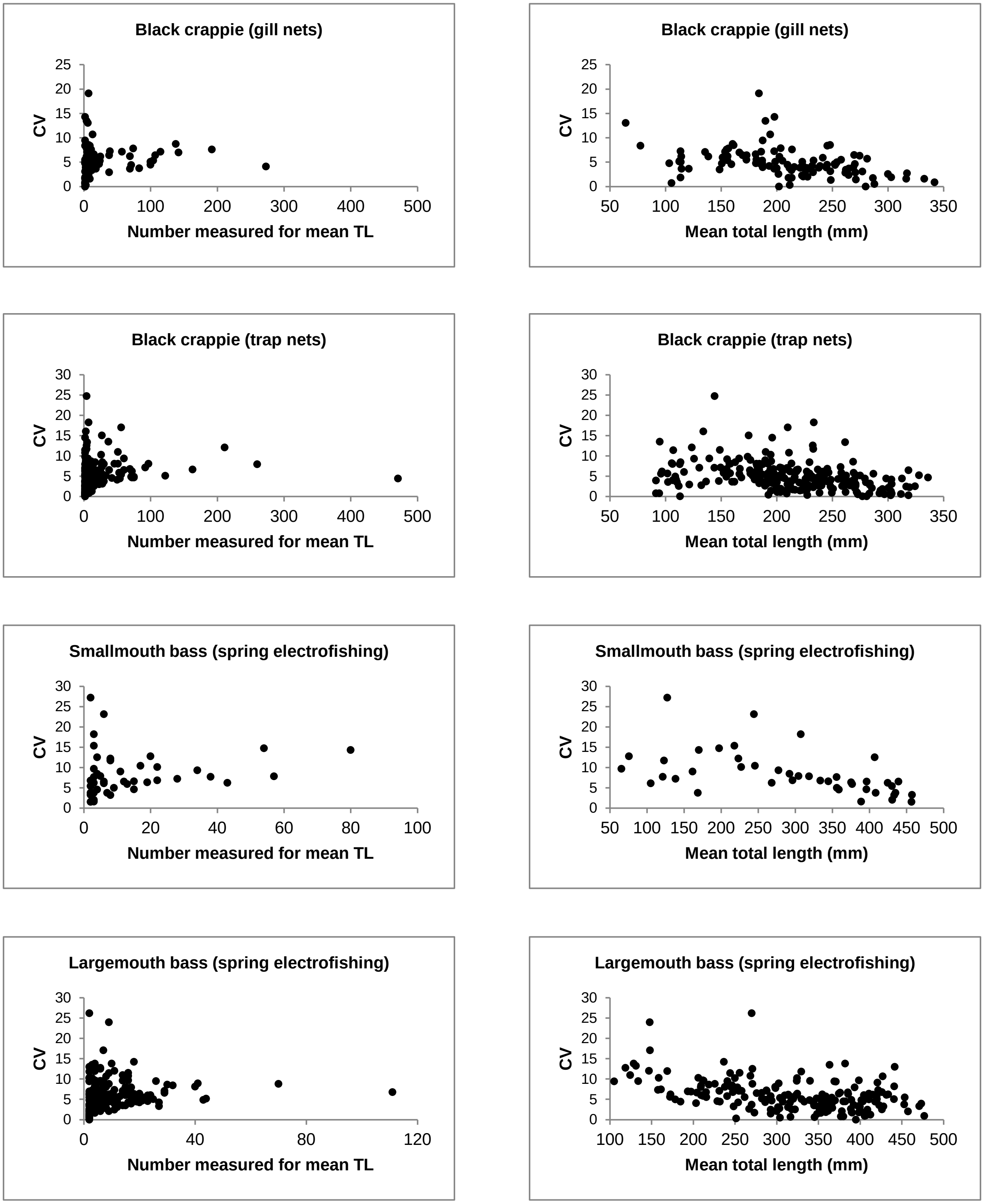


Figure 32. (continued).

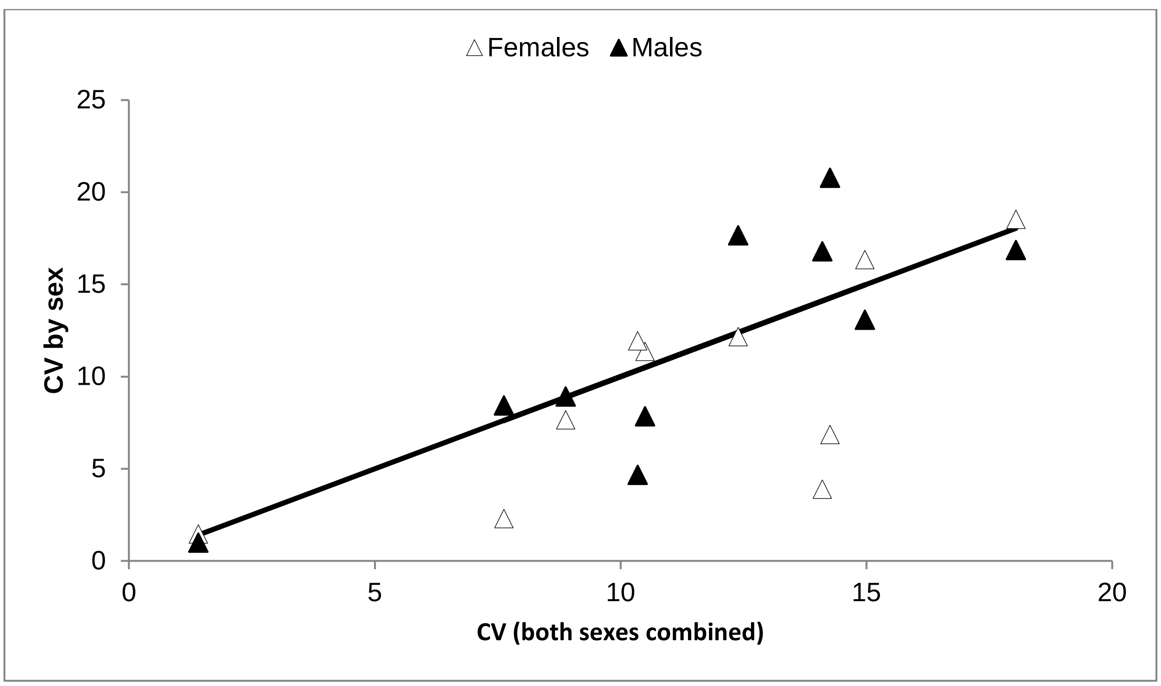


Figure 33. Mean back-calculated length at ages 1 through 5 of female and male rock bass in White Iron, Elk, Hill, and Carlos lakes (scale age $\leq$ 9), and coefficients of variation (CV) of mean back-calculated lengths at age 5 per assessment of female and male rock bass as a function of CV of mean back-calculated lengths at age per assessment for both sexes combined.

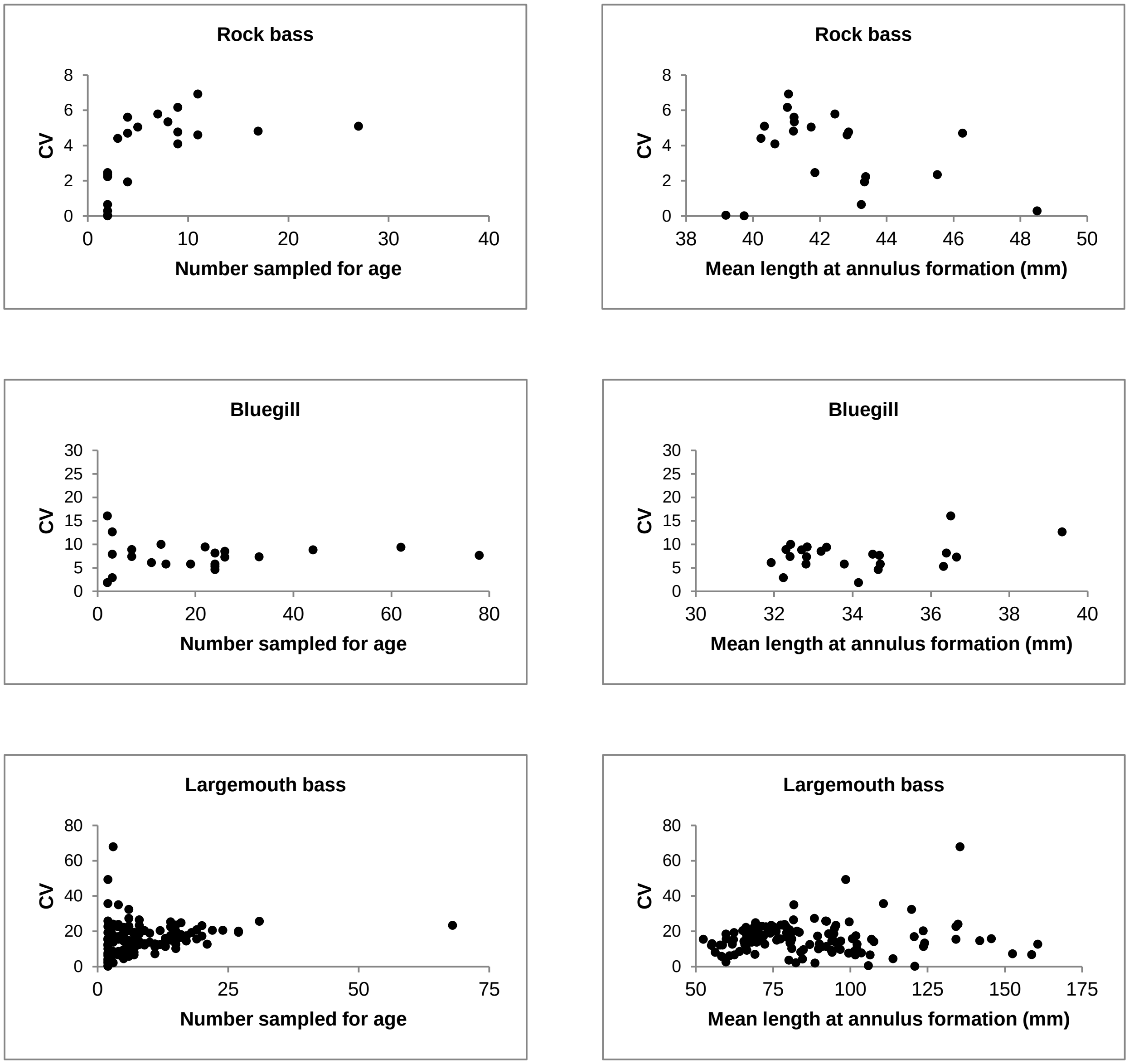


Figure 34. Coefficients of variation (CV) of mean back-calculated lengths at age 1 rock bass per assessment caught with gill nets, age 1 bluegill caught with trap nets, and age 1 largemouth bass caught with spring electrofishing; estimates determined from aging samples (age 9 and younger for rock bass, age 8 and younger for bluegill, age 6 and under for largemouth bass) collected with random subsampling among sentinel lakes.

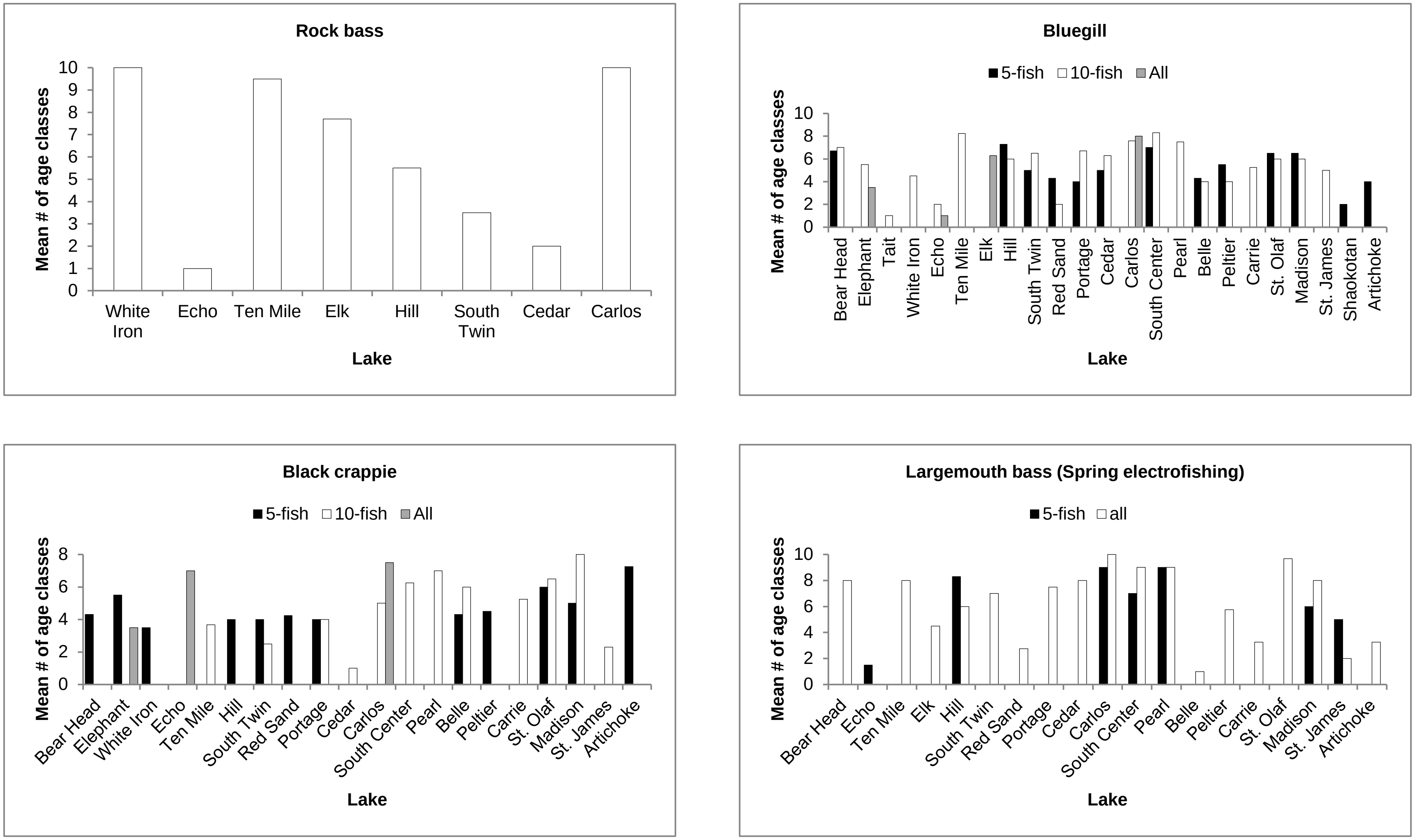


Figure 35. Mean number of age classes of rock bass collected per annual assessment, mean number of age classes of bluegill and black crappie collected per assessment by using either a fixed 5-fish/1-cm length group, a fixed 10-fish/1-cm length group or by removing aging structures from all individuals captured in some nets, and mean number of age classes of largemouth bass collected with the fixed 5-fish/cm method or by collecting aging structures from each bass sampled among 23 sentinel lakes.

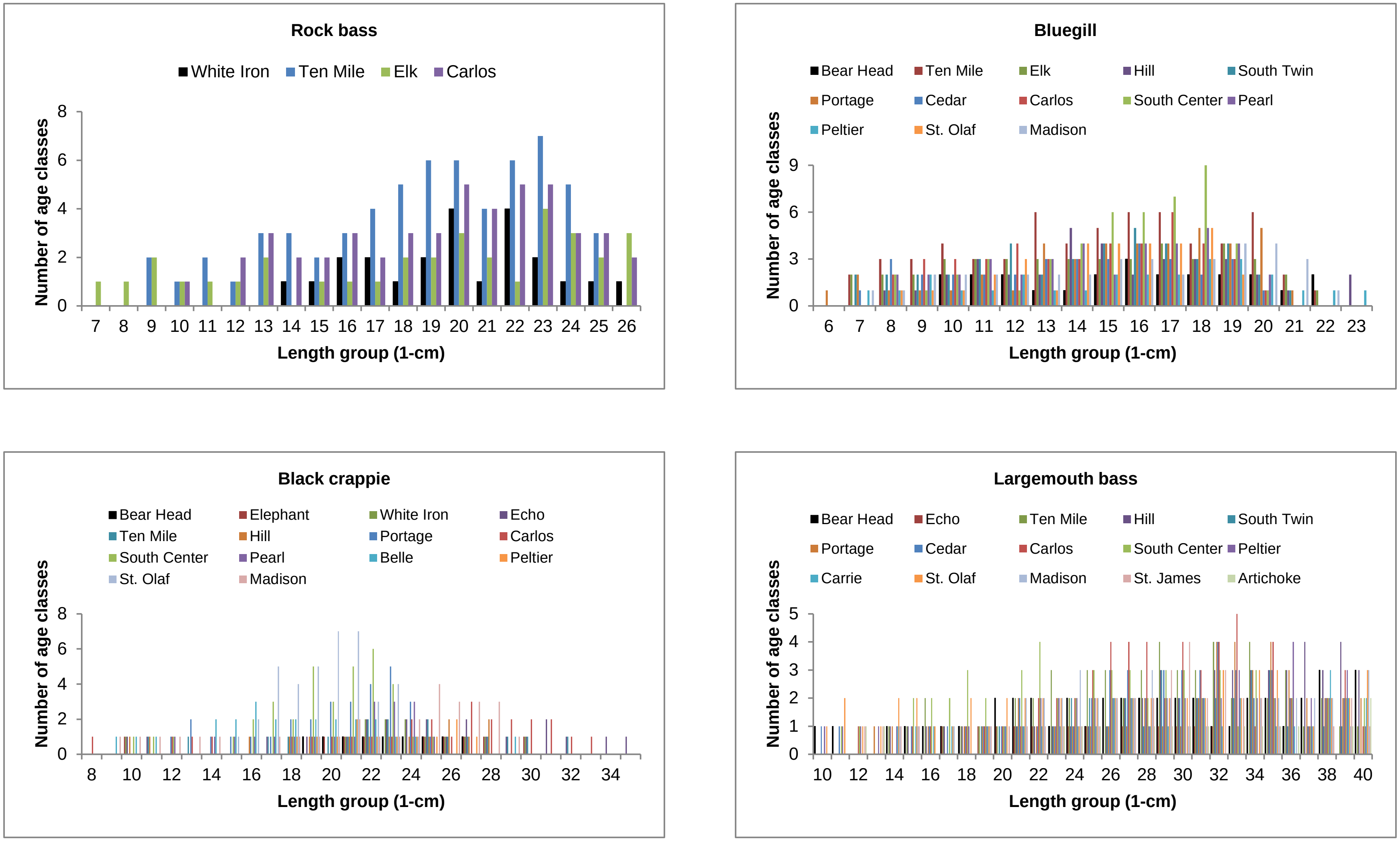
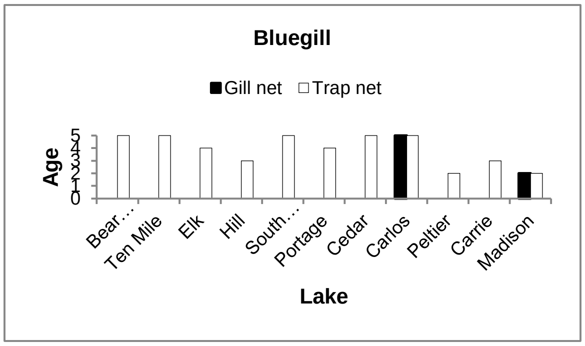
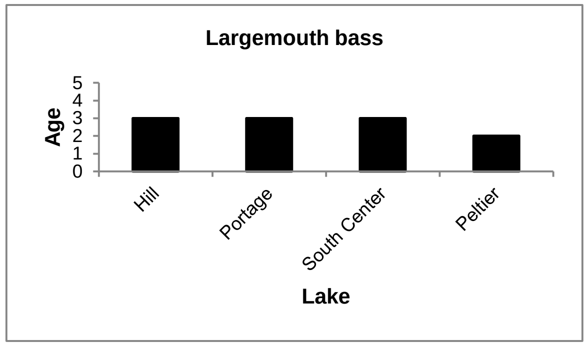


Figure 36. Total number of age classes (estimated with sectioned otoliths) of rock bass, bluegill, and black crappie sampled with either gill netting or trap netting during all assessments from 2008 through 2011, and total number of age classes (estimated with scales) of largemouth bass sampled with boom electrofishing among all assessments from 2008 through 2011 in four to 14 sentinel lakes.





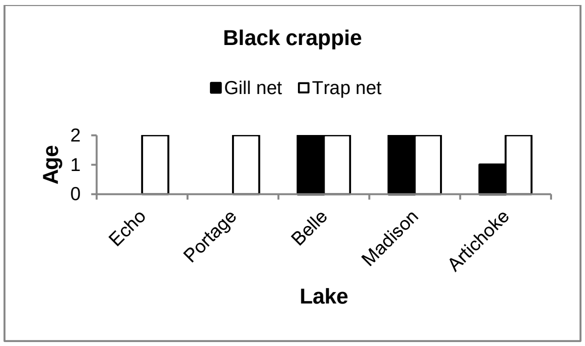


Figure 37. Youngest age of bluegill and black crappie when all lengths of that age class are fully vulnerable to gill netting and trap netting, and youngest age of largemouth bass when all lengths of that age class are fully vulnerable to spring electrofishing in four to 10 sentinel lakes.

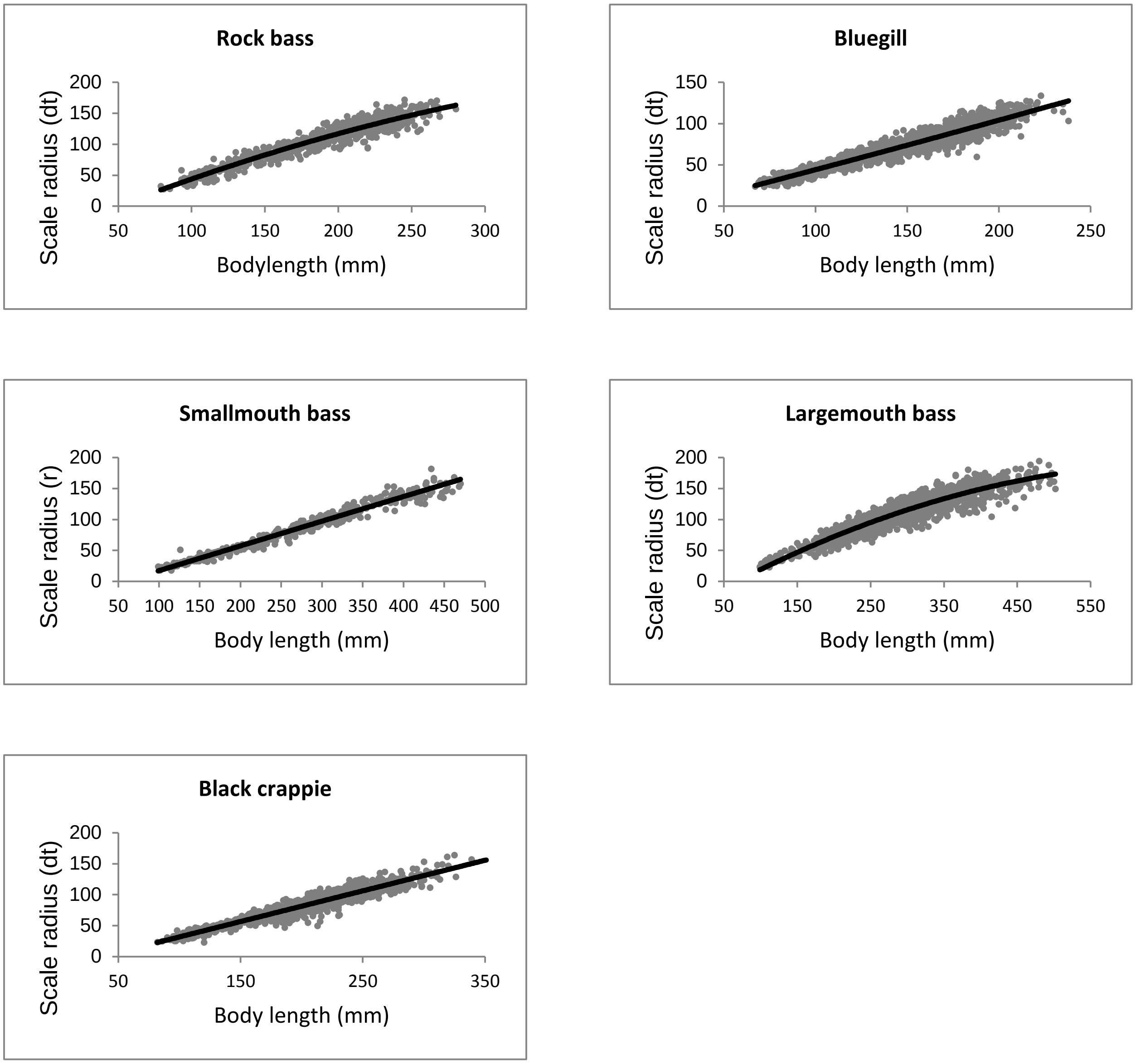


Figure 38. Scale radius measured with either a digitizing tablet (dt) or ruler (r) as a function of fish body length for rock bass, bluegill, smallmouth bass, largemouth bass, and black crappie among all samples of each species collected in 23 sentinel lakes.

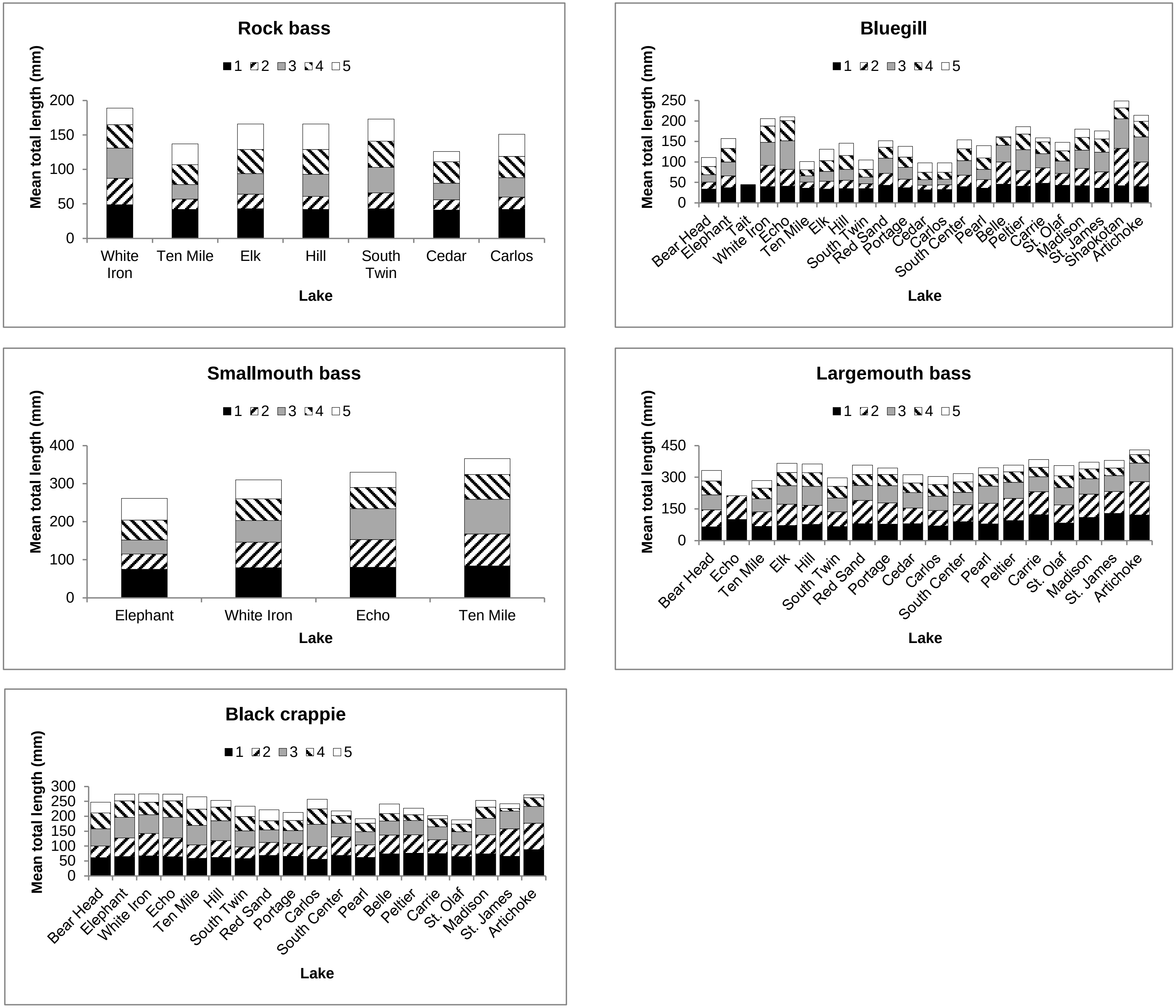


Figure 39. Mean back-calculated lengths at age of rock bass, bluegill, smallmouth bass, largemouth bass, and black crappie among sentinel lakes.

Estimating age and length at maturity with samples collected from gill nets, trap nets, or electrofishing

Assuming sufficient sample sizes, both gill nets and trap nets set during summer capture wide enough length ranges for estimating length or age of maturity of Rock Bass, Bluegill, and Black Crappie. Spring electrofishing captures wide enough length ranges for estimating length and age at maturity of Largemouth Bass. Rock Bass females and males begin maturing at around 150 to 170 mm TL (Figure 40). Female Bluegills begin maturing after reaching 100 to 119 mm, and parental males appear to mature at around 130 to 149 mm (Figure 40). Exceptions include Tait, Elk, and Belle lakes where precocial or early maturing males occur; those males mature at lengths less than 70 mm and gill netting or trap netting seldom capture Bluegills of those lengths (Figure 6 and 13). Female Black Crappies mature at about 130 to 180 cm and males mature at around 130 to 190 cm (Figure 40). Although both gears capture wide enough length ranges of Black Crappies, gill netting should provide better samples because it selects for sizes closer to lengths at which they mature (Figures 6 and 13). Among those examined after capture with spring electrofishing, all female and male Largemouth Bass less than 210 mm were immature and all those longer than 260 mm were mature (Figure 40). Too few Smallmouth Bass were examined to define lengths at which they mature, although all 9 individuals examined between 250 and 300 mm were mature. Gonads of Yellow Perch captured with summer gill nets lacked eggs, ova, or milt; thus, maturity was not estimated.

Uncertainty in estimating maturity of female Rock Bass and Black Crappie, and Bluegill of both sexes was lower in June through early July than from late July through August. Because of it was not clear if gonads were developed, maturity was not assigned for about 5% (3 of 55) of female and 5% (2 of 37) of male Rock Bass examined in June through early July, but maturity was assigned as unknown in 12% (17 of 139) of females (Figure 40). However, similar rates (5%; 2 of 37 in early summer; 5%; 8 of 158 in late summer) of uncertainty occurred for Rock Bass males regardless of time of year. Maturity of Bluegill was categorized as unknown in 11% (36 of 322) of females and 9% (45 of 480) of males examined from samples collected in June and early July compared to 19% (95 of 510) of females and 22% (117 of 544) males from samples collected in late July and August (Figure 40). Maturity was judged as unknown in six of 120 (5%) females examined in early summer and in 16 of 157 (10%) collected from late summer assessments (Figure 40). Conversely, maturity in 15% of male Black Crappie in early summer and 12% of males in late summer were categorized as unknown.

Recommendations:

Lengths at maturity of Rock Bass, Bluegill, Largemouth Bass, and Black Crappie observed during this study are similar to those found in Minnesota and locations of similar latitude (Eddy and Vessel 1941; Carlander 1977; Heidinger 1975). Length at maturity of Smallmouth Bass occurs at around 250 mm (Coble 1975; Shuter and Ridgway 2002), similar to the few observed in this study.

Gears capable of capturing Yellow Perch 50 to 100 mm will be needed in order to estimate age or length at maturity of this species. Males as short as 60 mm and females as short as 80 mm TL begin maturing (Jansen 1996); lengths much shorter than those caught with standard gill netting or trap netting (> 90 to 120 mm; Figures 6 and 13). Yellow Perch are often spawning when ice-out netting for northern pike occurs, and gonads become developed in late September the prior year (Jansen 1996); therefore this sampling should occur soon after ice-out in spring or in late September. Electrofishing and small-mesh trap nets (0.6-cm bar webbing) sample smaller Yellow Perch. Although electrofishing captured yellow perch 60 to 180 mm in six south central Minnesota lakes (McInerny and Cross 2004), small mesh trap nets might be the preferred gear because Yellow Perch as short as 40 mm were caught in this study (Figure 41). .

Although summer trap netting and gill netting capture sufficient length ranges for estimation of maturity metrics, guidelines with criteria for determining maturity could be beneficial in order to increase the correct identification of sex and maturity of fish being examined.

The following protocols should be used to collect samples for estimating age and length at maturity of Rock Bass, Bluegill, Largemouth Bass, Smallmouth Bass, and Black Crappie. Up to 10 Rock Bass per 1-cm length group between 120 and 200 mm, Bluegill 90 to 180 mm, Smallmouth Bass 180 to 280 mm, Largemouth Bass 200 to 300 mm, and Black Crappie 120 to 200 mm should be sacrificed and gonads examined for maturity. If age at maturity is to be estimated, additional samples per length category in lakes with high numbers of age classes per 1-cm length group will likely be required to ensure an adequate age sample. Because data are currently lacking, up to 10 Yellow Perch per 1-cm length group from 50 to 200 mm from sampling in either early spring soon after ice-out or in late September should be sacrificed and gonads examined for maturity. Furthermore, otoliths should be removed from these individuals so that age can be estimated.

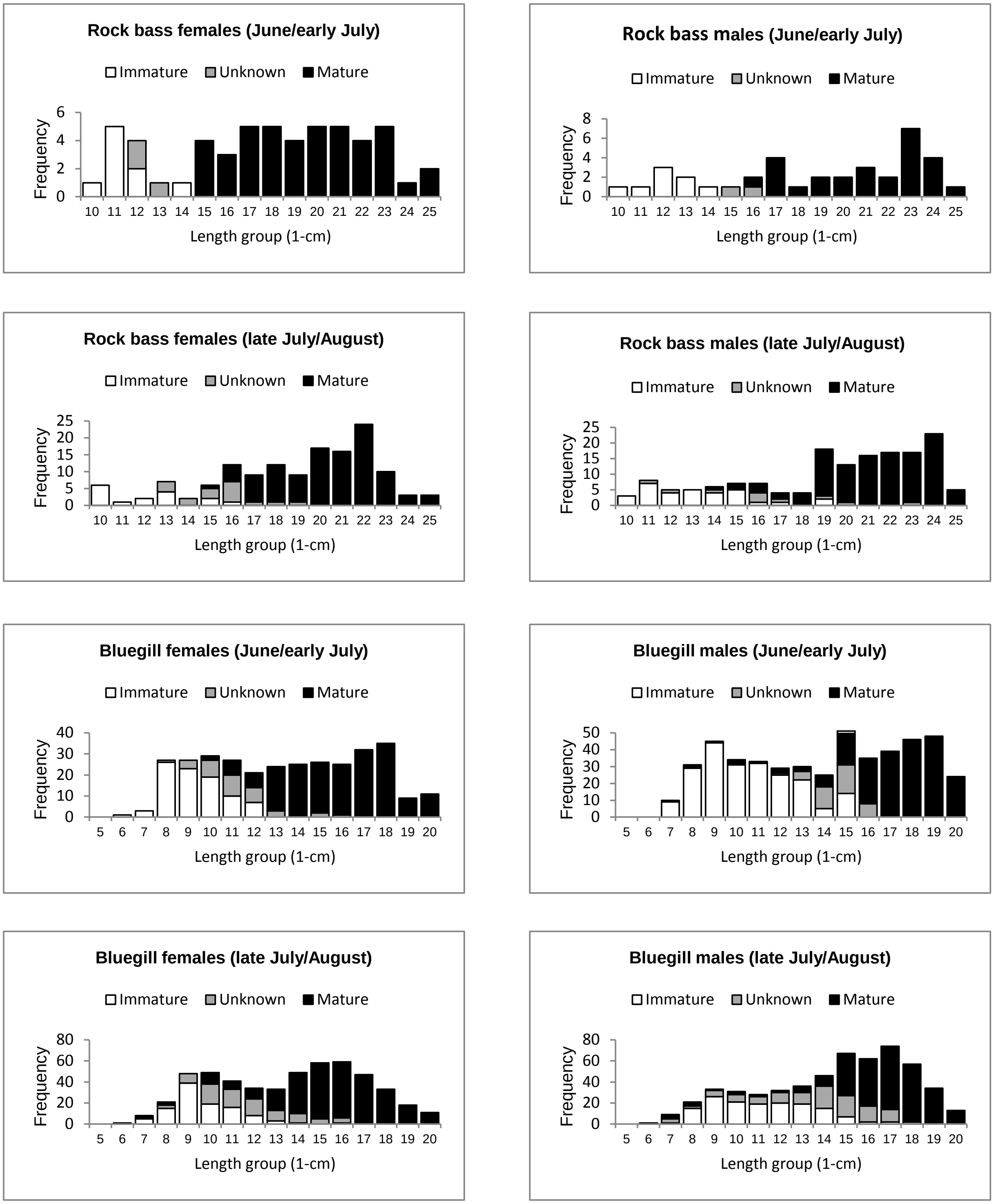


Figure 40. Frequency of immature, mature, and unknown maturity rock bass, bluegill, and black crappie captured with gill nets or trap nets, and frequency of immature, mature, and unknown maturity of largemouth bass caught with spring electrofishing in sentinel lakes (all lakes and gear combined).

(Figure 40 continued on next page.)

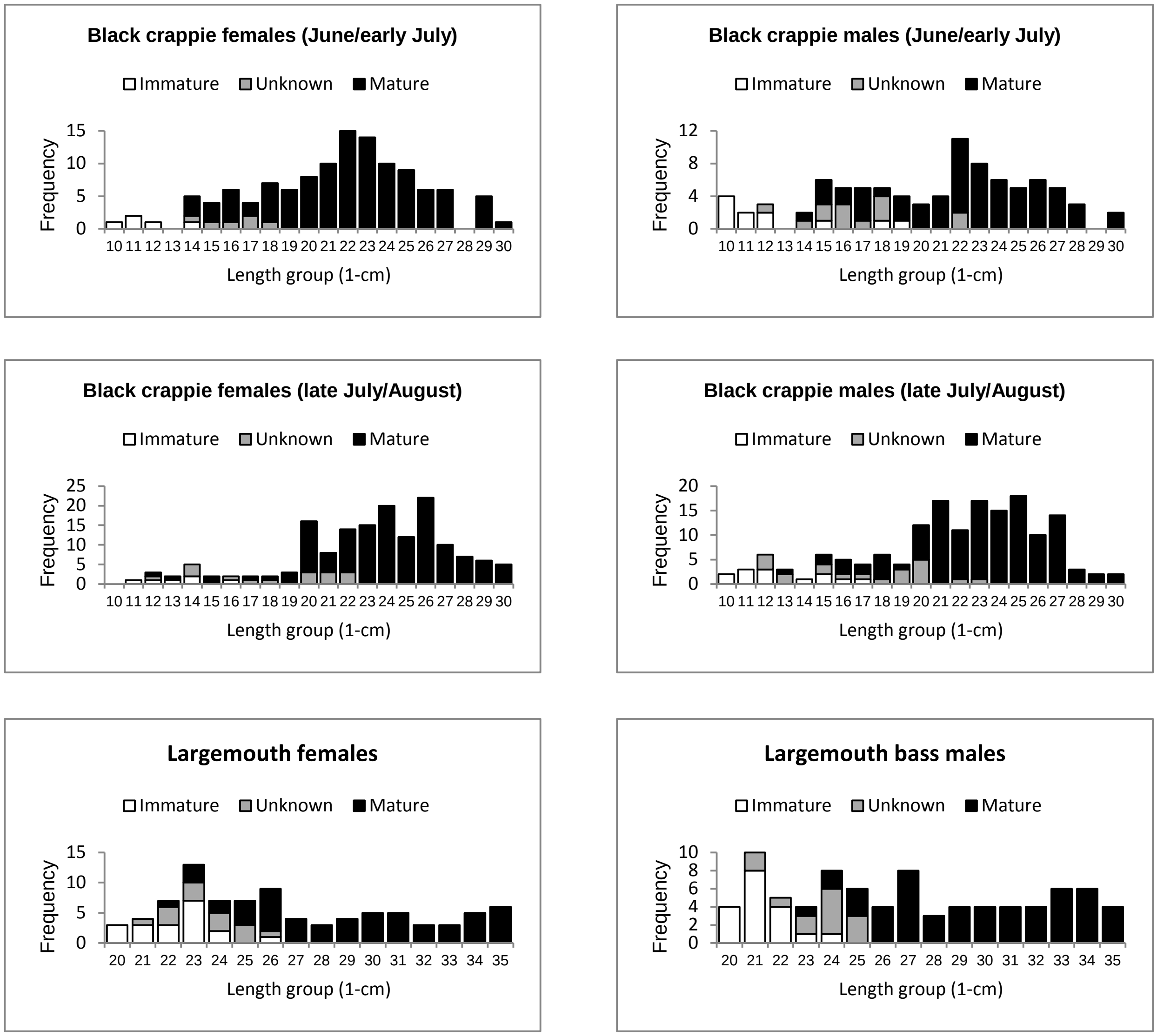


Figure 40. (continued).

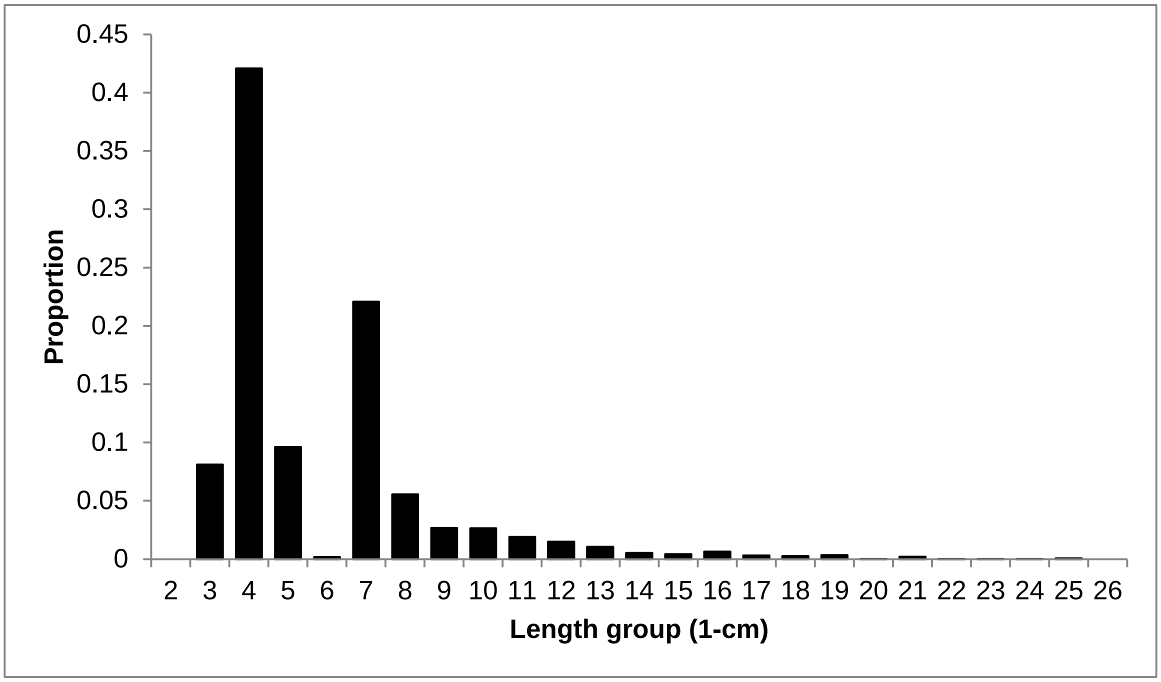


Figure 41. Mean (all lakes and years combined) proportion by 1-cm length groups of yellow perch caught in 0.6-cm bar mesh trap nets.

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APPENDIX -A-

SENTINEL LAKES FISH SAMPLING PROPOSAL - PHASE 2[1]

This sampling proposal is designed to quantify lake ecology and associated fish population responses to known or potential environmental stressors. These stressors include but are not limited to global climate change, landscape-level changes in land use, lakeshore development, concentrations of pollutants, introductions and expansions of non-native species, changes in angler demographics, and fisheries management. Other global or regional stochastic events such as large volcanic eruptions, drought/wet periods, and annual weather are likely to affect the ecology of Minnesota's lakes and fish populations as well.

Global climate change is expected to affect fish populations in Minnesota lakes via increases in water temperature, shorter ice cover periods and longer growing seasons, and reduced quantities of oxythermal habitat caused by longer periods of summer thermal stratification are expected. Examination of lake ice out and ice-on dates across Minnesota lakes suggests a recent climate warming event beginning in 1990 (Johnson and Stefan 2006). A doubling in atmospheric concentrations of carbon dioxide (CO_2) is predicted to cause decreases in suitable oxythermal habitat for Minnesota's cold water fish species in all but the deepest oligotrophic lakes (Stefan et al. 1995; Stefan et al. 1996). Conversely, as suitable thermal habitat increases, warmwater and coolwater fish species are predicted to benefit from a warming climate. Exceptions for coolwater species include for small (< 400 ha) eutrophic lakes with moderate depths (5-20 m deep), eutrophic lakes deeper than 20 m, and mesotrophic lakes between 400 and 5,000 ha in southern Minnesota (Stefan et al. 1995; Stefan et al. 1996). Changes in water temperatures and increased growing seasons will likely affect recruitment, growth, and mortality of fish species in Minnesota lakes (Pauly 1980; Griffiths and Harrod 2007).

Changing land use has altered nutrient loading in Minnesota lakes although it is expected that these alterations will mainly affect fish populations and lakes in central and southern Minnesota. Since pre-European settlement, increases in agriculture and urbanization have resulted in increased nutrient loading and chloride from road salt in lakes within the Central Hardwood Forest and Western Cornbelt Plains ecoregions, resulting in degraded water quality (Ramstack et al. 2004). This is contrasted by areas with relatively low landscape development, mainly the Northern Lakes and Forests ecoregion where little change in water quality has occurred since the 1750's (Ramstack et al. 2004). Water clarity trends across the state, as measured by Secchi disk readings, demonstrate that 37% of 806 regularly monitored lakes have trended clearer, 16% have trended more turbid, and the remainder did not change since the early 1970's (Citizens Lake Monitoring program, Minnesota Pollution Control Agency, unpublished data; T.K. Cross, personal communication). Secchi disk readings are strongly and inversely correlated with total phosphorus concentrations. Declines in production, commercial or recreational harvest, or in catch per effort (CPUE) in surveys of fishes occurred following reduced nutrient loading, but increases in abundance of fish intolerant to eutrophication also occurred (Downing et al. 1990; Ludsin et al. 2001; Jeppesen et al. 2005). Similar changes are expected to occur in Minnesota lakes.

Alterations in nearshore habitat also have increased, and oftentimes linked to decreases in fish habitat and changes in fish populations. The number of seasonal cabins and homes along lakeshores increased six-fold from the 1950's through the 1990's in class 23 lakes in Minnesota, and about two-thirds of nearshore emergent and floating leaf vegetation was lost per development in these lakes (Radomski and Goeman 2001). Similarly, density of coarse

[1] These sampling protocols were developed by the Fish Sampling Advisory Team during meetings held in 2012 and 2013. The advisory team consisted of Mike McInerny, Lead, Fisheries Research Scientist, Jacquelyn Bacigalupi, IBI Program Coordinator; Ryan Doorenbos, Windom Area Supervisor; Tom Heinrich, Large Lake Specialist; Nate Hodgins, Windom Assistant Area Supervisor; Beth Holbrook, Fisheries Research Biologist; John Hoxmeier, Fisheries Research Scientist; Steve Persons, Grand Marais Area Supervisor; Doug Schultz, Walker Areas Supervisor; Deb Sewell, Hinckley Assistant Areas Supervisor; Dave Staples, Fisheries Biometrician; and Melissa Treml, Fisheries Research Manager. While many of the recommendations are being implemented into ongoing Sentinel Lakes sampling, limitations of time, staffing, and funding will limit the implementation of others.

woody habitat, emergent vegetation, and floating vegetation all increased as shoreline development decreased among Wisconsin lakes (Christensen et al. 1996; Jennings et al. 2001). Among five lakes in northern Wisconsin, several fish species were linked to specific nearshore habitats during spring, summer, and fall, and residential development altered spatial distribution patterns of fishes in Wisconsin lakes (Hatzenbeler et al. 2000; Scheuerell and Schindler 2004). Conversely, littoral fish species assemblages, mostly cyprinids, based on minnow trap catches did not change following extensive logging near shores of three lakes in northwest Ontario (Steedman 2003).

Nationwide or global changes in pollutant discharges, such as sulfur dioxide and organochloride pesticides, can affect fish populations in Minnesota. Declines in pH in some lakes coincided with sulfur dioxide emissions from coal burning; declines in fish populations, including lake trout, yellow perch, and walleye, occurred in many of these waters (Harvey and Lee 1982). Population explosions of double-crested cormorants throughout North America followed the ban of organochloride pesticides. For example, numbers of nesting cormorants near the Lake of the Woods increased exponentially from the mid 1970's through 1989 but stabilized after that (Heinrich 2008). Double-crested cormorants feed opportunistically on a wide range of fish species, and localized declines in some of these species occurred when cormorant densities were high (Craven and Lev 1987; Johnson et al. 2002; Rudstam et al. 2004; Fielder 2010; Door et al. 2012; DeBruyne et al. 2013; D. Schultz, MNDNR, personal communication).

Introductions of non-native aquatic species have affected fish populations in Minnesota lakes; it is likely that new introductions will occur in Minnesota waters. At least 52 fish species have been either introduced intentionally or unintentionally to Minnesota waters. This list includes foreign species such as Brown Trout and Common Carp, those native to Minnesota but either stocked to provide angling opportunities or expanded range via habitat alterations e.g., Walleye or Largemouth Bass, and those species native to North America but not Minnesota, e.g. Rainbow Trout and Chinook Salmon (Fuller et al. 1999; Minnesota Department of Natural Resources unpublished data). Non-fish species include aquatic plants such as Eurasian watermilfoil, Brazilian elodea, brittle naiad, flowering rush, mussels and snails such as faucet snail, zebra mussel, New Zealand mudsnail and zooplankton such as *Bythotrephes longimanus* and *Daphnia lumholtzi*. Diseases including viral hemorrhagic septicemia (VHS) have also been found in waters near Minnesota.

Regardless of intentional or not, the introduction of new species to Minnesota waters have had serious consequences. For example, the effects of intentional introductions of Northern Pike ranged from negligible to causing declines in the abundances of Yellow Perch, Largemouth Bass, Walleye, and Pumpkinseed and increases in Bluegill abundance (Anderson and Schupp 1986; MNDNR unpublished data). Intentional introductions of Walleye caused no detectable change in fish populations in some lakes, whereas declines in Yellow Perch abundance and depressed recruitment of Walleye cohorts in both previous and following stocking events were noted in other lakes (Goeman et al. 1990; Li et al. 1996a; 1996b; Pierce et al. 2006). Following the intentional introduction of Channel Catfish, the abundance of Black Bullhead declined in four of six southern Minnesota lakes (Schultz 2008). Invasions of Rainbow Smelt led to increased growth in Lake Trout, but declines in year class strengths of Walleye in Minnesota and Wisconsin lakes (Hassinger and Close 1984; Mercado-Silva et al. 2007). Similarly, black bass invasions caused decreased growth in Lake Trout and altered habitat use of, reduced abundance of, or extirpated small-bodied fishes (MacRae and Jackson 2001; Jackson 2002; Vander Zanden et al. 2004). Conversely, Muskellunge introductions had negligible effects on Northern Pike, Cisco, White Sucker, Bluegill, Black Crappie, Walleye, and Yellow Perch in Minnesota lakes (Knapp et al. 2011).

Other, non-fish invasive species also will likely affect fish populations and lake ecology in Minnesota lakes. For example, water clarity in four Ontario lakes increased following reductions of total phosphorus loading coupled with invasions of zebra mussels (Robillard and Fox 2006). Furthermore, nearly all of Minnesota's game fishes are susceptible to VHS, currently found in the Great Lakes, which has caused kills of Yellow Perch, Smallmouth Bass, Black Crappie, and Bluegills in waters outside of Minnesota (Riley et al. 2008; Kim and Faisal 2010).

Numbers of licensed anglers and overall fishing pressure increased between the 1950's and 1990's in Minnesota, and, despite changes in statewide creel limits over time, declines in catches in quality sized fish, size structure, and age at maturity occurred in many game fishes in Minnesota (Olson and Cunningham 1989; Cook and Younk 1998; MNDNR unpublished data). Harvest and angling pressure has shown greater rates of increase during winter, and winter anglers keep smaller fish (Cook and Younk 1998; Schultz and Vondra 2011). Furthermore, angling pressure is greatest in the seven counties surrounding Minneapolis; thus, these fisheries appear most vulnerable to the effects of overfishing if increases in angling pressure continue (Cook and Younk 1998; Post et al. 2002). In response to these changes in angler demographics and an overall decline in fish quality, harvest regulations have become more restrictive in recent years, and more individual lake management now occurs in Minnesota. Statewide creel limits have changed (usually lowered) one to four times per game species since 1922, and at least 240 Minnesota lakes now have a creel limit and/or a length-based harvest limit more restrictive than statewide harvest regulations for at least one game fish species (Cook et al. 2001; L.E. Erickson, MNDNR, personal communication). When applied to appropriate populations, restrictive length limits (minimum, maximum, or protected slots) have the potential to improve catch rates, yields, and size structure (Colvin and Vasey 1986; Munger and Kraal 1997; Newman and Hoff 2000); however they can also alter angler behavior, causing anglers to fish elsewhere (Fayram and Schmalz 2006).

Finally, large- or small-scale stochastic events also affect fish populations. For example, weak year-classes of Bluegill, Smallmouth Bass, Largemouth Bass, and Walleye in 1992 and 1993 in Minnesota and Canada coincided with the eruption of Mt. Pinatubo in 1991 that caused a global cooling event in 1992 and 1993 (King et al. 1999; Casselman et al. 2002; Schupp 2002). Although overall frequency of winterkill in shallow lakes is projected to decline as global temperatures rise , the lack of those events could be offset, i.e., winterkill would still occur, due to decreased lake volumes resulting from predicted extended periods of drought (Fang and Stefan 2000). However, drought may also create conditions for increased water clarity in deeper lakes because of decreased nutrient loading (Bachman 1990; Danylchuk and Tonn 2003).

Fish communities and populations are expected to respond to one or more of the stressors listed above. The following sampling proposal is designed to estimate fish community metrics as well as focus on population parameters (growth, recruitment, age and size structure, and abundance) of selected fish species in Tier I and Tier II sentinel lakes. The species targeted for this monitoring are either valued by Minnesota anglers or are ecologically significant and are thought to be sensitive to the various stressors described above. These species include White Sucker, Northern Pike, Cisco, Lake Trout, Bluegill, Smallmouth Bass, Largemouth Bass, Black Crappie, and Yellow Perch. Sentinel Lakes and their location can be found in Figure 1.

The proposal is structured in a manner that objectives are listed, a justification of that metric or objective is given, and a sampling recommendation to meet the objective is then provided.

Phase 2 - Objectives

Objective 1: Estimate annually or every other year metrics developed for the fish-based index of biotic integrity (IBI) in each Tier I lake.

Justification for metrics:

Metrics developed for IBI should respond to changes in land use, should detect invasions of non-native fish species, and sampling for IBI provides opportunities to develop additional metrics sensitive to changing temperatures. A total of 16 metrics (total number of native species, total number of intolerant species, total number of tolerant species, total number of insectivorous species, total number of omnivorous species, total number of cyprinid species, total number of small benthic-dwelling species, and total number of vegetation-dwelling species caught collectively in nearshore gears, standard trap nets, and standard gill nets; proportions of intolerant, small benthic-dwelling, and vegetation-dwelling individuals caught in nearshore gears, proportions of insectivores, omnivores, and tolerant species by biomass in standard trap nets, and proportions of top carnivores and intolerant species by biomass caught in gill nets) either increased or decreased with changes in trophic state, floristic quality or land use among a set of Minnesota lakes (Drake and Pereira 2002; Drake and Valley 2005). Because most littoral habitats and some pelagic habitats are sampled with these gears, this sampling should detect invasions of exotic fish species. Lastly, because IBI scores will be calculated from these 16 original metrics, this objective can be integrated well within the objectives of the Minnesota Pollution Control Agency; thus enabling the capture of Clean Water funds.

Sampling methodology and justification:

Samples to calculate metrics will be collected from the combination of nearshore sampling gears (backpack electrofishing, 4.8 m seines, 16.1-m seines, or 0.6 cm trap nets), standard trap netting, and standard gill netting (MNDNR 1993; 2012).
Except for the small mesh trap nets, samples from these gears were used to develop the lake IBI (Drake and Pereira 2002; Drake and Valley 2005).

Objective 2: Estimate annually size structure and population size of mature White Suckers in Elk and Bear Head lakes, and estimate every one to two years age structure, size structure, length at age, and relative abundance of white suckers in each Tier I lake.

Justification for selection:

White Sucker was suggested as a target species because they are found throughout Minnesota, appear sensitive to warming water temperatures and declines in oxythermal habitat and are an important forage species. As such, White Sucker populations should respond inversely to changing abundances of Minnesota's larger piscivores. Furthermore, because they are not a popular game species, populations should be minimally affected from angling exploitation. White suckers are native to all of the major drainages in Minnesota, found in 22 of the 24 sentinel lakes, including all Tier I lakes except Trout (Hatch et al. 2003; Lyons et al. 2009). In the past, Trout Lake supported a white sucker population but now appears extirpated (Minnesota DNR lake survey database). Statewide, gill net CPUE of white sucker among Minnesota lakes has trended downward since 1993 (B. Bethke and D.F. Staples, In Review).

Thermal maxima of White Sucker range from 32-36 ºC, however they appear tolerant of low DO (0.8-1.2 mg/L at 26 ºC) (Lyons et al. 2009). Therefore, they should not be adversely affected in most Minnesota lakes, but could suffer declines in shallow, eutrophic lakes in southern Minnesota if a doubling of atmospheric CO_2 occurs (Stefan et al. 1995; Stefan et al. 1996). White Sucker growth may improve but population size may decrease with increasing abundances of their primary predators, Northern Pike or Walleye (Bertolo and Magnan 2005).

Angling exploitation of White Suckers is negligible in Minnesota; thus, direct affects from angling can be largely discounted as an explanatory variable if changes in White Sucker populations occur. No statewide creel limits exist for White Sucker, although "suckers" (most likely White Suckers) compose about 0.01% by number and .02% by weight of the mean annual angler harvests from Minnesota lakes (Cook and Younk 2001).

We know less about White Sucker biology than the other target species; therefore, we are less confident about how to effectively sample them. Mark-recapture experiments would provide opportunities to estimate population size, determine if gill net CPUE reflects population density, estimate size-selectivity of gill netting, verify age estimates, as well as estimate annual growth, recruitment, and mortality of White Suckers.

Sampling methodology and justification:

Initially, sampling of White Sucker will be accomplished with standard gill netting or annual ice out trap netting in each Tier I lake because we know these gears capture this species (MNDNR 1993; MNDNR lake survey database; authors' personal observations). We hypothesized that gill net CPUE reflects abundance of White Suckers because gill net CPUE reflects abundance of Walleye and Northern Pike, and White Suckers have similar life histories (i.e. they spawn in early spring and have similar thermal requirements)(Corbett and Powles 1986; Pierce and Tomkco 2003; MNDNR unpublished data).

We chose to focus on Elk and Bear Head lakes for estimating population size of White Suckers. Elk was chosen because of its small size and Bear Head Lake because it appears to have the highest density of White Suckers (Phase I data set). These two factors increase the odds of capturing sufficient numbers of marked White Suckers to estimate population size.

Elsewhere, counting annuli on scales, pectoral fin rays, opercular bones, or otoliths appears to provide accurate and precise age estimates of White Suckers ; however, our preliminary results suggest otherwise for scales, fin rays, and otoliths (Sylvester and Berry 2006; Perry and Casselman 2012; J. Hoxmeier, MNDNR, personal communication). Age estimates will be made if results from an outside evaluation find that one or more of these structures proves useful. Both standard gill netting and ice-out trap netting capture primarily large (> 400 mm TL) individuals; therefore, accurate age estimates will help us understand recruitment mechanisms in White Sucker populations.

Objective 3: Estimate annually population size, size structure, and angler exploitation of Northern Pike in Bear Head and Elk lakes, and estimate every one to two years size structure and relative abundance of Northern Pike in each Tier I lake.

Justification for selection:

Northern Pike was chosen as a target species because they appear sensitive to warming temperatures linked to climate change, are expected to respond to changing land-use, changes in nearshore habitat, and because they are a popular game fish in Minnesota and Northern Pike are sensitive to effects from angler exploitation. Northern Pike are native to all of major drainages in Minnesota and are found in 23 of 24 sentinel lakes and 6 of 7 Tier I lakes (Trout Lake lacks Northern Pike) (Hatch et al. 2003). Mean gill net CPUE of Northern Pike among Minnesota lakes has trended upward since 1993 (Bethke and Staples, In Review).

Northern Pike have thermal maxima ranging from 29-33 °C (Casselman 1978; Lyons et al. 2009), and growth, size structure, and abundance of this species could change in a warming climate. Temperature for optimal growth was higher for young of the year Northern Pike (22-23 °C) than for age 1 or older pike (19 °C)(Casselman 1978; Casselman and Lewis 1996); thus growth decreases in warmer temperatures. In Ohio impoundments, Northern Pike sought dissolved oxygen (DO) concentrations of at least 3 mg/L when water temperatures exceeded 25 °C (Headrick and Carline 1993). Because of their oxythermal habitat requirements, Northern Pike could suffer declines in shallow, eutrophic lakes in the southern part of the state. As an example, in 2012, one of the warmest summers on record, summer kills of Northern Pike occurred in many shallow eutrophic lakes, including Lake Shaokotan (MNDNR unpublished data). Small Northern Pike tolerate lower DO than larger pike (Casselman and Lewis 1996); thus, size structures in shallow, eutrophic lakes could decrease. Year-class strengths in eastern Lake Ontario increased with increasing mean July water temperature until it reached around 23.5-24 °C, but year-class strengths declined with increasing temperatures (Casselman and Lewis 1996).

Changes in land use within watersheds and nearshore development also appear to affect Northern Pike populations. Spatially, gill net CPUE of Northern Pike decreased in a set of lakes (mostly class 24 in the Central Hardwood Forest ecoregion) with higher total phosphorus concentrations, lower Secchi depths, or higher percentages of cultivation within watersheds (Cross and McInerny 1995; 2001). Growth of Northern Pike also decreased with increasing Secchi depth among lakes in northern Wisconsin (Margenau et al. 1998). Mean biomass of Northern Pike per gill net increased with increasing percentages of vegetation transects containing yellow lily, white water lily, arrowhead, or broadleaf cattail (Radomski and Goeman 2001). Northern Pike also exhibit strong spawning-site and natal-site fidelity (Miller et al. 2001; T. Heinrich, MNDNR, personal communication), suggesting that nearshore alterations could affect spawning and rearing of young.

Northern Pike are very popular among Minnesota anglers. About 11.8 to 13.5% of licensed anglers in Minnesota prefer fishing for Northern Pike over any other species, and Northern Pike compose 4.4% by number and 15.7% by weight of total annual harvests of fish in Minnesota waters (Jacobson et al. 1999; Cook and Younk 2001). Consequently, Northern Pike populations are sensitive to angler exploitation. Creel surveys among Minnesota lakes suggest statewide declines angler catch of Northern Pike between the 1930's and 1990's, and numbers of trophy ($\geq$ 4.3 kg) Northern Pike entered in the Fuller's Bait fishing contest in Park Rapids declined from 1948 through 1987 when the contest ended (Olson and Cunningham 1989; Cook and Younk 1998). A statewide creel limit of three Northern Pike has been in existence since 1948 and has been shown to be ineffective in regulating harvest of this species because few (1.1%) angler parties harvest limits (Cook et al. 1998; 2001). However, length-based harvest regulations improved size structure of Northern Pike (Pierce 2010; T. Heinrich, MNDNR personal communication), and length-based regulations are in effect in two Tier I lakes and three Tier II lakes. Current limits on Elk, Cedar and Elephant lakes are one fish > 40 inches in length in possession. Ten Mile Lake currently has a 24 to 36 inch protected slot and only one fish > 36 inches can be kept. Only one northern pike at least 30 inches in length can be harvested at St. Olaf Lake.

Sampling methodology and justification:

Annual ice out trap netting or annual standard gill netting will be used to sample Northern Pike in Tier I lakes. Ice-out trap netting captures a wider range of lengths than gill nets (Pierce and Tomcko 2003); thus should capture trends in length distributions. Standard gill netting coupled with size-selectivity adjustments should provide accurate estimates of size structure (sample size permitting) and relative abundance of Northern Pike (Pierce et al. 1994; Pierce and Tomkco 2003).

Age estimated by counting annuli on scales and cleithra appear accurate for some Northern Pike populations, but not so for other populations (Laine et al. 1991; R.B. Pierce, personal communication). Ages 1 through 10 in Squeers Lake, Ontario, were accurately estimated with both structures, but cleithra were the better structures for estimating age in older Northern Pike (Laine et al. 1991). No new tissue formed on the edge of cleithra or scales until late May or early June, and annuli were not completely formed on mature pike until early August (Laine et al. 1991).

Estimates of population size made with marking from ice-out trap nets and summer gill nets appear unbiased (Pierce 1997). Bias in estimates of Northern Pike from marking during the first year of ice-out netting and with recaptures from the following year is not known, but estimates of Muskellunge population size determined with this method appeared unbiased (Hanson 1986). Estimates of exploitation from tag returns by usually differed little from exploitation estimated with harvest and population estimates (Pierce et al. 1995).

Objective 4: Estimate annually population size, size structure, age structure, size structure, age at maturity, and length at age from hydroacoustics/vertical gill netting of Cisco in Elk, Ten Mile, Carlos, and Trout lakes.

Justification for selection:

Cisco was suggested as a target species because they are sensitive to warming water temperatures, are sensitive to declining water quality leading towards hypolimnetic anoxia, and, like white sucker, are important ecologically as prey and predator of zooplankton, and remain relatively unexploited by anglers. Mean gill net CPUE among Minnesota has declined from 1993 through 2010, although the reliability of standardized gill netting for assessing Cisco populations has recently come under scrutiny (D.F. Staples, MNDNR, personal communication, J.R. Reed, MNDNR, personal communication). Cisco is native to all drainages except the Missouri, Minnesota, and lower Mississippi, found in at least 620 lakes, in at least 6 of 24 sentinel lakes, and in at least 3 Tier I lakes (Hatch et al. 2003; Fang et al. 2012). The Cisco population of Trout Lake is now thought to be extirpated (Minnesota DNR lake survey database). Cisco is the second most sensitive target species towards declining oxythermal habitat (Jacobson et al. 2010). About 66 to 75% of Minnesota's lakes that currently support Cisco are projected to lose all or most of the oxythermal habitat capable of supporting populations if doubling of atmospheric CO_2 occurs (Fang et al. 2012; Jiang et al. 2012). During oxythermal stress, larger and older Ciscoes die before smaller, younger Ciscoes (Colby and Brooke 1969; Edsall and Colby 1970; Jacobson et al. 2008); thus, age and size structure and age and lengths at maturity could be affected by this large-scale habitat alteration.

Ciscoes are important forage in lakes where they occur, especially to Minnesota's largest coolwater piscivores. The largest Northern Pike occur in Minnesota's deepest lakes that also contain Ciscoes (Jacobson 1993). Female Walleye from 215 populations in Ontario reached longer lengths in lakes with Cisco than lakes without (Kaufman et al. 2009).

Similar to White Sucker, Ciscoes appear unaffected by angler exploitation. Ciscoes are unregulated by statewide creel limits, and they compose about 0.03% by number and 0.06% by weight of the mean annual angler harvests from Minnesota lakes (Cook and Younk 2001). However, some management staff have recently expressed concerns over the growing popularity of winter angling for Cisco (M. Bacigalupi, MNDNR, personal communication). Ciscoes and Lake Whitefish in some Minnesota lakes are also exploited recreationally by fall gill netting, but effects of this activity on Ciscoes are not known.

Sampling methodology and justification:

Hydroacoustic surveys in combination with vertical gill netting should provide accurate estimates of size and age structure, and population size of Cisco in Elk, Ten Mile, and Carlos. Split-beam hydroacoustics coupled with vertical gill netting effectively sampled Ciscoes in pelagic areas of an Alberta lake (Aku et al. 1997). Because of their spatial distribution patterns within lakes during thermal stratification, Ciscoes inhabit pelagic areas at depths below or near the thermocline they are inconsistently sampled with standard gill netting (Rudstam and Magnuson 1985). For example, standard gill netting at Lake Carlos captured a total of nine Ciscoes in 13 assessments since the mid 1950's, but one overnight set of vertical gill net panels (8 mesh sizes) captured 220 Ciscoes, and hydroacoustics assessments suggest that over one million Ciscoes inhabited the lake in 2012 (MNDNR statewide database; B. Holbrook, personal communication).

Gonads are sufficiently developed in late August and early September to determine sex and state of maturity (authors' personal observations). No comparisons of ageing structures from Cisco apparently have been done and this should be explored as part of further Sentinel Lakes work. However, annuli counts of closely related Lake Whitefish differed between scales, pectoral fin rays, and otoliths, and wider ranges of ages and more older ages were estimated with otoliths than scales or fin rays (Muir et al. 2008; Herbst and Marsden 2011).

Objective 5: Estimate every one to two years population size, relative abundance, age structure, size structure, age at maturity, length at age, angler exploitation, and angler harvest of Lake Trout.

Justification for selection:

Lake Trout was suggested as a target species because they are sensitive to warming water temperatures and declining water quality leading towards hypolimnetic anoxia. They are also a popular game fish, especially in northeast Minnesota, and therefore are susceptible to the effects from angler exploitation. Lake Trout is native to the Rainy River and Lake Superior drainages, found or thought to be found in about 135 Minnesota lakes and one sentinel lake(Trout); its distribution is limited mostly to lakes in Lake and Cook counties in northeast Minnesota (Siesennop 2000; Hatch et al. 2003).

Lake Trout is the target species most sensitive to declining oxythermal habitat; their abundance and distribution are projected to decline significantly in a warming climate coupled with eutrophication (Jacobson et al. 2010). Thermal maxima for Lake Trout in smaller (16 to 114 ha) lakes are about 20 ºC; they prefer water temperatures below 13 ºC and DO concentrations of at least 6 mg/L (Snucins and Gunn 1995; Sellers et al. 1998). About 72% of Minnesota's

Lake Trout lakes show clinograde DO curves during July (Siesennop 2000); thus, increases in phosphorus loading could affect this species. Optimal temperature for growth of yearling Lake Trout is 10-12 ^{o}C (O'Conner et al. 1981). Poorer growth of Lake Trout occurred during years with the earliest dates of thermal stratification in Lake Opeongo, Ontario (King et al. 1999).

Thought limited in distribution, Lake Trout are popular game fish and populations can be affected by angling exploitation. About 0.7% of licensed anglers prefer fishing for Lake Trout over any other species, but their popularity increases substantially in northeast Minnesota (MN DNR creel survey database; Jacobson et al. 1999). Consequently, Lake Trout can be easily overexploited, especially in small lakes with low productivity. In Ontario, estimated fishing mortality at maximum equilibrium yield ranged from 12% in small (25 ha) lakes with low (down to 15 mg/L) total dissolved solids (TDS) to 37% in large (10,000 ha) lakes with high (up to 180 mg/L) TDS (Shuter et al. 1998). Because of concerns of potential overexploitation, Minnesota's statewide creel limit was dropped from 3 to 2 in 2003; however, effectiveness of the new limit has not been evaluated.

Sampling methodology and justification:

Data to address this objective will be collected with standard gill netting, short-term gill netting in fall, winter angler checks, and creel surveys. Because standard gill netting (deep sets) captures relatively few Lake Trout, the addition of fall short-term gill netting and winter angler checks should improve sample sizes, thereby allowing better estimates of size and age structure. Standard gill netting in Trout Lake during late July or early August captured between 9 and 30 Lake Trout per population assessment between 1993 and 2011 (MNDNR lake survey database); thus, age and size structure could not be estimated. Sampling during fall, when Lake Trout are spawning, with monofilament gill nets (19-, 25-, and 32- bar mesh panels) fished for about 30 minutes during the day captured similar numbers but narrower length ranges (20 to 80 cm) than standard gill nets with similar mesh sizes fished overnight during summer in Minnesota lakes (Siesennop 1997). However, short term gill nets killed fewer Lake Trout, 10% mortality compared to 70% in standard gill nets. Standard gill netting (deep sets) can be dropped if adequate sample sizes of age and size structures from angler checks and short-term gill netting become sufficient.

Tagging for population estimates will be made with captures from short-term gill nets because most should survive the capture and tagging process. In one study where Lake Trout were caught with fall short-term gill netting and fitted with surgically implanted transmitters, about 16% died within seven days of capture, but the remainder lived for at least nine months (Dux et al. 2011). The handling proposed for Lake Trout captured with fall short-term gill netting in Trout Lake will be less invasive, so survival should be higher. In addition to providing direct estimates of abundance and survival, these mark-recapture experiments allows for evaluations of standard gill netting and fall short-term gill netting as sampling gear for measuring relative abundance and size structure of Lake Trout. Gill nets with mesh sizes ranging from 0.51- to 76-mm bar under-sampled both smaller and larger Lake Trout (Hansen et al. 1997); thus, similar biases are expected in gill nets with smaller mesh sizes.

Counting annuli on otoliths or opercular bones appear best for estimating age of mature Lake Trout; however, scales work well for estimating age of immature Lake Trout (Sharp and Bernard 1988). Studies addressing the utility of estimating age of Lake Trout with pectoral rays have not been found. However, ages of closely related Arctic Char estimated with pectoral fin rays differed greatly from ages estimated with sectioned and burnt otoliths (Barber and McFarlane 1987).

Estimation of angler harvest will be accomplished by conducting periodic creel surveys during summer and winter, and exploitation will be estimated with harvest and population estimates as well as with voluntary tag returns. Unlike the other sentinel lakes, annual summer creel surveys were conducted on Trout Lake from 1952 through 1984 and winter surveys, usually annual were from 1953 through 1983 and 1999 (Schumacher 1960; Micklus and Johnson 1962; Schumacher et al. 1966; Close et al. 1985; Persons 2000). Estimates of harvest, catch and harvest per hour, and angling pressure will be compared to previous surveys to determine if any changes in these parameters have occurred. These surveys will also provide an opportunity to evaluate the effectiveness of the aforementioned bag limit change. Lastly, creel surveys will also allow a comparison of estimators of angler exploitation of Lake Trout (voluntary tag returns vs. harvest/population estimates) and estimate non-reporting rates by anglers.

Objective 6: Estimate annually age and size structure, age and length at maturity, length at age, and relative abundance of Bluegill at all Tier I lakes.

Justification for selection:

Bluegill was suggested as a target species because of their widespread distribution and importance as both a prey species and a popular game fish. Bluegills are native to all major drainages in Minnesota (Hatch et al. 2003) and occur in 23 of the 24 sentinel lakes and 7 Tier I lakes. Bluegills appear to be sensitive to changing temperatures linked to climate change, changing land-use and nearshore habitat alterations, as well as angler exploitation. Bluegill have thermal maxima ranging from 36 to 41 ºC, and can tolerate low DO (0.6-0.7 mg/L at 26 ºC) (Lyons et al. 2009); thus should not be adversely affected in Minnesota lakes during a warming climate (Stefan et al. 1995; Stefan et al. 1996).

Both growth and survival of Bluegill are affected by water temperature; however, growth is also affected by other factors. Growth of Bluegill through ages 1-6 increased with increasing maximum July air temperatures among Minnesota lakes; however, growth also increased with decreasing Secchi depth, and increasing total alkalinity (Tomcko and Pierce 2001). Hoxmeier et al. (2009) found that in addition to temperature, prey availability also affected Bluegill growth among Illinois reservoirs, but size at maturation and angling did not. Overwinter survival of age 0 Bluegill also increased with increasing pre-winter length with longer lengths coinciding with earlier hatch dates (Cargnelli and Gross 1995; Shoup and Wahl 2008). Conversely, growth appeared lake-specific and unaffected by annual weather variability among nine Michigan lakes sampled eight consecutive years (Osenberg et al. 1988).

Bluegills appear strongly affected by changing land use and shoreline development, especially if these changes affect aquatic plant densities. Trap net CPUE of Bluegill decreased with higher total phosphorus concentrations, lower Secchi depth, or higher percentages of cultivation within watersheds in a set of lakes (mostly class 24) within the Central Hardwood Forest ecoregion (Cross and McInerny 1995; 2001). Mean biomass of Bluegill per trap net increased with increasing percentages of vegetation transects with yellow lily, white water lily, arrowhead, or broadleaf cattail among class 23 lakes, and trap net CPUE increased with increasing percentages of transects with fine-leaf submergent vegetation among class 24 lakes (Radomski and Goeman 2001; Cross and McInerny 2001; 2005).

Bluegills provide substantial forage for several game fish species in Minnesota; thus, changes in piscivore abundance could affect Bluegill populations and vice versa. Northern pike, Walleye, Largemouth Bass, Black Crappie, and larger Yellow Perch all prey on small, mostly young of year, Bluegill (Anderson and Schupp 1986; Cross et al. 1992; Reed and Parsons 1996; McInerny and Cross 2008). However, growth of Northern Pike, Largemouth Bass, and juvenile Walleye could decrease if Bluegill become their primary fish prey because they are difficult to catch, especially if aquatic plant density is high (Hoyle and Keast 1987; Wahl and Stein 1988; Savino and Stein 1989; Einfalt and Wahl 1997; Margenau et al. 1998).

Bluegill is one of the more popular game fish species in Minnesota, and excessive angling exploitation has been linked to declines in growth, size structure, age and length at maturity, and shifts in reproductive strategies. About 12.5 of licensed anglers in Minnesota prefer fishing for sunfish over any other species and Bluegill compose 30% by number and 14.3% by weight of total annual harvests of fish in Minnesota (Jacobson et al. 1999; Cook and Younk 2001). Entries of Bluegill $\geq$ 0.57 kg in the Fuller's Bait fishing contest peaked in the 1970's and declined soon after while at the same time, numbers of licensed anglers in Minnesota increased (Olson and Cunningham 1989). Similarly, declines in size structure of Bluegills occurred in Wisconsin lakes from 1967-1991, and high angling exploitation reduces size structure and length and age at maturity of males (Beard et al. 1997; Drake et al. 1997; Jennings et al. 1997; Beard and Kampa 1999; Beard and Essington 2000). High prevalence of cuckholdry is also symptomatic of high angler exploitation (Drake et al. 1997; Ehlinger 1997; Ehlinger et al. 1997). The statewide creel limit of sunfish was dropped from 30 to 20 in 2003 (L.E. Erickson, MNDNR, personal communication) however this change probably reduced harvest only by 4% (Cook et al. 2001). However, regulations designed to reduce angler harvest have the potential to alter bluegill size structure. Mean lengths and sizes at maturity of bluegills captured in trap nets responded positively in four Minnesota lakes after daily creel limits were reduced from 30 to 10 with two of lakes exhibiting strong responses (Jacobson 2005).

Sampling methodology and justification:

Samples from daytime electrofishing in fall, standard trap netting, and standard gill netting will be used to meet Objective 6. Age and size structure, age and length at maturity, and length at age of Bluegill will be estimated from samples collected with daytime electrofishing in fall because this gear samples smaller Bluegill and wider length ranges than standard trap netting or standard gill netting. Boom electrofishing during the day (0.95-cm bar mesh dip net) captured Bluegills from 30 to 160 mm TL (median length = 90 mm) in six south central Minnesota lakes whereas standard trap nets captured Bluegills from 60 to 180 mm TL (median length = 120 mm) (McInerny and Cross 2004). Modal lengths of Bluegill captured in standard trap nets and gill nets are about 150-160 mm TL (MN DNR lake survey database). Lastly, gonadal development begins in fall (authors' personal observation).

If catches appear insufficient with day electrofishing, then night electrofishing or trap netting with small (0.6-cm) mesh webbing should be considered. Catchability is higher at night than day and similar length ranges are sampled (McInerny and Cross 2004). Bluegill as short as 30 mm TL are captured in 0.6-cm trap nets in Minnesota lakes, but data are lacking to properly assess the merits of this gear. Elsewhere, 0.6-cm trap netting captured Bluegill 40 to 140 mm TL, but these were not modified fyke nets like those used in Minnesota assessments (MNDNR 1993; Shoup et al. 2003). Furthermore, median lengths and catchability of Bluegill in decreased with decreasing mesh sizes of trap nets (Shoup et al. 2003).

Metrics of relative abundance (CPUE) include electrofishing, standard trap netting, and standard gill netting; however, it is unclear which if any of these estimates reflects relative abundance. Day time electrofishing has been successfully used in the Minnesota portion of the Mississippi River in backwaters to monitor Bluegill size structure and relative abundance since 1993 (Dan Dieterman, MNDNR, personal communication). However, catchability with electrofishing declines with increasing fish density because of gear saturation, and day catch of Bluegills can approach 400 per hr (McInerny and Cross 2000; 2004; Schoenebeck and Hansen 2005). Standard trap netting and gill netting often occur when Bluegill are spawning, thus, catchability in both gears could differ over time because initiation of spawning differs over time. Cross et al. (1995) found that trap net CPUE of Bluegill within the same Minnesota lakes declined from June to August, that sample day of year explained 40% of variation in CPUE of all sizes and 66% of the variation in CPUE of Bluegill $\geq$ 150 mm TL, and that CPUE of Bluegills $\geq$ 150 mm peaked with peak gonadal development. Length at age of younger Bluegill is strongly and inversely correlated with Bluegill density (Osenberg et al. 1988); however, as stated above, other factors affect growth as well.

Because males grow faster than females in some Minnesota lakes, and size structure is disproportionally influenced by males (Phase I data set; Hoxmeier et al. 2009), sex-specific growth rates should be determined. Age estimated by counting annuli on scales and otoliths appear accurate for some Bluegill populations. However, precision of otolith estimates greatly exceeded precision of scale estimates, and agreement rates between otolith age and scale age declined with increasing age in Illinois Bluegill populations (Hoxmeier et al. 2001). Therefore, otoliths should be the preferred structure for aging Bluegill from sentinel lakes.

Objective 7: Estimate annually age and size structure, age and length at maturity, length at age, relative abundance, and pre-winter length at capture (age 0 bass only) of Smallmouth Bass in all Tier I lakes with one or both species of black bass.

Justification for selection:

Smallmouth Bass was suggested as a target species because of its range expansion, potential to benefit from warming temperatures linked to climate change, popularity as a game fish in Minnesota, and sensitivity to angler exploitation. Smallmouth Bass are native to all major drainages in Minnesota except the Missouri, Red River, and Rainy River drainages and are likely not native to Lake or Cook counties (Hatch et al. 2003); they occur in 5 of the 24 sentinel lakes and 2 Tier I lakes.

Smallmouth Bass have thermal maxima ranging from 36 to 37 ^{o}C, and can tolerate low DO concentrations (1.1 to 1.3 mg/L) at 26 C (Smale and Rabeni 1995; Lyons et al. 2009). As a result, growth and abundance could increase in most waters throughout Minnesota as the climate warms. Overwinter survival of age 0 Smallmouth Bass increases with pre-winter lengths, but these lengths appear unaffected by hatch time (Oliver et al. 1979; Phelps et al. 2008). Growth of Smallmouth Bass increased with increasing growing degree days in six northeast Minnesota lakes and increasing summer water temperatures in a Wisconsin lake (Serns 1982; Pereira et al. 1995). The strongest year-classes in eastern Lake Ontario occurred during the warmest years, between 1973 and 1996 (Casselman et al. 2002). Second-year growth also appears density dependent; increments between the first and second year decreased with increasing density of 1-4 year old Smallmouth Bass in Lake Opeongo (Ridgway et al. 2002).

Links between population metrics of Smallmouth Bass and land-use are unclear. Smallmouth Bass abundance in four Ontario lakes increased between 1980 and 2003 when water clarity increased in conjunction with declining phosphorus inputs; however, water temperatures also increased and zebra mussels became established within the same period (Robillard and Fox 2006).

Smallmouth Bass are relatively popular among anglers, and size structures could decrease from overexploitation by anglers. About 2.9 to 3.6% of licensed anglers in Minnesota prefer fishing for smallmouth bass over any other species, and they compose 0.8% by number and 1.2% by weight of total annual harvests of fish in Minnesota (Jacobson et al. 1999; Cook and Younk 2001). Numbers of Smallmouth Bass $\geq$ 1.8 kg entered into the Fuller's Bait contest did not change from 1930 through 1987; however, mean weights of all entries have declined since the early 1940's (Olson and Cunningham 1989). The creel limit of black bass has been six since 1930, and this limit results in negligible harvest reductions since few anglers catch and keep limits (Cook et al. 2001).

Sampling methodology and justification:

Assuming sufficient sample sizes, age and size structure, age and length at maturity, length at age, and relative abundance of Smallmouth Bass at Carlos and Ten Mile lakes will be estimated from samples collected with spring electrofishing at night and with standard gill netting. However, acquiring sufficient sample sizes will be challenging because Smallmouth Bass have seldom been caught in these two lakes. Spring electrofishing catch ranged from 0 to 3 per hour and total gill net catch ranged from 11 to 18 bass in 15 net sets at Ten Mile Lake. In Lake Carlos, the combination of electrofishing, trap netting, and gill netting yielded one Smallmouth Bass during Phase I sampling. Where it works, electrofishing usually captures a wider length range (40-520 mm TL for electrofishing; 120-520 mm TL for gill nets) of Smallmouth Bass than gill nets in Minnesota lakes (MNDNR statewide database). Night electrofishing CPUE of Smallmouth Bass in spring increased with increasing density among Wisconsin lakes, but catchability decreased with increasing density (Schoenebeck and Hansen 2005). Therefore, electrofishing CPUE should be an adequate indicator of population density until density increases substantially. Gill net CPUE should also provide good estimates of relative abundance of Smallmouth Bass because CPUE increased with increasing electrofishing CPUE or angler CPUE of Smallmouth Bass in Mille Lacs Lake, Aitkin County and Green Lake, Kandiyohi County (T. Jones, MNDNR, personal communication; MNDNR statewide database). First maturations nearly always occur when Smallmouth Bass are between 200 to 300 mm TL (Coble 1975; Shuter and Ridgway 2002), and growth of males and females in Minnesota lakes does not differ (M.C. McInerny, MNDNR; personal observation).

Pre-winter lengths of age 0 Smallmouth Bass will be estimated with samples collected with daytime electrofishing. Although untested, daytime electrofishing in fall should capture sufficient numbers of age 0 Smallmouth Bass as shoreline sampling with backpack electrofishing captured age 0 Smallmouth Bass in both Carlos and Ten Mile lakes (Phase I data sets).

Age estimated by counting annuli on scales and otoliths appear accurate for Smallmouth Bass; however, ages from sectioned otoliths appear most reliable (Long and Fisher 2001).

Objective 8: Estimate annually age and size structure, age and length at maturity, length at age, relative abundance, and pre-winter length at capture (age 0 bass only) of Largemouth Bass in all Tier I lakes with one or both species of black bass.

Justification for selection:

Largemouth Bass was suggested as a target species because of its range expansion, potential benefit from warming temperatures linked to climate change, potential abundance response with land-use changes, susceptibility to nearshore habitat alterations, popularity as a game fish, and sensitivity to angler exploitation. Largemouth Bass are native to all major drainages in Minnesota but probably not native to Lake or Cook counties (Hatch et al. 2003); they occur in 19 of the 24 sentinel lakes and 6 Tier I lakes. For various reasons, Largemouth Bass occur in more lakes now than in the past (MNDNR, lake survey database).

Largemouth Bass have high thermal maxima, ranging from 36 to 41 °C and can tolerate low DO (0.8-1.1 mg/L) concentrations in water 26°C (Smale and Rabeni 1995; Lyons et al. 2009); therefore, this species should experience more favorable conditions in Minnesota during a warming climate. Growth of Largemouth Bass increased with increasing air temperatures and growing seasons across North America (McCauley and Kilgour 1990). Year-class strengths improved with increasing pre-winter sizes of age 0 Largemouth Bass. Earlier hatch dates, warmer water temperatures, longer growing seasons, and diet all affect first-year growth (Kramer and Smith 1960; 1962; Ludsin and DeVries 1997; Garvey et al. 1998; Fullerton et al. 2000; Pine et al. 2000). Conversely, warming water temperatures could result in further die-offs of Largemouth Bass resulting from Largemouth Bass Virus, which has been detected in several Twin Cities area lakes (Grant et al. 2003).

Largemouth Bass are also expected to respond to within-lake habitat changes resulting from changing land use within watersheds and from nearshore habitat alterations; however, the lag time before changes are detectable is not known. Electrofishing CPUE of Largemouth Bass among a set of lakes (mostly class 24) within the Central Hardwood Forest ecoregion decreased with higher total phosphorus concentrations, lower Secchi depth, or higher percentages of cultivation within watersheds (Cross and McInerny 1995; 2001). Largemouth Bass abundance in four Ontario lakes increased with increased water clarity linked to declining inputs of phosphorus and invasions of zebra mussels between 1980 and 2003; however, water temperatures also increased within the same time period (Robillard and Fox 2006). Largemouth Bass abundance appears higher in Minnesota lakes with submergent plants than in those without (Cross and McInerny 2001). Furthermore, daytime electrofishing CPUE of Largemouth Bass in Lake Pepin from 1993 to 2010 increased with increasing percent frequency of submergent vegetation (Slade et al. 2005; USGS Long-term Monitoring data). Largemouth Bass usually selected nest sites along undeveloped shorelines in three Douglas County lakes (Reed and Pereira 2009), but nest site selection appears unaffected by density of coarse woody debris (Weis and Sass 2011).

Largemouth Bass are a popular game fish species, and size structures of bass populations have been altered by changing angler exploitation. About 5.6 to 6.1% of licensed anglers in Minnesota prefer fishing for Largemouth Bass over any other species, and they compose 1.9% by number and 3.9% by weight of total annual harvests of fish in Minnesota (Jacobson et al. 1999; Cook and Younk 2001). During the Fuller's Bait Fishing Contest which ran from 1930 to 1987, entries of largemouth bass $\geq$ 1.8 kg declined after 1977, a period of time that coincided with increased numbers of licensed anglers in Minnesota (Olson and Cunningham 1989). Conversely, average size of Largemouth Bass caught in fishing tournaments at Lake Minnetonka increased from 0.77 to 0.95 kg between 1981 and 1999; an increase that was linked to increased voluntary release rates by anglers between 1984 and 1999 (Pereira et al. 2002). Increased release rates occurred in mostly in southern Minnesota (Isermann et al. in press). Spatial difference in release rate trends could explain in part why size structures changed in outstate lakes but not in metro region lakes after implementation of restrictive length-based harvest regulations (Carlson and Isermann 2010). The statewide creel limit of six, in effect since 1930, has had no measureable effect on angler harvest of Largemouth Bass in Minnesota because very few (0.1%) angling parties harvest limits (Cook et al. 1998; 2001).

Sampling methodology and justification:

The combination of night electrofishing in spring, standard gill netting in summer, and daytime electrofishing in fall should provide the samples needed to address Objective 8. When electrode resistances and desired electroshock response are the same, night electrofishing CPUE increases with increasing density of Largemouth Bass; however, catchability decreases with increasing density (Coble 1992; McInerny and Cross 2000; Schoenebeck and Hansen 2005). Although it has not been evaluated as a measure of density, standard gill netting may better reflect increases in Largemouth Bass populations than electrofishing if population densities are high enough to cause saturation in electrofishing. Night electrofishing samples wider range of Largemouth Bass lengths (60-550 mm TL) than gill netting or trap netting (MNDNR lake survey database). Day electrofishing in fall captured more Largemouth Bass < 120 mm TL than night electrofishing in fall or day electrofishing in spring (McInerny and Cross 1996). As Largemouth Bass are typically at least 60 mm TL in the fall, pre-winter lengths of age 0 bass can be estimated using fall electrofishing.

Counting annuli on scales and otoliths can provide accurate estimates of age of Largemouth Bass; however, ages estimated with otoliths are more accurate and precise (Long and Fisher 2001; Buckmeier and Howells 2003). Otolith age estimates are accurate through age 16 in Texas (Buckmeier and Howells 2003). Largemouth Bass mature when they reach about 250 mm TL (Heidinger 1975; M.C. McInerny, personal observation); thus, accurate estimates of length and age at maturity can be made by examining individuals between 200 and 300 mm TL. Growth of males and females from Minnesota lakes did not differ (M.C. McInerny, MNDNR; personal observation).

Objective 9: Estimate annually age and size structure and length at age of Black Crappie in Tier I lakes.

Justification for selection:

Black Crappie was suggested as a target species because of its potential benefit from warming temperatures linked to climate change, potential population responses to land-use changes and nearshore habitat alterations, popularity as a game fish and sensitivity to angler exploitation. Black Crappie is native to all major drainages in Minnesota but probably not native to Lake or Cook counties (Hatch et al. 2003); they occur in 20 of the 24 sentinel lakes and 5 Tier I lakes.

Black Crappie have a high thermal maxima at about 35 ºC (Lyons et al. 2009); thus, increasing water temperatures during a warming climate should not adversely affect this species. Growth of Black Crappie in southern Minnesota was unaffected by length of growing seasons (McInerny and Cross 1999).

Similar to Bluegill, Black Crappie populations should respond to changing within-lake habitat linked with changing land-use within watersheds and nearshore development. However, unlike Bluegill, trap net CPUE of Black Crappie increased in lakes with higher total phosphorus concentrations, lower Secchi depth, and/or higher percentages of cultivation within watersheds (Cross and McInerny 1995; 2001). First year growth of Black Crappie in southern Minnesota lakes also increased with increasing chlorophyll-a concentrations (McInerny and Cross 1999). In three Douglas County lakes, Black Crappies built nests along undeveloped shorelines with emergent vegetation and lacking submergent vegetation (Reed and Pereira 2009). Variation of trap net CPUE was not strongly linked with any plant variable among class 24 lakes (Cross and McInerny 2001). McInerny and Cross (2008) found Black Crappie growth was highest in high alkalinity lakes (≥ 100 mg/L) with low plant diversity dominated by curly-leaf and sago pondweeds and slowest in lakes with the high aquatic plant diversity (no dominant species) regardless of total alkalinity throughout Minnesota.

Black Crappie is a popular game fish in Minnesota, and changes in size structure can be linked with angling exploitation. However, Black Crappies appear more resistant to angler exploitation compared to the other major game fishes in Minnesota (Olson and Cunningham 1989). About 12.5 to 12.9% of licensed anglers in Minnesota prefer fishing for crappies over any other species, and Black Crappie compose 13.1% by number and 9.2% by weight of total annual harvests of fish in Minnesota (Jacobson et al. 1999; Cook and Younk 2001). The number of entries of large (≥ 0.8 kg) Black Crappie in the Fuller's Bait contest peaked in the early 1940's and steadily trended downward until very few entries occurred after 1980 (Olson and Cunningham 1989). Additionally, lengths at ages 4 and 5 decreased with increasing angling pressure among Minnesota lakes (McInerny and Cross 2008). Conversely, size structure of Black Crappie populations sampled with trap nets did not change from 1967-1991, angler catch per hour did not change from 1980-1991, and size structure of harvested crappies increased between 1980 and 1991 in Wisconsin lakes (Beard and Kampa 1999). Fishing and natural mortality appears compensatory among many Black Crappie populations and, so far, many attempts to restructure size distributions via minimum length limits have failed (Larson et al. 1991; Hale et al. 1999; Hurley and Jackson 2002; Isermann and Carlson 2009). The statewide creel limit was reduced from 15 to 10 in 2003 (L.E. Erickson, MNDNR, personal communication), but because relatively few anglers harvested more than 10 fish, this reduction was expected to minimally affect anglers (Cook et al. 2001). No special or experimental size regulations on Black Crappie are in place at any Tier I lake, but a 5-fish creel limit is in place at Cedar Lake, a Tier II lake.

Sampling methodology and justification:

Similar to Lake Trout and Cisco, specialized sampling, trap netting in either September or spring would be required to monitor metrics linked to abundance and size structure of Black Crappies; however, they appear less sensitive than the other target species to changes from the major stressors. Therefore, we propose a limited sampling approach to monitor this species by estimating metrics from standard gill net and trap net samples.

Standard gill netting and trap netting should provide adequate samples for estimating age and size structure, but some estimates of relative abundance from trap net or gill net CPUE could be inaccurate. Catch per lift of Black Crappie in standard trap nets increased with increasing CPUE in standard gill nets among Minnesota lakes, CPUE in both gears increased with increasing angler catch per hour, but correlations were relatively weak (r = 0.36 to 0.51) (McInerny et al. 1993). However, standard trap net CPUE of Black Crappie $\geq$ 200 mm TL in June and July did not increase with increasing population density among seven Minnesota lakes, whereas CPUE in April, May, August, September, and October did (M.C. McInerny, MNDNR; personal observation). The strongest correlation was between CPUE in September and density.

Counting annuli on scales and otoliths usually work well for estimating ages 2 through 6 Black Crappies; however, counting annuli on dorsal spines appears less reliable (Isermann et al. 2010). Among reader precision of otoliths greatly exceed precision of age estimates made with scales (Isermann et al. 2010). Males grow faster than females in many Minnesota lakes; the differences are usually small (< 10 mm) (Isermann et al. 2010). Madison Lake has both crappie species; therefore, crappie hybrids probably occur in this lake. Inclusion of F_1 hybrids in age samples of Black Crappies caused upward bias in length at age estimates, but these can be omitted by removing outliers of skewed length distributions (Miller et al. 2008).

Objective 10: Estimate annually or every other year age and size structure, age and length at maturity, length at age, and relative abundance of Yellow Perch in all Tier I lakes.

Justification for selection:

Yellow Perch was chosen as a target species because this species could be affected by warming temperatures linked to climate change, abundance could change with changing land-use and nearshore habitat alterations. Yellow Perch are very important prey for many of Minnesota's game fishes and they have become a popular game fish in Minnesota. Consequently, they are sensitive to effects from angler exploitation. Yellow Perch is native to all major drainages in Minnesota (Hatch et al. 2003), and they are the only target species found in each of the sentinel lakes. Statewide trends in gill and trap net CPUE suggest a substantial decline in the abundance of yellow perch from 1993 through 2010 (Bethke and Staples, In Review.).

Yellow Perch have relatively high thermal maxima (about 35 ^{o}C) (Lyons et al. 2009), and both year-class strength and growth could improve during a warming climate. Survival or growth of age 0 Yellow Perch increased in some lakes with increasing temperature or growing season but not in others (Coble 1966; Clady 1975; Power and van den Heuvel 1999; Janetski et al. 2013). Over-winter survival of age 0 Yellow Perch increases with increasing size before ice cover (Post and Evans 1989). However, mid-June lengths of larval Yellow Perch appear unaffected by hatch date in late April to mid-May (Isermann and Willis 2008).

Yellow Perch abundance could increase in lakes with disturbed watersheds and well developed shorelines. Catch per effort of Yellow Perch in gill nets, trap nets, or electrofishing increased with increasing total phosphorus concentrations, decreasing Secchi depth, or higher percentages of cultivation within watersheds among Minnesota lakes, mostly class 24 lakes (Cross and McInerny 1995; 2001). Abundance, but not growth, of Yellow Perch in Lake Memphremagog, Vermont/Quebec, increased with increasing productivity (Nakashima and Leggett 1975). Abundance also appeared higher in lakes with lower densities of aquatic plants (Cross and McInerny 2001). Relative abundance of Yellow Perch increased with increased logging (as a % of the watershed) among Canadian Shield lakes (Bertolo and Magnan 2007).

Yellow Perch are important prey for many of Minnesota's game fishes. Therefore, changes in Yellow Perch abundance and size structure could affect the abundance and size structure of predators just as predator abundance may influence Yellow Perch abundance and size structure. Northern Pike, Lake Trout, Smallmouth Bass, Largemouth Bass, Black Crappie, and larger Yellow Perch all feed on various life stages of Yellow Perch (Johnson and Hale 1977; Anderson and Schupp 1986; Eiler and Sak 1993; Pierce and Tomcko 1998; McInerny and Cross 2008). First year growth of Yellow Perch declined with increasing biomass of piscivores in Canadian Shield lakes (Bertolo and Magnan 2005).

Increases in population size of double-crested cormorants also affect Yellow Perch populations in some lakes. Declines in Yellow Perch populations in Leech Lake occurred in conjunction with rising numbers of double-crested cormorant colonies in the vicinity (Schultz et al., 2013); however, changes in Yellow Perch abundance in Lake of the Woods appeared unaffected by rising numbers of cormorants (Heinrich 2008).

In certain situations Yellow Perch are a popular game fish and size structures can be affected by angler exploitation. Examination of creel surveys on Minnesota waters showed increasing harvests of Yellow Perch from the 1950's to the 1990's, and the percent of anglers preferring to fish for Yellow Perch increased from 1.4% in 1987 to 2.7% in 1998 (Cook and Younk 1998; Jacobson et al. 1999). Angler harvests of Yellow Perch averaged 11.1% by number and 6.7% by weight in Minnesota lakes (Cook and Younk 2001). High angler exploitation has caused declines in size structure of some Yellow Perch populations. For example, gill net CPUE of Yellow Perch > 229 mm TL and the percent of Yellow Perch longer than > 229 in the gill net catch at Lake Winnibigoshish decreased from 1953 to 2000 while angler exploitation increased from negligible to 62% (Radomski 2003). The statewide creel limit was reduced from 100 to 40 (20 daily/40 possession) in 2001. However, with the exception of specific, highly exploited populations, this change will have little effect on reducing state-wide harvest (an estimated 0.3%) because few anglers reach the 40 fish limits (Cook et al. 2001).

Sampling methodology and justification:

Electrofishing during the day should provide data to estimate all metrics for Yellow Perch except relative abundance. However, if catches from daytime electrofishing appear insufficient (because of high water clarity), then night electrofishing or 0.6-cm mesh trap netting should be considered instead. Yellow Perch as small as 60 mm and 80 mm TL mature, male and females respectively, and gonads are usually well developed by September (Jansen 1996). Electrofishing during the day captured yellow perch from 60 to 170 mm TL in six Minnesota lakes (McInerny and Cross 2004) whereas standard gill netting fails to capture Yellow Perch less than 120 mm TL (MNDNR lake survey database). Thus, samples from electrofishing should be sufficient for estimating length at age, length at age at maturity, and estimate pre-winter lengths. Similar length ranges of Yellow Perch are caught with night electrofishing, but catchability is higher at night (McInerny and Cross 2004). Trap nets with 0.6-cm mesh captured Yellow Perch 30 to 220 mm TL in Minnesota lakes during summer assessments (Phase I data for Trout Lake; D. Schultz, MNDNR, personal communication); thus, catches from nets set in fall should provide appropriate data to estimate these metrics.

Catch per effort from standard gill netting probably reflects density of Yellow Perch, especially if net locations that consistently fail to capture Yellow Perch are removed from CPUE calculations. Deeper gill net sets, those near or below the thermocline, often failed to capture Yellow Perch (Phase I data); Yellow Perch consistently inhabit water above the thermocline so deeper nets are not likely to reflect their abundance (Rudstam and Magnuson 1985). Electrofishing catch of Yellow Perch approached 600 per hour in some lakes in southern Minnesota; thus, catchability probably decreases with increasing density at some point, making electrofishing CPUE a less valuable metric when populations are high (McInerny and Cross 2000; 2004; Schoenebeck and Hansen 2005).

Annuli counts on scales, dorsal spines, and otoliths work for estimating age of Yellow Perch. However, older ages were best estimated using otoliths and otolith age estimates had higher precision than other structures (Niewinski and Ferreri 1999). Among South Dakota lakes, annuli formation on whole otoliths of Yellow Perch less than age 4 usually occurred in July, but annulus formation occurred later in the summer (July and August) for older perch (Blackwell and Kaufman 2012). Females grow faster than males, but differences do not become apparent until they mature (Beckman 1949; Carlander 1950; Ney and Smith 1975).

Objective 11: Estimate annually or every other year age and size structure and relative abundance of stocked and naturally produced Walleye and in Tier I lakes.

Justification for selection:

Information from this objective provides an opportunity to monitor the effects of a stocked piscivore on fish populations and to monitor Walleye stocking effects on naturalized populations. Tier I lakes are probably poor candidates for monitoring the effects of nearly all stressors on Walleye populations because each lake except Trout, which lacks Walleye, is routinely stocked with various combinations and amounts of Walleye fry, fingerlings, yearlings, and/or adults. White Iron and Tait lakes are the only sentinel lakes with self-sustaining, un-stocked Walleye populations.

We recommend using similar information gathered from the MNDNR Large Lakes program to monitor Walleye metrics. Numerous population parameters of Walleye have been estimated annually from standardized sampling within the MN DNR large lake sampling program (Wingate and Schupp 1984). Changes in these parameters can be linked with some stressors including angling, climate change, exotic species introductions, double-crested cormorants, and stochastic events.

Stocking strategies differed among the Tier I lakes. For example, within the last 8-10 years, Elk Lake was stocked with fingerlings every even-numbered year, Bear Head Lake was fry-stocked every odd-numbered year, and Shaokotan Lake was fry-stocked two of three years. Conversely, from 2004 to 2010, Pearl Lake was stocked with fingerlings each year except 2009, yearlings in 2005, 2006, and 2008, and fry and adults in 2006. From 2003 to 2011, Lake Carlos was stocked with fingerlings each year except 2004, yearlings each year except 2004 and 2009, and adults in 2003, 2006, 2008, and 2010. Ten Mile Lake was stocked with fingerlings each year except 2004 and 2010, yearlings in 2003, 2005, 2006, 2007, and 2009, and adults in 2003, 2005, and 2007. Madison Lake was fry-stocked annually except 2005, was stocked with fingerlings in 2003, 2004, 2006, and 2008, yearlings in 2006, and adults in 2004 and 2006. Due to the vast differences in stocking strategies between Areas, and shifting public attitudes regarding Walleye stocking makes the species a marginal candidate as an indicator species.

Stocking and sampling methodology

Meeting this objective will require changing management plans for some lakes coupled with standard gill netting and night electrofishing in fall for sampling Walleye populations. Attempts will be made to alter lake management plans for Pearl, Carlos, Ten Mile, and Madison lakes so that blank stocking years occur periodically and age of stocked Walleye are known. Stocking plans at Elk, Shaokotan, and Bear Head already include known age walleye and blank stocking years. Initially, stocking effects will be assessed by comparing CPUE and length at age of Walleyes of un-stocked year-classes with stocked year-classes. If this proves insufficient to estimate stocking effects, batch marking with oxytetracycline or isolating genetic markers unique to stocked Walleyes should be considered (Logsdon et al. 2004; 2009). Evaluation of stocking effects will be most challenging at Lake Carlos because this lake is strongly connected with several other lakes stocked with various rates and ages of Walleye.

Gill netting coupled with size-selectivity corrections may provide better estimates of population size structure of Walleye in Minnesota lakes than raw gillnet catches (Hamley and Regier 1973; Anderson 1998; Grant et al. 2004), however, additional review is still needed. Furthermore gill net CPUE increased with increasing population density among 21 lakes ranging from 80 to 1,935 ha ($r = 0.51$; $n = 26$; $P = 0.0081$) (MNDNR unpublished data). Catch per lift of Walleyes declined in survey nets in Lake Erie when soak times exceeded 10 hours and catch density in nets exceeded two walleye per m^2 (Li et al. 2011). Walleye < 25 cm were seldom caught with day electrofishing in French Lake, Wright County, but appeared vulnerable to night electrofishing in fall (McInerny and Cross 2004). Similar to gill netting, night electrofishing CPUE crudely reflects population density of age 0 Walleye; however, sampling efficacy decreases at high densities. Fall density of age 0 Walleye explained about 40% of night electrofishing catch per mile in fall among 19 Wisconsin lakes, and catchability decreased with increasing density (Hansen et al. 2004). Electrofishing effort should also focus on sampling both age 0 and age 1 Walleye because of differing survival rates between naturalized and stocked Walleye which are not detectable until the end of the second growing season (Eldridge et al. 2002).

Counting annuli on sectioned otoliths provide accurate estimates of age of walleye, and ages estimated from scales work well in some lakes (Erickson 1983). Females grow faster than males; thus, determining sex appears warranted.

Objective 12: Estimate every one to two years species assemblages of fishes in pelagic zones of each Tier I lake.

Justification for selection:

Similar to the other IBI metrics, metrics developed from pelagic sampling should respond to changes in climate, land-use, the presence of exotic species, and other environmental stressors. Furthermore, this sampling should improve our understanding of aquatic ecosystems as a whole, as very little is known about the pelagic fish communities in our inland lakes. Although limited pelagic sampling has occurred in Minnesota lakes, it has provided information on responses of fish metrics with a changing stressor. For example, catch per haul of Bluegill 60 to 100 mm TL in a 30 X 3 m purse seine (3-mm mesh) dropped following vegetation removal in two Twin Cities metro area lakes (Pothoven et al. 1998). Furthermore, pelagic sampling allowed tracking the growth of young of the year of Black Crappie, Bluegill and Yellow Perch in four central Minnesota lakes (Parsons et al. 2004).

Sampling methodology and justification:

Methodology has not been developed; however, sampling gears could include the same vertical gill nets used for sampling ciscoes, small purse seines, and side-scanning hydroacoustics. Besides Ciscoes, vertical gill netting samples many of the target species, as well as smaller forage species including shiners, Yellow Perch and centrarchids (Reeves, MNDNR, unpublished manuscript; MNDNR unpublished data; Parsons et al. 2004).

Objective 13: Estimate from archived tissues trends of metrics yet to be determined.

Justification for selection:

One objective in long-term monitoring programs is to capture responses to environmental perturbations not yet known or recognized, and examination of archived materials could meet this objective. For example, long-term food web changes were detected by examining stable isotopes from tissues extracted from preserved fish (Schmidt et al. 2009). Elemental analyses of otoliths have potential including linking fish species to particular habitat types (Kennedy et al. 2002; Brazner et al. 2004), and bones have higher concentrations of elements than otoliths (Campana and Thorrold 2001). Microsatellite DNA markers can be extracted from scales whereby ancestry and hybridization, among other potential genetic metrics, can be estimated (Miller et al. 2008; 2012; Logsdon et al. 2009).

Proposed Sampling Procedures

Data to address these objectives will be collected from annual ice-out trap netting, annual nighttime electrofishing in late May or early June, annual standard trap netting, annual or biannual standard gill netting, annual or biannual nearshore sampling (backpack electrofishing, shoreline seining, small-mesh trap nets and other potential gears), annual vertical gill netting in August or September, annual daytime electrofishing in September, annual fall nighttime electrofishing , annual short-term gill netting (Lake Trout lakes only), annual winter angler checks (Lake Trout lakes only), and periodic creel surveys. We propose that these sampling frequencies be done for 10 years.

Ice out trap netting

Annual ice out trap netting (either standard double-frame or single-frame nets with the same mesh; throats sufficiently open to allow larger fish to be captured) will be used to sample White Suckers and Northern Pike at Elk and Bear Head lakes. Ice out netting will run concurrently with sampling for Northern Pike in Elk and Bear Head lakes; peaks of White Sucker catches usually follow peaks of Northern Pike catches. Because the goal of this netting is to maximize catch nets at locations failing to capture White Suckers and Northern Pike should be removed or moved to a different location. Captured White Suckers will be measured (TL in mm), sexed, examined for numbered tags, marked with numbered tags if untagged, and rays from one pectoral fin and a scale sample be removed from 10 individuals per 25-mm length group. Northern Pike will be measured (TL in mm), sexed, examined for numbered tags, marked with numbered tags if untagged, and a scale sample collected from10 individuals per 25-mm length group.

Spring electrofishing

Spring electrofishing at night will be done annually at each Tier I lake with one or both species of black bass. Water temperatures should be at least 15 ^{o}C in order to increase the odds that both species will be spawning in Carlos and Ten Mile lakes, the only two Tier I lakes with both bass species (Carlander 1977). In two Douglas County lakes, Largemouth Bass usually begin spawning at similar dates among years (J.R. Reed, MNDNR; personal observations); therefore, once sampling times are established, efforts should be made to electrofish during the same week of the year within a given lake. At all Tier I lakes except Carlos, Pearl, and Ten Mile, the same stations will be electrofished; however, end points should be extended so that a total of two hours of on-time effort are expended in each lake. Both start and end points shall be established. At Lake Carlos, several new stations will be established so that effort occurs throughout the lake. At Pearl, at least one additional location on the east side of the lake will be added to ensure that sampling effort is representative of the lake. Furthermore, Pearl Lake has an extended shallow shelf; thus, shoreline reference points typical for most electrofishing stations will not be visible. Therefore, the entire electrofishing runs will be recorded with GPS and these same tracks sampled each year.

The same boat type and electrode configurations will be used for all electrofishing. The boat will be the cathode, and anodes will consist of two 4-cable spider arrays positioned approximately 6 feet apart, cables submerged about a foot in depth, and the control box will be either a Smith-Root GPP series, ETS MBS series, or Midwest Lake Management MLES series (no Smith-Root VVP-15 or Coffelt control boxes); these criteria ensure consistent power output into the water among samples (Miranda and Kratochvil 2008; Miranda 2009; Martinez and Kolz 2013). Power will applied continually and set at levels for desirable electroshock responses whereby fish are sufficiently stunned for netting but not so severe to cause mortalities (i.e., bass held in the livewell should become upright within a minute). A single netter will dip all sizes of black basses. All bass will be measured (TL in mm). Scale samples removed from up to 10 individuals per 1-cm length group, and then released. To minimize the number of Largemouth Bass to sacrifice for age and length at maturity estimates, up to 10 per 25-mm length bin between 200 and 300 mm TL and 5 individuals from 175 to 199 mm and five individuals from 301 to 325 mm TL will be dissected to determine sex and maturity, and scale samples and otoliths will be removed from sacrificed fish. The same methods should be used for Smallmouth Bass.

Standard gill netting

Standard gill netting will be done annually at all Tier I lakes except in Trout and Elk Lakes where gill netting will be done every other year (MNDNR 1993). Sampling frequency was based on projected mortalities of target species and of species designated as primary in management plans. Annual gill netting is projected to be low in six lakes but, because of low natural mortality and high longevity, gill netting could kill excessive numbers of Muskellunge at Elk Lake and Lake Trout in Trout Lake (Table 1). Sampling dates will be similar to those used in past surveys and assessments. Most net locations will be the same as those in the past; however, new locations could be added if coefficients of variation (CV) of CPUE for Yellow Perch, Walleye, or Northern Pike consistently exceed 25%. Unless deemed necessary based on CV estimates of CPUE, no more than 12 gill net locations will be sampled per lake per year. Set and lift times will be recorded so that soak times can be estimated. All fishes captured with each mesh will be identified to species, counted, and weighed (g) either individually or in bulk. From these samples, up to 25 randomly selected individuals of each target fish species from each mesh will be measured (TL in mm) (MNDNR 1993). Sex will be determined and ageing structures will be removed from up to 10 individuals per 25-mm length group for White Sucker, Northern Pike, and Walleye, and sex will be determined and ageing structures will be removed from up to 10 individuals per 10-cm length group for Bluegill, Smallmouth Bass, Largemouth Bass, Black Crappie and Yellow Perch. For ageing structures, scales, pectoral rays, lapillae otoliths, and the opercular bones will be removed from White Sucker; scales and cleithra will be removed from Northern Pike; scales, pectoral rays, and otoliths will be removed from Lake Trout; and scales and otoliths will be removed from Bluegill, Smallmouth Bass, Largemouth Bass, Black Crappie, Yellow Perch, and Walleye. Lastly, all White Suckers, Northern Pike, and Lake Trout in Elk, Bear Head, and Trout lakes will examined for numbered tags, and, if tagged, the tag number will be recorded, length will be measured, sex will be determined, and the appropriate ageing structures will be removed.

Table 1. Estimated gill net mortality (% killed) of Lake Trout, Northern Pike, Muskellunge, and Walleye per assessment in Tier I lakes.

	Estimated % killed per assessment			
Lake (n = number of gill net sets)	Lake trout	Northern pike	Muskellunge	Walleye
Trout (n = 8)	1.2			
Bear Head (n = 12)		1.1		2.3
Elk (n = 6)		3.3	4.8	2.6
Ten Mile (n = 12)		1.1		1.8
Carlos (n = 12)		1.1		1.8
Pearl (n = 8)		1.1		1.5
Madison (n = 12)		1.1		1.8
Shaokotan (n = 3)		1.1		3.3

Gill net mortality estimates were calculated from gill net catch in lakes where population estimates were made. Gill net mortality of Lake Trout was estimated at 0.2% per set, but only 6 of the 8 gill nets set at Trout Lake consistently capture lake trout (S.E. Persons, personal communication; Phase I data set). Gill net mortality of Northern Pike increased with decreasing lake surface area among 12 Minnesota lakes smaller than 500 acres, but estimates averaged 1.1 % among three larger (627 to 1890 acres) lakes (R.B. Pierce, MNDNR, personal communication). We used the following equation to estimate mortality of Northern Pike in lakes < 500 acres: % mortality = - 0.0129 (Lake Area in acres) + 6.84. For Walleye, gill net mortality is affected by both lake depth and lake surface area. Among 21 lakes (26 estimates of population size and gill net CPUE) with maximum depths ranging from 4 to 208 feet and surface areas ranging from 196 to 4,782 acres, gill net mortality for lakes with maximum depths < 12 feet was about 1.1% per net regardless of lake area. For lakes with maximum depths $\geq$ 12 feet, mortality was estimated at 0.44% per net in lakes < 576 acres, 0.19% per net in lakes $\geq$ 576 and less than 837 acres, and 0.15% per net in lakes $\geq$ 837 acres (S.E Persons, personal communication; MNDNR unpublished data). The Muskellunge mortality estimate at Elk Lake was based on 5 adult Muskellunge killed in the 2008 assessment and a population estimate of 105 adults in 2003 (G. Barnard MNDNR and J. A. Younk, MNDNR, personal communications).

Standard trap netting

Standard trap netting will occur annually at all Tier I lakes and the same locations will be sampled during the same time of year (MNDNR 1993). At a minimum, fishes sampled with standard trap nets will be identified to species, counted, and weighed either individually or collectively as bulk weight (MNDNR 1993). All Black Crappie and Bluegill sampled with trap nets will be measured (TL in mm), and up to 10 individuals per 1-cm length group will be sacrificed in order to determine sex and remove otoliths. Scale samples will also be collected from each of the sacrificed fish.

Nearshore sampling

Annual nearshore samples will be collected at Tier I lakes except at Elk, Ten Mile, and Shaokotan lakes, which will be sampled every other year; nearshore metrics at these latter three lakes have been stable during Phase I sampling. In Tier I lakes with wadeable shorelines (all except Bear Head and Trout), nearshore gears will be back pack electrofishing and seines (MNDNR 2012). Other nearshore gears (i.e., 0.6-cm trap nets) will be used to sample nearshore fishes in Bear Head and Trout lakes because much of the shorelines in these lakes are not wadeable. Nearshore sampling should occur during the same week in July or August and at the same sampling locations during each sampling year. Fishes collected with nearshore sampling will be identified to species and counted; voucher specimens will be kept according to procedures listed in MNDNR (2012).

Hydroacoustics and vertical gill netting for cisco

Annual surveys in Tier I lakes with Cisco will be conducted using either a 120-khz or 38-khz frequency split beam transducer that will be field calibrated before data collection. A vertical profile of water temperature and DO concentration will be collected concurrently during calibration to estimate the frequency-specific speed of sound and absorption coefficient. Predetermined GPS transects will be sampled at approximately 8 km/h two hours after sunset when pelagic fish become more homogenously distributed. The size estimates of single fish targets within the 'Cisco layer' will be analyzed in Echoview software (Myriax Software Pty., Hobart, Tasmania) by using phase differences of the returning signal to identify the position of the targets within the beam. Once the position of the fish target is known, corrections for attenuation and depth will be applied to attain measurements of acoustic size (dB). Acoustic sizes (dB) will be converted to lengths (cm) using standard relationships reported in the literature (Love 1971; Rudstam et al. 1987; Brandt et al. 1991; Rudstam et al. 2003). Average acoustic size (dB) will be calculated per 1 m vertical depth bin and used to calculate volumetric density (ρ_{vS}, individuals/m^3) per vertical depth bin using the equation:

$$\rho_{vS} = \frac{s_v}{10^{\frac{TS_S}{10}}}$$

where s_v is the linear mean volume backscattering coefficient (m^2/m^3) and TS_s is the expected target strength returned from an individual of species S (dB). Volumetric biomass (g/m^3) will be calculated by multiplying density estimates by the average weight of an individual of species S within each depth bin using length-weight regressions established from vertical gillnets. Volumetric density and biomass can be summed across depth bins within the 'Cisco layer' to estimate overall areal density (individuals/ha) or biomass (g/ha). Lake-wide Cisco population estimates (individuals or kg) will be estimated by multiplying volumetric density (#/m^3) and volumetric biomass estimates (g/m^3) in each 1 m depth bin with the volume of water (m^3) within that depth bin estimated using a Geographic Information Systems (Esri ArcMap).

A vertical gill net with separate panels of 3/8-in, ½-in, ¾-in, 1-in, 1 ¼-in, 1 ½-in, 1 ¾-in, and 2-in bar mesh monofilament will be set from surface to just off the bottom in one or two deep locations within each lake. The first 150 fish of each species encountered will be measured (TL in mm), and mesh size and depth (nearest m) of capture recorded, and all other remaining individuals of each species will be counted. Additionally, weight (g), sex, maturity of up to 10 Ciscoes per 25 mm length bin will be recorded, and otoliths and scale samples will be collected from the samples of Ciscoes measured for length.

Short-term gill netting in fall for Lake Trout

Short-term gill netting for Lake Trout will be done annually at Trout Lake. Monofilament gill nets (19-, 25-, and 32-mm bar mesh panels) will be set either perpendicular or obliquely to shore at depths at least 2.4 m but less than 18 m during fall when water temperatures drop below 13^{o} C (Siesennop 1997). Soak times will be limited to 30 to 45 min; decisions on the number of days to sample have not been made. All Lake Trout captured will be measured (TL in mm), weighed, examined for sex via external methods, examined for visible tags, and marked with a visible tag if unmarked and likely to survive. Scale samples and rays from one pectoral fin will be removed from each newly captured Lake Trout. Scale samples and the fin ray from the other pectoral fin will be removed from recaptured Lake Trout marked in prior years. All trout likely to survive this capture experience will be released.

Fall daytime electrofishing

Boom electrofishing during the day will be done at each Tier I lake to sample Bluegill, Smallmouth Bass, Largemouth Bass, and Yellow Perch. At least 8 stations (distributed equidistantly around each lake; and GPS coordinates of start and stopping points will be recorded. Electrofishing runs will be about 5 minutes in length (but should vary among lakes depending on fish catches), and a single netter equipped with a 0.95-cm bar mesh dip net will net all targeted species. Power on control boxes will be set so that target species are sufficiently stunned for netting, foot switches will be depressed constantly. Boat configurations will be the same as described for spring electrofishing. Total on-time per run will also be recorded. All Bluegill, Yellow Perch, Smallmouth Bass < 300 mm TL, and Largemouth Bass < 300 mm TL will be measured (TL in mm). However, if the sample size of a species appears to exceed 40, then a randomly selected subsample of at least 40 individuals can be measured per station.

Sex will be determined, maturity estimated, and aging structures (scales and otoliths) will be removed from 10 individuals per 1-cm length bin of measured Bluegill and Yellow Perch. Scales will be removed from 5 individuals per 1-cm length group of Smallmouth Bass and Largemouth Bass < 250 mm TL so that age 0 bass can be separated from older bass.

Fall nighttime electrofishing for walleye

Electrofishing for Walleye will be done at the same locations as those in the past or the same locations sampled for black basses. Sampling should occur during the same week in the last half of September as long as water temperatures exceed 10 ^{o}C (Borkholder and Parsons 2001). Boat configurations will be the same as described for spring electrofishing. Power will applied continually and set at levels for desirable electroshock responses; whereby Walleye are sufficiently stunned for netting but not so severe to cause mortalities (Walleye held in the livewell should become upright within a minute). A single netter will dip all walleye about 4^{0}0 mm TL or shorter. Scale samples will be removed from 5 individuals per 1-cm length bin to separate by age (age 0, age 1, older than 1) catches of Walleye.

Fall 0.6-cm mesh-trap netting

If daytime electrofishing fails to capture sufficient numbers of Bluegill, age 0 Smallmouth Bass, age 0 Largemouth Bass, or Yellow Perch and nighttime electrofishing proves impractical because of scheduling, then 0.6-cm mesh trap nets will be set during September as long as water temperatures remain above 10 ^{o}C; fishes appear to move offshore when temperatures drop below 10 C (Colvin and Vasey 1986; Borkholder and Parsons 2001).

Winter angler checks

Lake Trout caught by anglers fishing during the winter will also be examined periodically. Upon securing permission from anglers, Lake Trout will be measured (TL in mm), examined for marks (tag number recorded if marked), and scale samples and pectoral fin rays for ageing will be removed.

Creel surveys

Summer and winter creel surveys should be done every three to five years preferably at Trout but, if funding allows, also at Madison and Ten Mile lakes. Among Tier I lakes past creel surveys were conducted at Elk, Pearl, Ten Mile, Madison, and Trout lakes, but multiple creel surveys were done only at the latter three (MNDNR statewide database). These surveys will consist of a stratified random design coupled with instantaneous angler counts and interviews of complete trips by roving creel clerks in order to estimate pressure, catch, and harvest of fish (Pollock et al. 1994). All fish examined during interviews will be identified to species, measured (TL in mm), weighed, and checked for visible tags and if present tag numbers will be recorded.

Sampling effort

Estimated number of days for ice-out trap netting (TN), number of electrofishing runs in spring, number of standard trap nets (TN), number of standard gill nets (GN), number of nearshore sampling sites, number of vertical gill net sites, number of day electrofishing sights in fall, number of night electrofishing runs at night, and number of days of short-term gill nets needed to collect samples for metrics in Objectives 1 through 11.

Lake	Ice-out TN	Spring EF	Standard TN	Standard GN	Nearshore EF,SE,TQU	Vertical GN*	Fall Day EF	Fall night EF	Short-term GN
Trout			12	8	TBD		8		1-4 days
Bear Head	8-10 days	4 30-min	12	12	TBD		8	4 30-min	
Elk	8-10 days	Entire shoreline	9	6	9	1	8	Entire shoreline	
Ten Mile		10 12-min	15	12	20	2	8	10 12-min	
Pearl		4 30-min	12	9	14		8	4 30-min	
Carlos		6 20-min	15	15	20	2	8	6 20-min	
Shaokotan			12	3	10		8	6 20-min	
Madison		4 30-min	12	12	16		8	4 30-min	

*****hydroacoustics sampling will be done concurrently with gill netting

Estimating age, size structure, and growth of target species

The type of size structure estimates will vary depending on sample sizes collected. For length distributions (1-cm bins) with acceptable accuracy (within 10% of true distribution 80% of the time), sample sizes should be at least 300 to 400 individuals (Vokoun et al. 2001; Miranda 2007). This should be achievable for Bluegill and Yellow perch sampled with electrofishing in fall in several lakes. Distributions with 2.5-cm bins require 150 measured fish , and sample sizes for mean lengths and for proportional stock densities should be at least 75 (Kritzer et al. 2001; Miranda 2007).

Because it is more practical it is proposed to sample for aging a fixed number (usually 10) of fish per length bin rather than sampling proportional to the length distributions for aging.. This should provide a minimum of 7-10 samples per age class, which appears sufficient to estimate several growth parameters including asymptotic length and growth coefficients that could be sensitive to one or more stressors (Kritzer et al. 2001). However, fixed sampling increases odds of estimating biased length at age estimates and inflates standard errors (Bettoli and Miranda 2001). Therefore, it should be investigated how length distributions can be incorporated into these age samples, whereby less biased length at age estimates can be made with lower standard errors. Because of size selectivity in fish sampling gears and inconsistencies of measurements of aging structures (Casselman 1990), various estimators of growth will be calculated and evaluated.

Estimating population size, exploitation, and survival

Estimates of population size or relative abundance of White Sucker, Northern Pike, and Lake Trout can be made with closed or open models depending on how many and when marked fish are recaptured. Closed estimates of population size of White Sucker and Northern Pike in Elk and Bear Head lakes can be accomplished with marking via ice out trap netting and recapture via ice-out trap netting one year after, and by marking via ice-out trap netting and recapture in standard gill nets set the same year (Ricker 1975; Williams et al. 2002). Closed estimates of Lake Trout population size in Trout Lake can be accomplished with marking during short-term gill netting in fall and with recaptures from winter angler checks, recapture in standard gill nets the following year, or with recaptures from short-term gill netting the following year.

Open models will also be explored and relative abundance of White Suckers can also be estimated by monitoring the population index lambda in Program Mark (White and Burnham 1999). Data collected with annual ice-out trap netting will be used to estimate abundance of White Sucker and Northern Pike in Elk and Bear Head lakes, and data collected with short-term gill netting in fall will be used to estimate abundance of Lake Trout in Trout Lake.

By examining recapture to capture ratios with respect to size, size selectivity in gill nets can also be estimated for Lake Trout and White Sucker.
Tag returns from anglers will be used to estimate angler exploitation; exploitation estimates from this method usually differed little from exploitation estimated with harvest during creel surveys and population estimates (Pierce et al. 1995). Estimates of survival and lifespan can also be estimated with tag returns (Brownie et al. 1985). Efforts will be made to ensure anglers are aware that tagged fish occur in these lakes and provide information on how they can report the information on tags.

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