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Preliminary Assessment of Bluegill and Redear Sunfish Populations in Small Impoundments

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ABSTRACT

Bluegill *Lepomis macrochirus* and redear sunfish *L. microlophus* population data was collected from 2007 to 2011 at Beaver, Corinth, and Elmer Davis lakes, three small central Kentucky impoundments. Results of spring electrofishing sampling conducted during the latter half of March, April, and May in 2007 indicated that the May sample provided the most representative sample. Sunfish seining conducted in fall 2006 as a potential method to index recruitment collected mainly bluegill and redear sunfish in the 1- and 2-in classes and showed high variability for both species. The increased effort needed to overcome the variability was not warranted as recruitment was expected to be determined at larger sizes. The five years of bluegill and redear sunfish population data provided estimates of von Bertalanffy growth equations, weight-length equations, and annual total mortality estimates. Growth rates of bluegill and redear sunfish at Corinth Lake were lower than Beaver and Elmer Davis lakes. Annual total mortality rates of bluegill and redear sunfish were lowest at Beaver Lake and highest at Elmer Davis Lake. Exploitation studies were conducted at each of the three study lakes to provide estimates of fishing mortality. Corrected exploitation rates of both species were lowest at Corinth Lake and highest at Elmer Davis Lake. Population estimates were also made at Beaver and Corinth lakes. Bluegill and redear sunfish population estimates multiplied by the exploitation rates compared favorably with concurrent creel survey data at Corinth Lake and somewhat for redear sunfish at Beaver Lake. The bluegill creel survey harvest estimate was higher than the product of the exploitation rate and population estimate for Beaver Lake. The data generated in the current study provides robust estimates of bluegill and redear sunfish growth, total mortality, and fishing mortality and can be used in population simulations to predict the impacts of harvest restrictions in Kentucky small impoundments.

INTRODUCTION

The Kentucky Department of Fish and Wildlife Resources (KDFWR) manages fish populations in hundreds of small impoundments across the state, which support a multitude of recreational fishing opportunities for Kentucky anglers. Primary targets of anglers in these waters are sunfish species *Lepomis* spp. Nationally, the number of sunfish anglers ranks 2nd behind only black bass anglers (USDI 2001a) and here in Kentucky fishing for sunfish ranks 3rd in popularity behind black bass and catfish (USDI 2001b). However, even with their angling popularity, regulations have not been widely used by biologists to manage these sunfish fisheries, so there is a paucity of research evaluating the effects of harvest restrictions on sunfish populations. However, recently there have been some investigations with simulation modeling on the potential of improving sunfish fisheries with length limits (Paukert et al. 2002; Crawford and Allen 2006; Sammons and Maceina 2007), reduced creel limits (Rypel 2015) or both (Sammons et al. 2006).

Department-owned small impoundments in central Kentucky are noted for providing good fisheries for both bluegill *Lepomis macrochirus* and redear sunfish *L. microlophus*. One technique employed by the KDFWR to manage for the bluegill fisheries is to not stock shad in these waters or selectively remove them from impoundments to be managed for sunfish, thus eliminating a potential competitor and leaving bluegill as the primary prey of largemouth bass. The direct and indirect effects of gizzard shad have been shown to affect both bluegill growth and population size structure (Aday et al. 2003). The KDFWR also enhances the bluegill fisheries in some of these small impoundments with occasional fertilization to increase production. However, outside of small urban lakes, no size limits and very limited creel limit restrictions (Cedar Creek Lake and Greenbo Lake) for bluegill have ever been imposed by KDFWR.

Redear sunfish are known to favor lakes and ponds with abundant vegetation (Pflieger 1997). With their molariform pharyngeal teeth and associated musculature they are adapted for feeding on the mollusks (Etnier and Starnes 1993) that are often associated with vegetation in small impoundments. The growth potential of redear sunfish is greater on average than bluegill and other sunfish species. Also the redear sunfish's relatively lower reproductive rate keeps them from overpopulating, a common problem with other sunfish populations. These factors make them well-suited for management to provide a quality sunfish fishery in many of these small impoundments. The KDFWR recently imposed "sport fish" status on redear sunfish by instituting a statewide creel limit of 20 fish per day. However, no length limit regulations have ever been imposed on this species by KDFWR.

There was angler support for a bluegill minimum length limit in Nebraska Sandhill lakes (Paukert et al. 2002). Edison et al. (2006) found that anglers in Illinois small impoundments also would support bluegill minimum size limits and creel limits. When considering harvest restrictions such as length limits, estimates of exploitation, natural mortality, and growth rates are more valuable than other measures such as size structure or angler catch rates (Crawford and Allen 2006). It is necessary to gather preliminary data to calculate growth and mortality rates for bluegill and redear sunfish in Kentucky small impoundments before those fisheries could be managed effectively with length limits. The objective of this research was to provide these population metrics for three small, northcentral Kentucky impoundments.

STUDY AREAS

This project to gather bluegill and redear sunfish population parameters in three small impoundments was begun in 2006. The study lakes for the first year were Beaver Lake, Cedar Creek Lake, and Corinth Lake. Beaver Lake is a 158 acre lake in Anderson County constructed in 1963 (Figure 1). Cedar Creek Lake is a 784 acre lake in Lincoln County that was impounded in 2002. Corinth Lake is 78 acre impoundment that was constructed in 1963 (Figure 2). Because of dissimilarities like size and age of the reservoirs, it was decided after the initial year of sampling in 2006, that Elmer Davis Lake would be a better fit for the project than Cedar Creek Lake. Elmer Davis Lake is a 149 acre lake that was completed in 1958 (Figure 3). Data was analyzed from Beaver Lake, Corinth Lake, and Elmer Davis Lake for the sampling years of 2007 through 2011.

Beaver Lake has not contained gizzard shad *Dorosoma cepedianum* since a successful shad eradication was conducted in 1998. There was an unsuccessful shad eradication attempt at Corinth Lake in 2006 so shad were present to some degree throughout the study. Elmer Davis Lake contained a healthy gizzard shad population throughout the study.

METHODS

Sampling

Basic physicochemical parameter measurements were conducted at monthly intervals on the three study lakes from May through October each year. Three stations were chosen at each lake where temperature and dissolved oxygen profiles were taken along with a Secchi depth reading. Cursory notes were also recorded on visual lake and vegetation conditions. Since both Beaver and Elmer Davis lakes have two major creek arms, a station was assigned in each arm and a third station was located in the area in front of the dam at each lake (Figures 1 and 3). Three water quality monitoring stations were assigned longitudinally from downstream to upstream at Corinth Lake (Figure 2).

Diurnal electrofishing was conducted each spring to determine population abundance and size structure of bluegill and redear sunfish populations at each lake. Beginning in 2007, sampling for the current project consisted of twenty, standardized 7.5-minute shoreline electrofishing runs that were conducted during the latter half of May at about the time when bluegill and redear sunfish were spawning. However, prior sampling followed the same methods but consisted of ten, standardized 7.5-minute shoreline electrofishing runs. Diurnal electrofishing sampling was also conducted in March and April at each lake in 2007 in order to verify that sampling during the late May timeframe would provide the most representative sample of the bluegill and redear sunfish populations. Sampling effort consisted of ten 7.5-min runs in March and April. All fish were measured to the nearest 0.1 in TL. Otoliths were removed from ten fish per inch class of each species during spring electrofishing each year for calculation of age and growth information. The Kentucky Fisheries Analysis System for SAS was used to backcalculate mean length at age and estimate age frequencies with age-length keys for bluegill and redear sunfish for each lake from 2007 to 2011. Von Bertalanffy growth parameters were generated using Fisheries Analysis and Modeling Simulator software (FAMS 1.64; Slipke and Maceina 2014). The von Bertalanffy growth equation is:

$$L_t = L_{inf}\,(1 - e^{-K(t - to)})$$

where: L_t is length at some age (t), L_{inf} is maximum theoretical length that can be obtained, K is the growth coefficient, t_o is the time in years when length would theoretically be equal to zero. Metric equivalents of length at age data and von Bertalanffy growth parameters are reported in Appendix Tables 1-6.

Age frequency data was input into FAMS 1.64 software to calculate catch curve regression equations and total annual mortality estimates for each species among years. The catch curve regression equation is:

$$\ln(N_t) = \ln(N_o) - Z(t)$$

where N_t is the number at time t, N_o is the original number in a year class, Z is the instantaneous rate of change, and t is time. In certain situations, older and rarer fish can bias the results of the regression when there are not any fish in a particular year class, but fish are collected from older year classes. In this case, a value of one was added to all age classes because the natural log of zero cannot be calculated. As an alternative to the unweighted regression method, FAMS software can generate a weighted catch curve using a weighted regression technique. Both unweighted and weighted catch curve regressions were calculated for bluegill and redear sunfish at each lake. Annual survival can be derived from the equation above with the formula:

$$S = e^{-Z}$$

and annual mortality is equal to:

$$AM = 1 - S$$

FAMS also generates maximum age, which can be defined as the theoretical age when a year class has suffered complete mortality.

Prior to substituting Elmer Davis Lake for Cedar Creek Lake as a study lake, shoreline seining was conducted in September 2006 at Beaver, Corinth, and Cedar Creek lakes in an attempt to gain an index of year class strength of young-of-the-year (YOY) bluegill and redear sunfish. Ten seine hauls were made at each lake using an 8 ft. X 20 ft. seine with 1/8 in mesh. Care was taken to try to find shorelines of moderate slope that were relatively free of aquatic vegetation so effective seine hauls could be made.

Fall diurnal electrofishing was conducted for bluegill and redear sunfish at each study lake to collect length and weight data for relative weight calculations. Weight-length equations for each species at each lake were generated by pooling data from 2007-2011. The data was $\log_{10}$ transformed and weight regressed on length according to the equation:

$$\log_{10}(W) = a + b^* \log_{10}(L)$$

where W is weight, a is the y-intercept, b is the slope, and L is length. Metric equivalents of weight-length equations are reported in Appendix Table 7.

Exploitation Studies

An angler exploitation study of both bluegill and redear sunfish was conducted at each of the study lakes: Beaver Lake during 2008-2009, Elmer Davis Lake during 2009-2010, and Corinth Lake during 2010-2011. Tagging for the exploitation studies was initiated in late March or early April and each study lasted 12 months. Fish were collected and tagged using electrofishing throughout the entire lake. Only fish ≥6.0 in were tagged as both local creel survey information and the literature (Crawford and Allen 2006) suggest this as the minimum size for harvest by the majority of harvest-oriented anglers. The fish were marked using Hallprint T-bar anchor tags placed in the area just below the spiny dorsal fin. The T-bar tags consisted of a 0.75 in long filament and 1.25 in long brightly colored marker printed with KDFWR, a toll-free phone number, and sequential 4-digit numbers.

Postage paid tag return envelopes were designed with an area on the back where anglers could fill out harvest information. These envelopes were dispensed from a metal box(s) posted at the primary access area(s) at each lake and anglers could return envelopes containing tags to a mail slot on one side of the box or take with them for later return via mail. Signs were posted around the lake and at boat ramps to publicize the presence of tagged fish. A press release also went out to all media outlets describing the study. The reward system devised for the study was for all anglers returning tags to receive a pewter sunfish pin for each tag returned. Each returned tag was also an entry into monthly drawings for nine cash awards ranging from $10 to $100 (1-$100, 1-$50, 2-$25, 5-$10 awards).

To test for tagging induced mortality, 30 tagged fish of each species (≥6.0 in) were placed in a 4 ft square live car floated at the surface. For a control, 30 untagged individuals of each species (≥6.0 in) were placed in a similar live car floated beside the first. The fish remained in the live cars for 7 days and then were recovered from the net to calculate mortality due to the tagging procedure. Tag loss was estimated by double tagging approximately 25% of each species. The tag would be assumed to have been lost when an angler returns only one tag from a double tagged fish. Estimates of the tag reporting rate by anglers is essential for estimating exploitation (Pollock et al. 1991) and can be the greatest source of error when estimating exploitation (Miranda et al. 2002). There are various methods of estimating the tag reporting rate but a direct measure using creel clerk observations was used in the current study (Paukert et al. 2002; Crawford and Allen 2006). Concurrent creel surveys were conducted in conjunction with each of the exploitation studies. An estimate of non-reporting error was made by having the creel clerk surreptitiously record the tag number of tagged fish during the process of measuring the angler's catch. This allowed the comparison of tags recorded in the angler's creel with the tag return database later to determine the rate of non-reporting. A second method of determining tag non-reporting was also tested. Creel clerks gave anglers a tag and instructed them that they could return the tag and be eligible for the same rewards as if they had returned a tag from a fish. Exploitation rate (u) was calculated for each lake with tag mortality, tag loss, and non-reporting corrections using the formula:

$$u = \frac{N_r/\lambda}{[N_o(1-t)(1-m)]}$$

where: N_r is the number of tags returned from harvested fish, λ is the rate of tag reporting, N_o is the number of fish tagged, t is the percent tag loss, and m is the percent tag-induced mortality

A population estimate was also calculated at Beaver Lake in 2008 and Corinth Lake in 2010 by observing the number of tagged and untagged fish of each species (≥6.0 in) collected during a follow-up sampling and standardized spring sampling.

Creel Surveys

A roving creel survey was conducted concurrently with the exploitation studies at each lake to assess the angling effort and harvest of sunfish and other species and to observe tagged fish for estimating reporting rate. Creel surveys generally began in late March or early April and ran through the end of October. A roving creel survey design was used with all areas having equal probabilities. The creel clerk surveyed ten weekdays and six weekend days during all months. One instantaneous count was made by boat at a random time during a one hour interval each survey period. Creel survey periods were half days in all months and also had equal probabilities. Harvested fish were counted, measured, and observed for tags. Angling effort for bluegill and redear sunfish was combined, but catch and harvest for sunfish was separated by species. Creel clerks were instructed to make every effort to gain completed trip information. In conjunction with the creel survey, the creel clerk also administered a survey to query anglers as to their satisfaction with the fishery and their experience.

RESULTS and DISCUSSION

Each of the three study lakes was somewhat distinct in terms of amount and type of aquatic macrophytes during the project. Beaver Lake typically had an early, dense infestation of curly-leaf pondweed *Potamogeton crispus* that was topped out in 8 to 12 feet of water by the end of May. The pondweed would die back during the heat of the summer and then a much less dense community of spiny-leaf naiad *Najas minor* would appear. Corinth Lake was dominated by beds of water willow *Justicia americana* that would extend out to a depth of 5-6 feet. There were also pockets of creeping water primrose *Ludwigia peploides* and water lily *Nuphar spp*. At Elmer Davis Lake, the aquatic macrophytes community was dominated by curly-leaf pondweed early, although not near the same density or coverage as at Beaver Lake. As the pondweed died back, coontail *Ceratophyllum demersum* would proliferate in its place.

Monthly basic physicochemical parameters were collected at each lake from 2006 through 2011. It is beyond the scope of this analysis to attempt to relate this data to sunfish population parameters, so this data will not be presented here. The data can be found in the F-40, Subsection I: Lake Fisheries Investigation Annual Performance Reports, Segments 29 through 34.

Timing of Sampling

Sampling at Beaver Lake took place on 21 March, 27 April and 21 May 2007. Bluegill up to the 8-in class were collected in each month of sampling with an overall catch rate of 256.0 fish/h, 59.2 fish/h, and 103.2 fish/h, respectively (Figure 4). The higher relative catch rate in March at Beaver Lake is likely strongly influenced by the fact that by April shoreline aquatic vegetation is so dense as to prevent effective electrofishing. Sampling at Corinth Lake took place on 23 March, 25 April and 23 May 2007. No bluegill of the 8-in class or greater were collected in any month (Figure 5). Overall catch rate was 312.0 fish/h, 268.8 fish/h, and 257.6 fish/h, respectively. Large fish were captured in early spring sampling, however, in relative terms, smaller bluegill were noticeably less abundant at Beaver and Corinth lakes in early samples. The results from Elmer Davis Lake followed a different pattern. Sampling took place on 21 March, 30 April and 22 May 2007. Bluegill up to the 8-in class were collected in each month sampled with the exception of a single 9-in class fish in April. The overall catch rates were 244.8 fish/h, 452.8 fish/h, and 140.0 fish/h, respectively (Figure 6). There was higher relative abundance of the smaller bluegill inch classes in the May sample. This and the higher relative catch rate observed in April cannot be confidently explained, although similar to Beaver Lake, the abundant shoreline vegetation by May could have precluded higher catch rates. Catch patterns of redear sunfish (Figures 7, 8, and 9) were similar to the bluegill in that the relative abundance of smaller inch classes was best in the May samples at Beaver and Corinth lakes but not at Elmer Davis Lake. It was concluded to continue using May sampling to get the best representative sample for trend analysis of ≥2.0 in bluegill and redear populations.

<u>Spring electrofishing</u>

Spring diurnal electrofishing showed variable trends among lakes and between species. These variations can likely be explained by inconsistent recruitment, varying aquatic macrophytes densities, and changing predator and prey communities. For example, project sampling, in combination with prior sampling, indicated that bluegill catch rates at Beaver Lake may have been declining and size structure improving (Table 1) after a shad eradication in 1998. However, the catch rate of bluegill more than doubled in 2011 relative to the prior year. The increased catch rates were seen across all length classes. It is possible that the higher catch rates could be attributed to increased catchability of the bluegill after lake-wide herbicide treatment resulted in substantial aquatic vegetation reduction. The bluegill population at Corinth Lake was generally dominated by smaller fish as bluegill exceeding 8.0 in were rare (Table 2). The size structure of the bluegill population at Elmer Davis Lake (Table 3) was consistently better than at either Beaver or Corinth lakes.

The abundance of aquatic macrophytes at Beaver Lake during the project (2007-2011) likely favored the redear sunfish population (Table 4). There had been an exceptional redear sunfish population at Corinth Lake during the 1990’s and early 2000’s that was likely due to the presence of the invasive Chinese Mystery Snail *Cipangopaludina chinensis*. The redear sunfish population received heavy fishing pressure and at about the same time the invasive snails seemed to decline (Table 5). By the time the sunfish project began, electrofishing sampling no longer produced redear sunfish exceeding the 10-in class. Seining in 2006 confirmed that the Chinese mystery snail population had either dramatically dropped or been lost altogether as seine hauls produced only dead snail shells. In the 5-year span from 2007 to 2011, the Elmer Davis Lake redear sunfish population had low density but relatively good size structure (Table 6).

<u>Recruitment</u>

Results from fall 2006 seining were consistent across each of the three lakes that were sampled (Cedar Creek Lake data included even though it was subsequently dropped in favor of Elmer Davis Lake). The vast majority of bluegill collected with seining were in the 1-in class. Most redear sunfish collected with seining were in the 1- or 2-in size classes. Bluegill at Beaver Lake were limited almost exclusively to the 1-in size class, encompassing over 92 % of those collected (Table 7) while the redear collected were a little more diverse with 65% in the 1-in class (Table 8). Nearly 95% of bluegill collected in seine hauls at Cedar Creek Lake were in the 1-in class (Table 9). Redear sunfish collected were split with 60% in the 1-in class and 40 % in the 2-in classes (Table 10). Nearly 82% of bluegill collected in seine hauls at Corinth Lake were in the 1-in class (Table 11). Redear sunfish collected were split with 45% in the 1-in class and 55% in the 2-in classes (Table 12). As can be seen from the high standard errors of the mean CPUE, highly variable seine hauls resulted in coefficients of variation for bluegill of 63%, 49%, and 65% at Beaver, Cedar Creek, and Corinth lakes, respectively and coefficients of variation for redear sunfish of 96%, 83%, and 74%. Coefficients of variation at this level are too high for reliable usage of seining. Increasing effort would be necessary to bring down variability and the benefits do not outweigh the effort as recruitment is likely determined at larger sizes anyway.

Growth

The back-calculated lengths at age and the von Bertalanffy growth parameters for bluegill were very consistent among years at Beaver Lake with L_{inf} ranging from 8.0 to 8.4 in (Table 13). Bluegill growth was slower and slightly more variable at Corinth Lake (Table 14). The maximum age of bluegill collected from Elmer Davis Lake varied from age-4 to age-10 among the five years of age data (Table 15). The 2009 Elmer Davis Lake data, where the oldest fish collected was age-4, provided an L_{inf} of 14.8 in. This is an example where the quality of the data needs to be evaluated before it is used for further analysis. Ages with only a single fish can skew the data and the same can be said, if for whatever reason, the biggest (i.e. oldest) fish in the population were not collected in the sample. The maximum length observed in empirical data of the species in question can be used as a guide. FAMS software allows the investigator to manually set the L_{inf}. If sunfish maximum theoretical length was not within 10% (Sammons et al. 2006) or 25% (Sammons and Maceina 2009) of the observed length then the L_{inf} was fixed at the observed maximum length and the model rerun. The maximum lengths of bluegill observed over the five years in the current study were 8.5, 7.8, and 8.9 in at Beaver, Corinth, and Elmer Davis lakes.

With a few exceptions, the growth of redear sunfish also showed consistency within each lake. In 2008, a single slow-growing eight year old fish contributed to a relatively lower L_{inf} at Beaver Lake (Table 16). As was seen with bluegill, redear sunfish maximum length at Corinth Lake was lower relative to the other two lakes (Table 17). The calculated maximum length of redear sunfish was greatest at Elmer Davis Lake (Table 18). It appeared that redear sunfish were living longer at both Corinth and Elmer Davis Lakes during the study, but not necessarily attaining a greater length. The maximum lengths of redear sunfish observed over the five years of the study were 10.2, 9.9, and 10.1 in at Beaver, Corinth, and Elmer Davis lakes. The benefit of having five years of data is the investigator can omit the most biased data and average the remaining von Bertalanffy growth equation parameter estimates allowing for the most reliable estimate of growth.

Species weight-length equations from individual bodies of water can be used to give the best predictions of yield and mean weight of harvested fish during population modeling. There were very strong relationships between weight and length of both bluegill and redear sunfish at all three study lakes (Table 19).

Total annual mortality

Both bluegill and redear sunfish were considered fully recruited to the gear at age-2 for catch curve regression equations. Instantaneous rate of mortality (Z), annual mortality (AM), and maximum age values for both un-weighted and weighted catch curves were calculated for bluegill (Tables 20-22) and redear sunfish (Tables 23-25) for each lake. Catch curves can be biased by several factors, such as: 1) variable recruitment, 2) variable survival among year classes, 3) variable survival over time, and 4) samples that are not representative of the true age structure of the population (Ricker 1975). Each of these biases may be present at some level in some years in the current study considering the trophic level of sunfish and the fact that the spring collections were sometimes made during the spawning season when it was possible that there was an inordinate vulnerability of large fish. As with the back-calculated length data, there are some instances when too much bias exists in the catch data to be useful. In this case, the investigator can use the age-frequency data and the maximum age as a guide. The maximum age of both species in most years at the three lakes was age-8. The best example of bias is the 2008 redear sunfish data from Beaver Lake (Table 23). The estimated maximum age in the un-weighted (19.5) and weighted (21.6) catch curves is substantially higher than estimates from the other four years and double the oldest fish observed in empirical data (age-9). Looking at the age-frequency data, the relatively high catch rate of age-6 fish is the likely source of the bias. Again, the benefit of having multiple years of data is the investigator can omit the most biased data and average the remaining un-weighted and weighted estimates to have the most reliable estimate of mortality (Slipke and Maceina 2014). With biased data omitted, the total annual mortality of both bluegill and redear sunfish was lowest at Beaver Lake and highest at Elmer Davis Lake.

<u>Exploitation rates</u>

A total of 736 bluegill and 652 redear sunfish were tagged at Beaver Lake in spring 2008 (Table 26), 500 bluegill and 883 redear sunfish were tagged at Elmer Davis Lake in spring 2009 (Table 27), and 845 bluegill and 499 redear sunfish were tagged at Corinth Lake in spring 2010 (Table 28). Tagging was completed in one or two days for each study. No mortality of bluegill or redear sunfish was ever observed from either the treatment or control live cars in any of the three studies, thus tagging induced mortality was always zero. The tag loss estimates for bluegill and redear sunfish at Beaver Lake were 22.9% and 8.9%, respectively (Table 26). The reason for the disparity in rates of tag loss is unknown. The Elmer Davis Lake tag loss estimates for bluegill (18.2%) and redear sunfish (15.7%) were more similar (Table 27). Tag loss rates between the two species were also similar, but slightly lower at Corinth Lake (Table 28). The estimate of non-reporting error made by having the creel clerk surreptitiously record the tag number of tagged fish during the process of measuring the angler’s catch was initially poor at Beaver Lake. The sample size was very small as only six tags were observed by the creel clerk and two of these were not returned. This translated to a non-reporting estimate of 33.3%. The procedure of estimating non-reporting by the creel clerk handing out tags to anglers and then tracking returns was more problematic because the tag returns were highly variable over the course of the year and so this method was completely abandoned.

Creel clerks were able to observe more tagged fish in the anglers’ creel and the non-reporting estimates were judged to be more reliable in the two subsequent exploitation studies. At Elmer Davis, 44 tags were observed and 38 were subsequently returned for a non-reporting estimate of 13.6%. During the Corinth Lake exploitation study, 16 tags were observed and 13 were returned for a non-reporting estimate of 18.8%. Crawford and Allen (2006) evaluated both the creel clerk observation technique and high reward tags for estimating reporting rate during a sunfish exploitation study in a Florida lake. They used the creel clerk observations reporting estimate for their exploitation calculations. Using post cards as a surrogate for tags to estimate tag reporting was judged to be low in several studies (Maceina et al. 1998; Miranda et al. 2002; Quist et al.

2010). In the current study, creel clerk observations were higher and estimates of non-reporting were lower than those observed by Crawford and Allen (2006). It was judged more appropriate to conservatively use the higher of the Elmer Davis and Corinth non-reporting estimates when calculating the corrected 12-month exploitation estimate at Beaver Lake.

Tags from 115 harvested bluegill and 168 harvested redear sunfish were returned during the Beaver Lake exploitation study. After correcting for tag loss and angler non-reporting, the annual exploitation rate of fish ≥6.0 in was 0.25 for bluegill and 0.35 for redear sunfish (Table 26). At Elmer Davis Lake, 128 harvested bluegill tags and 244 harvested redear sunfish tags were returned for a corrected exploitation rate of the 0.36 and 0.38 for bluegill and redear sunfish ≥6.0 in (Table 27). The 118 harvested bluegill tags and 63 harvested redear sunfish tags that were returned from Corinth Lake resulted in a corrected annual exploitation rate (≥6.0 in) of 0.20 and 0.18 (Table 28).

The population estimates of bluegill and redear sunfish (≥6.0 in) at Beaver Lake was 42,332 or 268 fish/acre and 13,342 or 84 fish/acre (Table 29). Multiplying the population estimates and the corrected exploitation rates results in an estimated harvest of 67 bluegill per acre and 29 redear sunfish per acre at Beaver Lake during 2008 (Table 29). As a check, comparisons can be made between these numbers and the harvest estimates from the 2008 Beaver Lake creel survey. The exploitation rate x population estimate for bluegill (67 fish/acre) is much less than the creel survey harvest estimate of 144 fish/acre. The exploitation rate x population estimate (29 fish/acre) and the redear sunfish harvest estimate from the creel survey (38 fish/acre) were more similar (Table 29). There was a lower population density of both bluegill and redear sunfish at Corinth Lake in 2010 as the population estimates were 197 and 27 fish/acre. However, when comparing the two methods of estimating harvest, the exploitation rate x population estimates of 39 bluegill/acre and 5 redear sunfish/acre were very similar to the creel survey harvest estimates of 42 and 4 fish/acre (Table 30). Another way of checking the exploitation estimates from the tagging studies is a direct estimate of exploitation that is the ratio of the creel survey fish harvest estimate and the population estimate (Miranda et al. 2002). The ratios of these two estimates from Beaver Lake yield exploitation estimates of 0.54 for bluegill and 0.45 for redear sunfish (Table 29), which is higher than the tagging study estimates. However, this same ratio calculated for Corinth Lake yields exploitation estimates of 0.21 and 0.15 for bluegill and redear sunfish, which are quite similar to the tagging study exploitation estimates. The similarity of the results of these disparate ways at estimating exploitation and harvest lends credence to their validity. A full presentation of the creel survey data from Beaver (2008), Elmer Davis (2009), and Corinth (2010) lakes can be found in the F-50, Project I Annual Performance Reports, Segments 31 through 33, respectively.

The results of this research project provide estimates of bluegill and redear sunfish growth, annual total mortality, and annual fishing mortality. These are all of the population metrics necessary to conduct population simulations and evaluate the effects of various minimum length limits. Other population metrics can be derived given the known data. With reliable estimates of total mortality and exploitation (fishing mortality), annual natural mortality can be estimated by using the following equation and solving for annual natural mortality:

$$\mathrm{AM} = u + v$$

where AM is annual total mortality, u is the annual exploitation rate, and v is the annual natural mortality. There are also other methods to estimate natural mortality. The FAMS 1.64 software has six differing methods for estimating natural mortality built into the program. See the FAMS manual (Slipke and Maceina 2014) for a complete description of each and for references.

Population modeling allows the analyst to quickly and efficiently explore the potential outcome of various management options (Johnson 1995). When conducting population modeling, it is advisable to use a range of fishing and natural mortality rates that encompass the investigators best estimates of these rates from the population modeled (Maceina et al. 1998; Paukert et al. 2002; Slipke and Maceina 2014). Analysts should also simulate a range of minimum size limit regulations as it may reveal some threshold at which the risks outweigh the reward. The simulations on bluegill in Nebraska Sandhill lakes indicated that yield and size structure were only higher at the lowest natural mortality and exploitation rates of 30% or greater (Paukert et al. 2002). Modeling of bluegill and redear sunfish populations in a Florida lake showed that a high rate of natural mortality precluded any benefits of minimum size limits (Crawford and Allen 2006). This was in contrast to Georgia rivers where natural mortality was low enough to allow harvest restrictions on bluegill and redear sunfish if growth was fast (Sammons and Maceina 2007). Population modeling showed that natural mortality of bluegills in three southeastern reservoirs was too high for any benefit of minimum size limits or reduced creel limits but the lower natural mortality rate of redear sunfish showed significant improvements in size structure and minimal decline in yield from various harvest restriction scenarios (Sammons et al. 2006). Looking at empirical data from eight Wisconsin lakes, Rypel (2015) found that reduction in the aggregate creel limit led to improved bluegill size structure, especially on more productive lakes.

MANAGEMENT IMPLICATIONS

The data generated from this project can be used to predict the impacts of harvest restrictions on bluegill and redear sunfish in Kentucky small impoundments. The robust estimates of growth, total mortality, and fishing mortality for three lakes should allow a good comparison of population simulations of various length limit options. Additionally, an analysis of the recent creel data would allow the analyst to determine the relative effects of creel reductions to adjust the mortality estimates accordingly in population simulations. If harvest restrictions were implemented, it is recommended that a new research project be initiated to evaluate the empirical effects of the regulations and compare them to the results of the simulations.

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REFERENCES

Aday, D. D., R. J. H. Hoxmeier, and D. H. Wahl. 2003. Direct and indirect effects of gizzard shad on bluegill growth and population size structure. Transactions of the American Fisheries Society 132:47-56.

Crawford, S., and M. S. Allen. 2006. Fishing and natural mortality of bluegills and redear sunfish at Lake Panasoffkee, Florida: implications for size limits. North American Journal of Fisheries Management 26:42-51.

Edison, T. W., D. H. Wahl, M. J. Diana, D. P. Philipp, and D. J. Austen. 2006. Angler opinion of potential bluegill regulations on Illinois lakes: effects of angler demographics and bluegill population size structure. North American Journal of Fisheries Management 26:800-811.

Etnier, D. A. and W. C. Starnes. 1993. The fishes of Tennessee. The University of Tennessee Press, Knoxville.

Johnson, B. L. 1995. Applying computer simulation models as learning tools in fishery management. North American Journal of Fisheries Management 15:736-747.

Maceina, M. J., P. W. Bettoli, S. D. Finely, and V. J. DiCenzo. 1998. Analyses of the sauger fishery with simulated effects of a minimum size limit in the Tennessee River of Alabama. North American Journal of Fisheries Management 18:66-75.

Miranda, L. E., R. E. Brock, and B. S. Dorr. 2002. Uncertainty of exploitation estimates made from tag returns. North American Journal of Fisheries Management 22:1358-1363.

Paukert, C. P., D. W. Willis, and D. W. Gabelhouse, Jr. 2002. Effect and acceptance of bluegill length limits in Nebraska natural lakes. North American Journal of Fisheries Management 22:1306-1313.

Pflieger, W. L. 1997. The Fishes of Missouri. Missouri Department of Conservation. Jefferson City, Missouri.

Pollock, K. H., J. M. Hoenig, and C. M. Jones. 1991. Estimation of fishing and natural mortality when a tagging study is combined with a creel survey or port sampling. Pages 423-434 *in* D. Guthrie, J. M. Hoenig, M. Holliday, C. M. Jones, M. J. Mills, S. A. Moberly, K. H. Pollock, and D. R. Talhelm, editors. Creel and angler surveys in fisheries management. American Fisheries Society, Symposium 12, Bethesda, Maryland.

Quist, M. C., J. L. Stephen, S. T. Lynott, J. M. Goeckler, and R. D. Schultz. 2010. Exploitation of walleye in a Great Plains reservoir: harvest patterns and management scenarios. Fisheries Management and Ecology 17:522-531.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Fisheries Research Board of Canada Bulletin 191.

Rypel, A. L. 2015. Effects of a reduced daily bag limit on bluegill size structure in Wisconsin lakes. North American Journal of Fisheries Management 35:388-397.

Sammons, S. M., and M. J. Maceina. 2007. Population dynamics of sunfish (Lepomis spp.) in Georgia rivers with emphasis on the influence of hydrology on growth and recruitment. Final Report, Project F-77, Georgia Department of Natural Resources, Social Circle.

Sammons, S. M., and M. J. Maceina. 2009. Variation in growth and survival of bluegills and redbreast sunfish in Georgia rivers. North American Journal of Fisheries Management 29:101-108.

Sammons, S. M., D. G. Partridge, and M. J. Maceina. 2006. Differences in population metrics between bluegill and redear sunfish: implications for the effectiveness of harvest restrictions. North American Journal of Fisheries Management 26:777-787.

Slipke, J.W., and M. J. Maceina. 2014. Fishery Analysis and Modeling Simulator (FAMS). Version 1.64. American Fisheries Society, Bethesda, Maryland.

USDI. 2001a. 2001 National survey of fishing, hunting, and wildlife-associated recreation: U.S. U.S. Department of the Interior, U. S. Fish and Wildlife Service, Washington D.C.

USDI. 2001b. 2001 National survey of fishing, hunting, and wildlife-associated recreation: Kentucky. U.S. Department of the Interior, U. S. Fish and Wildlife Service, Washington D.C.

Table 1. Spring electrofishing CPUE (fish/h) for each length group of bluegill collected from Beaver Lake from 2002-2011.

Year	<3.0 in		3.0-5.9 in		6.0-7.9 in		≥8.0 in		Total	
	CPUE	S.E.	CPUE	S.E.	CPUE	S.E.	CPUE	S.E.	CPUE	S.E.
2002	5.6	1.7	175.2	22.9	152.8	27.7	0.0		333.6	44.7
2003	33.6	6.4	141.6	17.5	128.8	21.9	0.0		304.0	30.1
2004	36.0	16.0	118.4	32.4	143.2	29.3	0.0		297.6	56.4
2005	21.6	4.5	109.6	14.6	97.6	19.3	4.0	2.2	232.8	19.7
2006	20.1	4.9	60.9	8.6	55.7	13.5	8.3	2.9	145.1	24.7
2007	12.0	2.6	34.8	4.6	54.0	9.5	2.4	1.7	103.2	10.7
2008	69.6	11.1	112.4	13.3	38.0	6.3	4.0	1.4	224.0	24.6
2009	17.2	5.1	60.4	10.0	40.4	5.9	1.6	0.9	119.6	15.3
2010	35.6	8.2	134.8	10.6	24.4	5.9	4.4	1.5	199.2	17.5
2011	68.4	20.3	299.2	47.8	51.6	8.1	5.2	1.9	424.4	70.4

Table 2. Spring electrofishing CPUE (fish/h) for each length group of bluegill collected from Corinth Lake from 2002-2011.

Year	<3.0 in		3.0-5.9 in		6.0-7.9 in		≥8.0 in		Total	
	CPUE	S.E.	CPUE	S.E.	CPUE	S.E.	CPUE	S.E.	CPUE	S.E.
2002	2.4	1.2	140.0	16.7	56.8	12.1	0.0		199.2	26.6
2003	14.2	6.2	164.4	14.1	91.6	10.7	0.9	0.9	271.1	23.3
2004	17.6	4.9	174.4	15.9	61.6	10.9	0.0		253.6	22.7
2005	12.0	4.2	262.4	32.7	82.4	22.2	0.0		356.8	47.8
2006	40.4	6.0	211.2	17.9	32.8	6.4	0.0		284.4	14.7
2007	12.8	2.6	148.0	12.1	96.8	10.2	0.0		257.6	18.2
2008	4.8	1.2	180.4	13.7	105.2	12.4	0.4	0.4	290.8	18.8
2009	9.2	4.0	151.6	15.3	166.8	19.4	0.0		327.6	30.6
2010	9.4	2.6	126.6	11.1	55.1	6.9	0.0		191.1	15.5
2011	32.0	6.9	222.8	16.4	60.0	10.5	0.0		314.8	27.0

Table 3. Spring electrofishing CPUE (fish/h) for each length group of bluegill collected from Elmer Davis Lake from 2002-2011.

Year	<3.0 in		3.0-5.9 in		6.0-7.9 in		≥8.0 in		Total	
	CPUE	S.E.	CPUE	S.E.	CPUE	S.E.	CPUE	S.E.	CPUE	S.E.
2002	33.6	11.8	78.4	19.3	272.8	55.3	0.8	0.8	385.6	78.2
2003	17.6	4.7	89.6	12.9	151.2	30.1	2.4	1.7	260.8	37.1
2004	40.0	8.7	100.8	13.7	119.2	29.8	8.8	3.9	268.8	44.7
2005	38.4	11.4	92.8	16.1	59.2	9.8	8.8	3.0	199.2	23.9
2006	162.4	35.9	115.2	20.1	42.4	8.5	16.0	4.5	336.0	43.8
2007	7.6	1.8	81.6	7.4	41.6	9.7	9.2	2.4	140.0	14.9
2008	34.4	5.7	133.2	24.7	58.8	9.3	6.8	2.3	233.2	33.0
2009	8.8	1.8	58.1	6.5	33.9	3.7	1.1	0.5	101.9	7.3
2010	51.6	12.8	126.8	16.2	26.8	4.1	0.0		205.2	23.4
2011	112.4	19.6	226.0	18.9	50.0	7.3	5.6	2.5	394.0	36.2

Table 4. Spring electrofishing CPUE (fish/h) for each length group of redear sunfish collected from Beaver Lake from 2002-2011.

Year	<4.0 in		4.0-6.9 in		7.0-8.9 in		≥9.0 in		Total	
	CPUE	S.E.	CPUE	S.E.	CPUE	S.E.	CPUE	S.E.	CPUE	S.E.
2002	0.8	0.8	89.6	20.4	43.2	16.0	0.8	0.8	134.4	27.8
2003	2.4	1.2	51.2	14.0	63.2	11.4	0.0		116.8	20.0
2004	8.8	3.7	37.6	8.2	59.2	12.2	3.2	1.8	108.0	17.1
2005	7.2	2.8	84.0	7.8	92.0	14.7	8.0	2.1	191.2	22.6
2006	7.9	2.3	74.3	8.6	78.7	9.8	3.5	1.2	164.4	13.8
2007	3.2	1.7	48.8	9.7	77.2	13.9	1.6	0.8	130.8	23.3
2008	13.6	3.2	24.0	4.1	122.4	30.1	14.0	3.5	174.0	26.8
2009	2.4	0.8	30.8	5.2	44.8	8.2	2.8	1.1	80.8	11.5
2010	2.4	1.8	32.4	4.5	34.4	6.0	14.0	3.0	83.2	10.5
2011	2.4	0.8	17.2	3.9	15.6	2.8	15.6	2.8	48.0	6.3

Table 5. Spring electrofishing CPUE (fish/h) for each length group of redear sunfish collected from Corinth Lake from 2002-2011.

Year	<4.0 in		4.0-6.9 in		7.0-8.9 in		9.0-10.9 in		≥11.0 in		Total	
	CPUE	S.E.	CPUE	S.E.	CPUE	S.E.	CPUE	S.E.	CPUE	S.E.	CPUE	S.E.
2002	1.6	1.1	4.8	1.8	8.0	2.9	42.4	10.3	36.0	6.9	92.8	15.9
2003	5.3	3.0	13.3	4.2	8.9	2.5	11.6	4.4	13.3	5.0	52.4	6.1
2004	6.4	2.0	20.0	4.7	9.6	2.9	6.4	2.3	8.8	3.0	51.2	6.8
2005	9.6	2.9	42.4	3.8	38.4	13.2	4.8	2.1	3.2	1.8	98.4	17.3
2006	1.2	0.7	38.8	4.7	40.8	5.8	0.0		0.4	0.4	81.2	7.2
2007	4.8	1.4	6.0	1.6	51.2	10.3	1.2	0.7	0.0		63.2	11.6
2008	0.0		37.2	3.7	31.6	5.4	2.8	1.5	0.0		71.6	7.9
2009	0.0		16.0	3.0	80.4	11.2	9.2	2.8	0.0		105.6	14.1
2010	2.9	1.2	15.1	2.1	19.7	3.8	1.1	0.5	0.0		38.9	5.0
2011	4.8	1.9	43.2	4.9	35.2	4.8	1.2	0.7	0.0		84.4	8.0

Length group spans the <4.0 in through ≥11.0 in columns.

Table 6. Spring electrofishing CPUE (fish/h) for each length group of redear sunfish collected from Elmer Davis Lake from 2002-2011.

Year	<4.0 in		4.0-6.9 in		7.0-8.9 in		9.0-10.9 in		≥11.0 in		Total	
	CPUE	S.E.	CPUE	S.E.	CPUE	S.E.	CPUE	S.E.	CPUE	S.E.	CPUE	S.E.
2002	1.6	1.6	6.4	2.3	16.0	4.6	4.8	2.1	0.0		28.8	6.1
2003	5.6	3.2	20.0	4.2	17.6	5.3	16.0	6.0	0.0		59.2	13.5
2004	6.4	4.1	37.6	7.8	49.6	19.3	9.6	3.9	0.0		103.2	29.1
2005	0.0		44.0	11.0	60.0	16.1	24.0	5.3	0.8	0.8	128.8	26.9
2006	12.8	4.2	3.2	1.8	17.6	4.9	17.6	3.9	0.0		51.2	10.0
2007	0.4	0.4	4.8	1.7	18.4	3.4	11.6	2.9	0.0		35.2	5.7
2008	3.6	1.1	35.2	7.2	25.6	6.1	8.4	3.6	0.0		72.8	14.7
2009	1.1	0.6	17.6	2.8	10.4	2.3	2.1	0.8	0.3	0.3	31.5	4.3
2010	3.2	1.2	18.8	2.6	15.6	3.2	3.6	1.5	0.0		41.2	4.7
2011	24.0	4.4	5.6	1.7	34.4	4.5	28.0	5.0	0.0		92.0	10.3

Table 7. Length frequency distribution and CPUE (fish/h) for bluegill collected during 10 seine hauls (8 ft. X 20 ft, 1/8 in mesh) on Beaver Lake on September 18, 2006.

Inch class	Freq.	Cum. freq.	Pct.	Cum. Pct.	CPUE	Std. Err.
0	29	29	1.2	1.2	2.9	1.0
1	2218	2247	92.5	93.7	221.8	45.6
2	138	2385	5.8	99.5	13.8	5.2
3	13	2398	0.5	100.0	1.3	0.6
					239.8	48.1

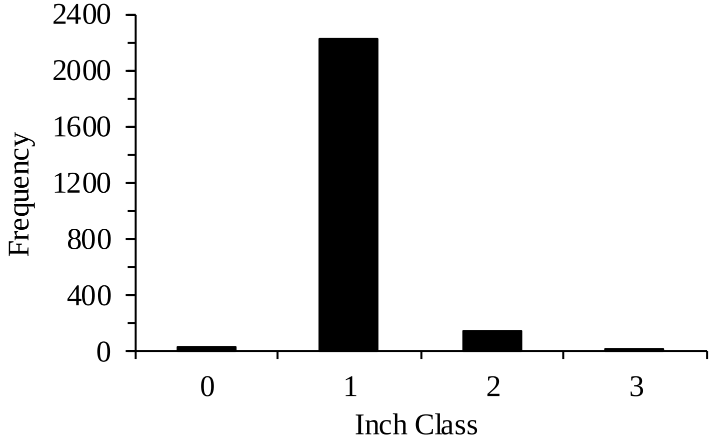

Table 8. Length frequency distribution and CPUE (fish/h) for redear sunfish collected during 10 seine hauls (8 ft. X 20 ft, 1/8 in mesh) on Beaver Lake on September 18, 2006.

Inch class	Freq.	Cum. freq.	Pct.	Cum. Pct.	CPUE	Std. Err.
1	60	60	65.2	65.2	6.0	1.6
2	14	74	15.2	80.4	1.4	0.8
3	16	90	17.4	97.8	1.6	0.8
4	2	92	2.2	100.0	0.2	0.1
					9.2	2.8

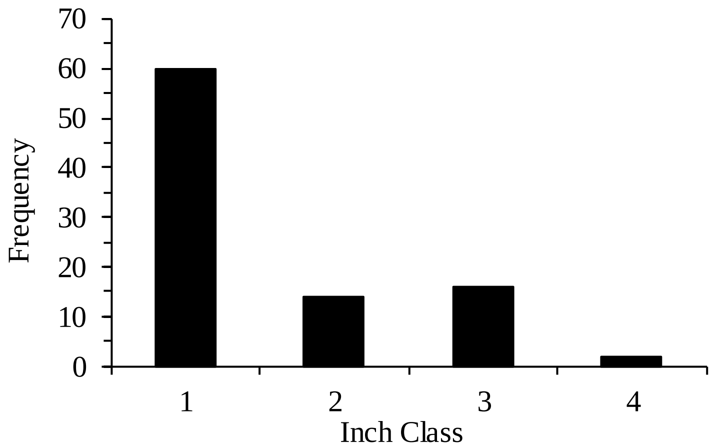

Table 9. Length frequency distribution and CPUE (fish/h) for bluegill collected during 10 seine hauls (8 ft. X 20 ft, 1/8 in mesh) on Cedar Creek Lake on September 14, 2006.

Inch class	Freq.	Cum. freq.	Pct.	Cum. Pct.	CPUE	Std. Err.
0	10	10	0.6	0.6	1.0	0.5
1	1537	1547	94.6	95.2	153.7	24.3
2	66	1613	4.1	99.3	6.6	3.6
3	12	1625	0.7	100.0	1.2	0.8
					162.5	25.0

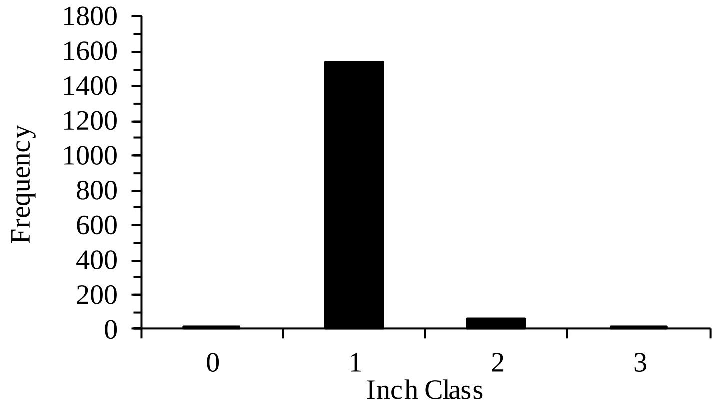

Table 10. Length frequency distribution and CPUE (fish/h) for redear sunfish collected during 10 seine hauls (8 ft. X 20 ft, 1/8 in mesh) on Cedar Creek Lake on September 14, 2006.

Inch class	Freq.	Cum. freq.	Pct.	Cum. Pct.	CPUE	Std. Err.
1	109	109	59.9	59.9	10.9	3.1
2	73	182	40.1	100.0	7.3	3.1
					18.2	4.8

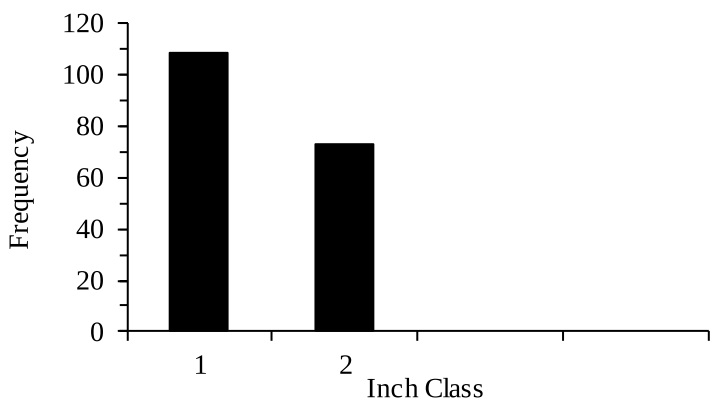

Table 11. Length frequency distribution and CPUE (fish/h) for bluegill collected during 10 seine hauls (8 ft. X 20 ft, 1/8 in mesh) on Corinth Lake on September 13, 2006.

Inch class	Freq.	Cum. freq.	Pct.	Cum. Pct.	CPUE	Std. Err.
0	128	128	13.3	13.3	12.8	5.5
1	816	944	85.0	98.3	81.6	16.7
2	12	956	1.3	99.6	1.2	0.7
3	4	960	0.4	100.0	0.4	0.2
					96.0	19.6

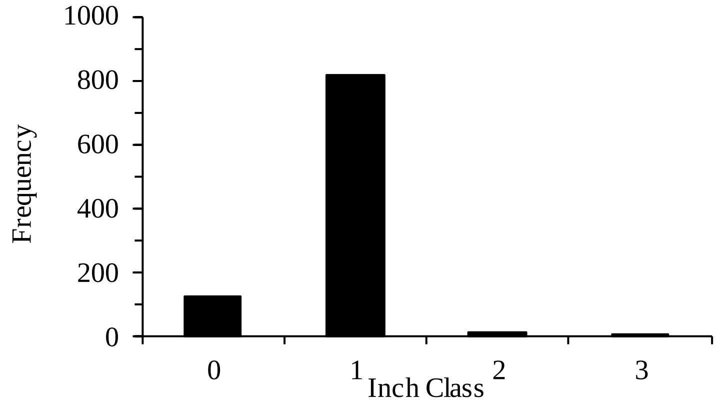

Table 12. Length frequency distribution and CPUE (fish/h) for redear sunfish collected during 10 seine hauls (8 ft. X 20 ft, 1/8 in mesh) on Corinth Lake on September 13, 2006.

Inch class	Freq.	Cum. freq.	Pct.	Cum. Pct.	CPUE	Std. Err.
1	38	38	44.7	44.7	3.8	0.7
2	47	85	55.3	100.0	4.7	1.5
					8.5	2.0

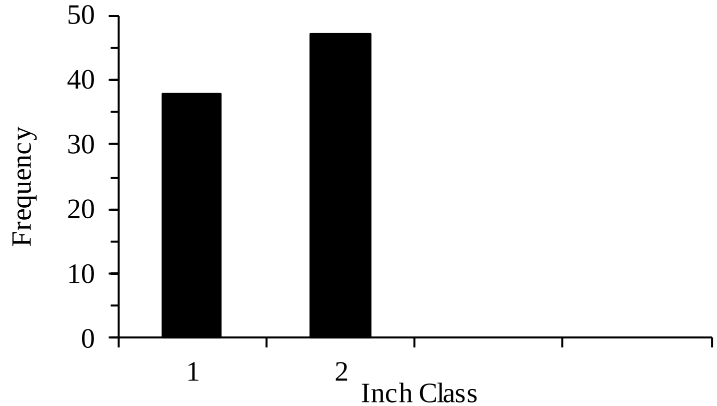

Table 13. Backcalculated lengths (in) at age from otoliths of bluegill collected from Beaver Lake in spring 2007-2011 and resulting von Bertalanffy growth parameters. L_{inf} is the maximum theoretical length (in), K is the growth coefficient, and t_o is the time in years when length would theoretically equal zero.

	Backcalculated Length (in) at Age									von Bertalanffy Growth Parameters		
Year	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	L_{inf} (in)	K	t_o
2007	2.4	4.2	6.0	6.8	7.2	7.6	7.8	8.1		8.3	0.436	0.247
2008	2.0	4.0	5.7	6.6	6.8	7.4	7.5	7.6	8.0	8.0	0.455	0.379
2009	2.6	4.6	6.0	6.9	7.2	7.5	7.8	7.9	8.3	8.2	0.446	0.148
2010	2.3	4.2	6.0	7.0	7.3	7.5	7.7	8.0	8.3	8.3	0.462	0.321
2011	2.3	4.5	6.4	7.2	7.5	7.8	8.1	8.4		8.4	0.506	0.386

Table 14. Backcalculated lengths (in) at age from otoliths of bluegill collected from Corinth Lake in spring 2007-2011 and resulting von Bertalanffy growth parameters. L_{inf} is the maximum theoretical length (in), K is the growth coefficient, and t_o is the time in years when length would theoretically equal zero.

	Backcalculated Length (in) at Age								von Bertalanffy Growth Parameters		
Year	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	L_{inf} (in)	K	t_o
2007	2.6	4.5	5.7	6.6	7.0	7.0	7.3	7.5	7.6	0.502	0.173
2008	2.3	4.4	5.8	6.5	6.9	6.6			7.0	0.661	0.417
2009	2.8	4.7	5.9	6.8	7.1	7.5			8.0	0.461	0.070
2010	2.3	4.2	5.6	6.3	6.9	6.7	7.1	7.4	7.4	0.503	0.271
2011	2.3	4.4	5.7	6.5	6.8	6.8			7.2	0.606	0.373

Table 15. Backcalculated lengths (in) at age from otoliths of bluegill collected from Elmer Davis Lake in spring 2007-2011 and resulting von Bertalanffy growth parameters, L_{inf} is the maximum theoretical length (in), K is the growth coefficient, and t_o is the time in years when length would theoretically equal zero.

	Backcalculated (in) Length at Age										von Bertalanffy Growth Parameters		
Year	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	L_{inf} (in)	K	t_o
2007	2.4	4.5	6.5	7.4	7.8	8.1	8.7				9.0	0.448	0.331
2008	2.5	4.5	6.3	7.3	7.5	7.9	8.0	8.3	8.3	8.4	8.4	0.492	0.313
2009	2.4	4.3	6.1	7.4							14.8	0.175	-0.008
2010	2.3	4.4	6.4	7.1	7.4	8.0					8.5	0.490	0.375
2011	2.4	4.5	6.4	7.3	7.6	7.7	7.9				8.2	0.561	0.412

Table 16. Backcalculated lengths (in) at age from otoliths of redear sunfish collected from Beaver Lake in spring 2007-2011 and resulting von Bertalanffy growth parameters. L_{inf} is the maximum theoretical length (in), K is the growth coefficient, and t_o is the time in years when length would theoretically equal zero.

	Backcalculated Length (in) at Age								von Bertalanffy Growth Parameters		
Year	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	L_{inf} (in)	K	t_o
2007	2.8	4.8	6.7	7.9	8.7	9.5	9.3		10.5	0.358	0.174
2008	2.4	4.5	6.3	7.3	8.2	8.8	8.6	8.5	9.1	0.447	0.360
2009	2.8	4.8	6.6	7.6	8.3	8.9	9.4		10.4	0.332	0.066
2010	2.5	4.9	7.0	8.0	8.7	9.3	9.7		10.4	0.398	0.323
2011	2.8	5.4	7.4	8.6	9.1	9.5	9.5		10.0	0.508	0.377

Table 17. Backcalculated lengths (in) at age from otoliths of redear sunfish collected from Corinth Lake in spring 2007-2011 and resulting von Bertalanffy growth parameters. L_{inf} is the maximum theoretical length (in), K is the growth coefficient, and t_o is the time in years when length would theoretically equal zero.

	Backcalculated Length (in) at Age								von Bertalanffy Growth Parameters		
Year	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	L_{inf} (in)	K	t_o
2007	3.5	6.2	7.6	8.1	8.8				9.1	0.639	0.237
2008	3.4	5.9	7.4	8.0	8.7	8.9			9.3	0.553	0.171
2009	3.3	6.1	7.5	8.1	8.8	9.1	9.0		9.2	0.610	0.269
2010	3.0	5.6	7.2	8.1	8.9	9.1	9.5		9.9	0.470	0.224
2011	3.0	6.0	7.7	8.2	8.3	8.3	8.9	9.3	8.9	0.712	0.418

Table 18. Backcalculated lengths (in) at age from otoliths of redear sunfish collected from Elmer Davis Lake in spring 2007-2011 and resulting von Bertalanffy growth parameters. L_{inf} is the maximum theoretical length (in), K is the growth coefficient, and t_o is the time in years when length would theoretically equal zero.

	Backcalculated Length (in) at Age								von Bertalanffy Growth Parameters		
Year	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	L_{inf} (in)	K	t_o
2007	3.3	6.7	8.7	9.8	10.1				10.8	0.626	0.424
2008	3.3	6.6	8.8	9.7	10.2	10.6			11.0	0.598	0.409
2009	3.1	6.1	7.9	8.4	9.1	9.9	10.4		10.6	0.454	0.207
2010	3.1	6.5	8.3	9.0	9.6	10.1	10.5	10.8	10.7	0.531	0.335
2011	3.3	6.7	8.8	9.8	9.6				10.2	0.745	0.488

Table 19. Log_{10} transformed weight-length regression coefficients for bluegill and redear sunfish from Beaver, Corinth, and Elmer Davis lakes. Length (in) and weight (lbs) data collected in the fall from 2007-2011 was pooled.

	Bluegill			Redear Sunfish		
Lake	Intercept	Slope	r^2	Intercept	Slope	r^2
Beaver Lake	-3.411	3.273	0.953	-3.456	3.316	0.975
Corinth Lake	-3.162	2.952	0.941	-3.311	3.136	0.976
Elmer Davis Lake	-3.233	3.099	0.941	-3.335	3.222	0.962

Table 20. Catch data used to calculate catch curves of bluegill collected from Beaver Lake in spring 2007-2011 and resulting un-weighted and weighted estimates of instantaneous mortality (Z), annual mortality (AM), and maximum age.

	Frequency by Age								Un-weighted Catch Curve			Weighted Catch Curve		
Year	2	3	4	5	6	7	8	9	Z	AM	Max. Age	Z	AM	Max. Age
2007	57	74	69	9	19	1	3		-0.669	0.488	9.0	-0.635	0.470	9.3
2008	258	46	29	27	20	8	5	9	-0.461	0.370	12.3	-0.495	0.391	11.8
2009	141	42	26	21	7	2	1	2	-0.682	0.494	8.9	-0.723	0.515	8.6
2010	240	32	25	8	6	8	2	2	-0.608	0.456	9.5	-0.669	0.488	9.1
2011	601	65	45	16	12	3	3		-0.835	0.566	8.7	-0.900	0.593	8.4

Table 21. Catch data used to calculate catch curves of bluegill collected from Corinth Lake in spring 2007-2011 and resulting un-weighted and weighted estimates of instantaneous mortality (Z), annual mortality (AM), and maximum age.

	Frequency by Age							Un-weighted Catch Curve			Weighted Catch Curve		
Year	2	3	4	5	6	7	8	Z	AM	Max. Age	Z	AM	Max. Age
2007	308	44	185	26	1	1	13	-0.796	0.549	8.7	-0.906	0.596	8.1
2008	378	114	61	99	60			-0.382	0.318	16.3	-0.399	0.329	15.8
2009	171	221	286	12	12			-0.823	0.561	9.1	-0.758	0.531	9.6
2010	284	134	181	23	1	1	2	-1.067	0.656	7.6	-1.119	0.673	7.4
2011	371	67	89	35	28			-0.582	0.441	11.4	-0.602	0.452	11.1

Table 22. Catch data used to calculate catch curves of bluegill collected from Elmer Davis Lake in spring 2007-2011 and resulting un-weighted and weighted estimates of instantaneous mortality (Z), annual mortality (AM), and maximum age.

	Frequency by Age									Un-weighted Catch Curve			Weighted Catch Curve		
Year	2	3	4	5	6	7	8	9	10	Z	AM	Max. Age	Z	AM	Max. Age
2007	206	60	45	19	9	5				-0.719	0.512	9.1	-0.728	0.517	9.1
2008	191	173	43	9	5	1	7	2	2	-0.624	0.464	9.8	-0.747	0.526	9.0
2009	177	73	88							-0.349	0.295	16.3	-0.361	0.303	15.9
2010	279	54	22	3						-1.450	0.765	5.9	-1.423	0.759	5.9
2011	399	81	63	10	2	10				-0.897	0.592	8.2	-0.993	0.629	7.8

Table 23. Catch data used to calculate catch curves of redear sunfish collected from Beaver Lake in spring 2007-2011 and resulting un-weighted and weighted estimates of instantaneous mortality (Z), annual mortality (AM), and maximum age.

	Frequency by Age							Un-weighted Catch Curve			Weighted Catch Curve		
Year	2	3	4	5	6	7	8	Z	AM	Max. Age	Z	AM	Max. Age
2007	40	111	121	54	1			-0.810	0.555	8.2	-0.596	0.449	9.9
2008	30	60	55	94	154	4	13	-0.246	0.218	19.5	-0.216	0.194	21.6
2009	65	34	20	54	20	4		-0.415	0.340	12.2	-0.389	0.323	12.7
2010	76	59	28	11	20	9		-0.424	0.346	12.1	-0.435	0.353	11.9
2011	42	24	24	11	6	7		-0.397	0.328	11.3	-0.402	0.331	11.2

Table 24. Catch data used to calculate catch curves of redear sunfish collected from Corinth Lake in spring 2007-2011 and resulting un-weighted and weighted estimates of instantaneous mortality (Z), annual mortality (AM), and maximum age.

	Frequency by Age							Un-weighted Catch Curve			Weighted Catch Curve		
Year	2	3	4	5	6	7	8	Z	AM	Max. Age	Z	AM	Max. Age
2007	26	43	68	8				-0.308	0.265	14.3	-0.270	0.237	15.8
2008	98	18	19	37	5			-0.523	0.407	10.0	-0.523	0.407	10.0
2009	37	171	7	18	29	2		-0.542	0.418	9.9	-0.507	0.398	10.3
2010	76	59	28	11	20	9		-0.424	0.346	12.1	-0.435	0.353	11.9
2011	110	69	13	6	1	1	3	-0.780	0.542	7.6	-0.954	0.615	7.0

Table 25. Catch data used to calculate catch curves of redear sunfish collected from Elmer Davis Lake in spring 2007-2011 and resulting un-weighted and weighted estimates of instantaneous mortality (Z), annual mortality (AM), and maximum age.

	Frequency by Age							Un-weighted Catch Curve			Weighted Catch Curve		
Year	2	3	4	5	6	7	8	Z	AM	Max. Age	Z	AM	Max. Age
2007	50	16	16	4				-0.758	0.531	7.1	-0.747	0.526	7.1
2008	113	44	3	4	3			-0.966	0.619	6.5	-1.110	0.670	6.1
2009	78	27	3	1	3	6		-0.586	0.444	7.8	-0.775	0.539	6.9
2010	55	33	5	2	1	2	2	-0.613	0.458	7.6	-0.785	0.554	6.8
2011	20	107	30	8				-0.402	0.331	11.7	-0.345	0.292	13.0

Table 26. Summary statistics of the bluegill and redear sunfish (≥6.0 in) exploitation study conducted in Beaver Lake from March 18, 2008 to March 17, 2009.

	Bluegill		Redear Sunfish	
	Number	Mean Length (in)	Number	Mean Length (in)
Total Fish Tagged	736		652	
Total Return	142	7.2	213	7.9
Total Kept	115	7.2	168	7.9
Total Released	27	7.0	45	7.6
Uncorrected 12 month exploitation	0.16		0.26	
Tag loss estimate (return one tag from a double tagged fish)	22.9% (11 of 48)		8.9% (5 of 56)	
Nonreporting estimate	18.8%		18.8%	
Tag induced mortality estimate	0.0%		0.0%	
Corrected 12 month exploitation	0.25		0.35	

Table 27. Summary statistics of the bluegill and redear sunfish (≥6.0 in) exploitation study conducted in Elmer Davis Lake from March 30, 2009 to March 29, 2010.

	Bluegill		Redear Sunfish	
	Number	Mean Length (in)	Number	Mean Length (in)
Total Fish Tagged	500		883	
Total Return	156	6.9	287	7.4
Total Kept	128	6.9	244	7.4
Total Released	28	6.7	43	7.3
Uncorrected 12 month exploitation	0.26		0.28	
Tag loss estimate (return one tag from a double tagged fish)	18.2 % (8 of 44)		15.7 % (11 of 70)	
Nonreporting estimate	13.6%		13.6%	
Tag induced mortality estimate	0.0%		0.0%	
Corrected 12 month exploitation	0.36		0.38	

Table 28. Summary statistics of the Bluegill and Redear Sunfish (≥6.0 in) exploitation study conducted in Corinth Lake from April 5, 2010 to April 4, 2011.

	Bluegill		Redear Sunfish	
	Number	Mean Length (in)	Number	Mean Length (in)
Total Fish Tagged	845		499	
Total Return	179	6.5	92	7.6
Total Kept	118	6.5	63	7.7
Total Released	61	6.4	29	7.6
Uncorrected 12 month exploitation	14.0%		12.6%	
Tag loss estimate (return one tag from a double tagged fish)	13.6% (6 of 44)		14.3% (4 of 28)	
Nonreporting estimate	18.8%		18.8%	
Tag induced mortality estimate	0.0%		0.0%	
Corrected 12 month exploitation	0.20		0.18	

Table 29. Population estimate of bluegill and redear sunfish (≥6.0 in) at Beaver Lake derived from fish tagged and recaptured in spring 2008 during the exploitation study.

	Bluegill		Redear	
	Total	Per acre	Total	Per acre
Number marked	736	4.7	652	4.1
Number captured	1,783	11.3	1,371	8.7
Number recaptured	31	0.2	67	0.4
Population estimate	42,332	268	13,342	84
Variance	54,409,853	344,366	2,267,392	14,351
90% Confidence interval	12,134	77	2,477	16
Lower limit	30,198	191	10,865	69
Upper limit	54,466	345	15,819	100
Corrected exploitation rate x population estimate	10,583	67	4,643	29
2008 Beaver Lake creel survey harvest estimate	22,827	144	6,048	38
Ratio of creel survey harvest estimate and population estimate	0.54		0.45	

Table 30. Population estimate of the bluegill and redear sunfish (≥6.0 in) at Corinth Lake derived from fish tagged and recaptured in spring 2010 during the exploitation study.

	Bluegill		Redear Sunfish	
	Total	Per acre	Total	Per acre
Number marked	845	10.8	499	6.4
Number captured	508	6.5	318	4.1
Number recaptured	18	0.2	74	0.9
Population estimate	15,331	197	2,144	27
Variance	7,668,986	98,320	40,627	521
90% CI	4,555	58	332	4
Lower Limit	10,776	138	1,813	23
Upper Limit	19,886	255	2,476	32
Corrected exploitation rate x population estimate	3,051	39	388	5
2010 Corinth Lake creel survey harvest estimate	3,244	42	313	4
Ratio of creel survey harvest estimate and population estimate	0.21		0.15	

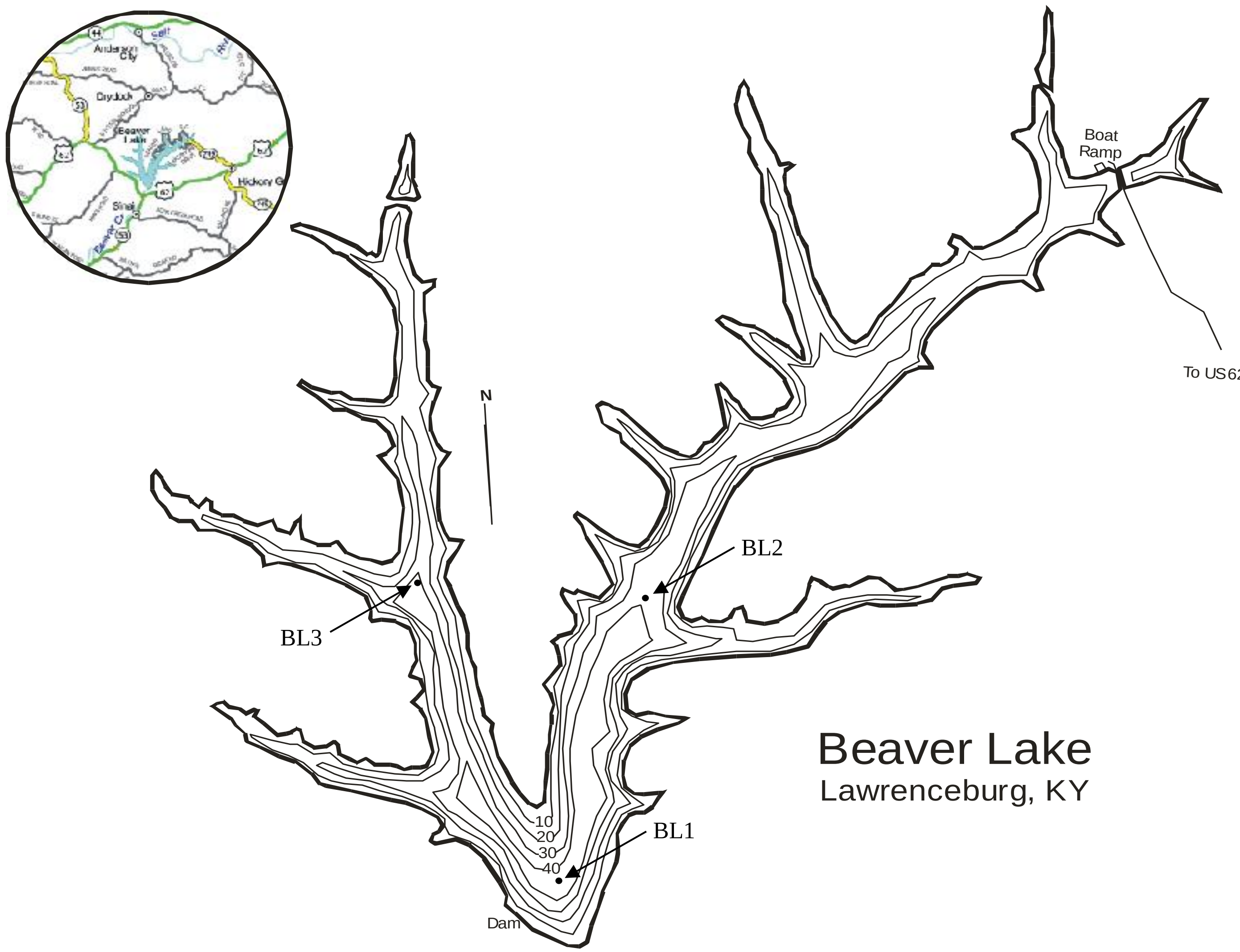

Figure 1. Map of Beaver Lake with locations of 3 stations where bimonthly temperature/dissolved oxygen profiles were collected from May to October 2007-2011.

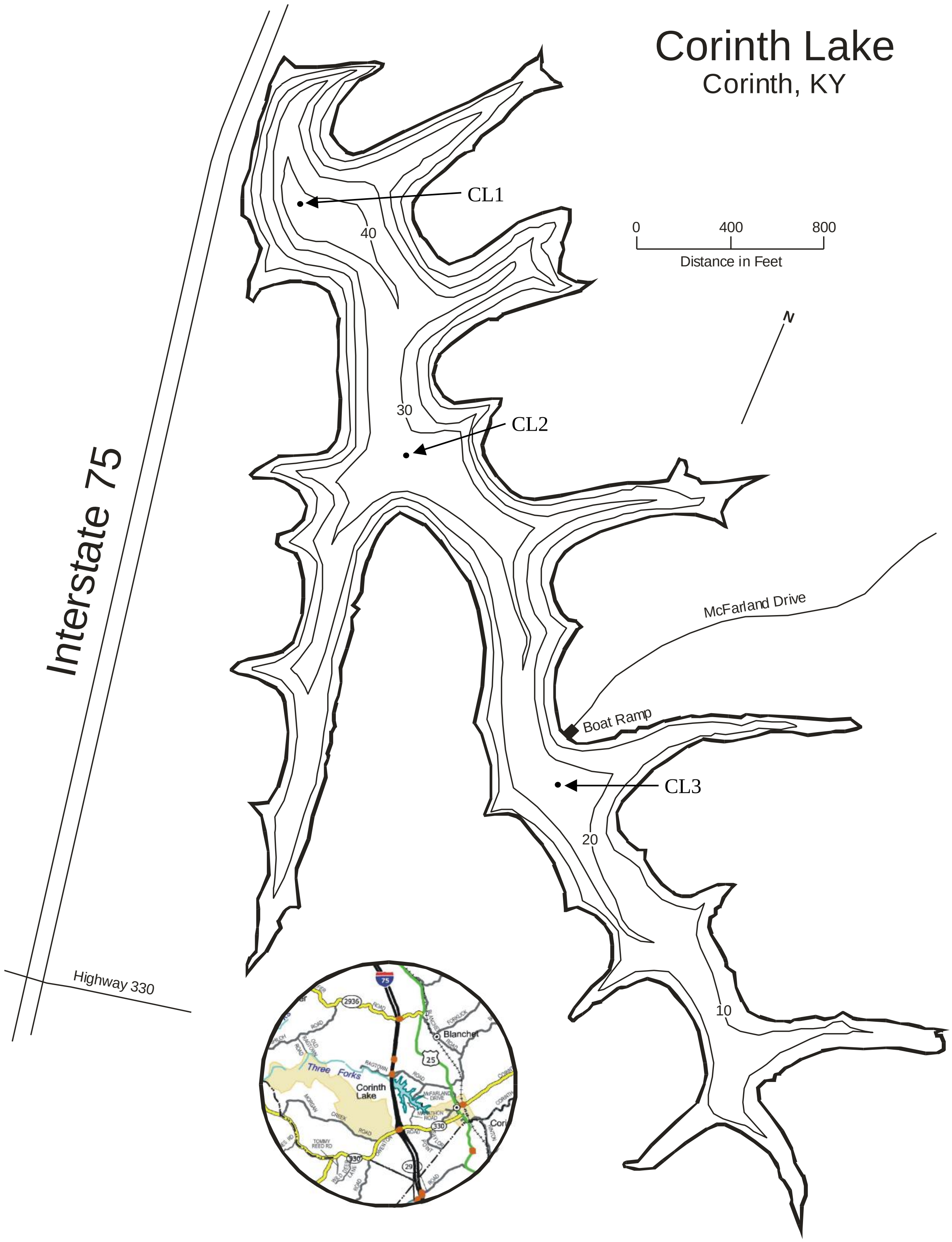

Figure 2. Map of Corinth Lake with locations of 3 stations where monthly temperature/dissolved oxygen profiles were collected from May to October 2007-2011.

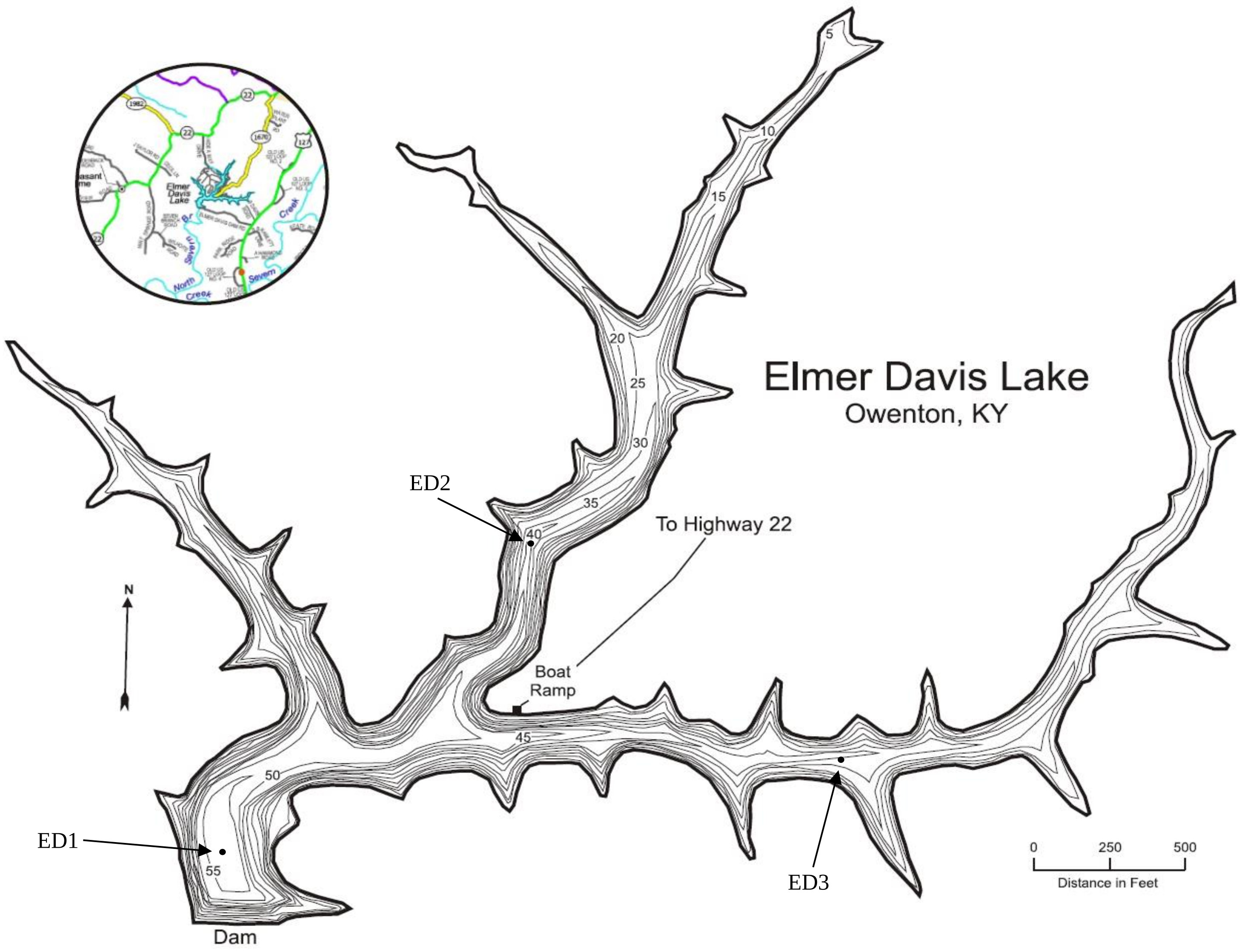

Figure 3. Map of Elmer Davis Lake with locations of 3 stations where monthly temperature/dissolved oxygen profiles were collected from May to October 2007-2011.

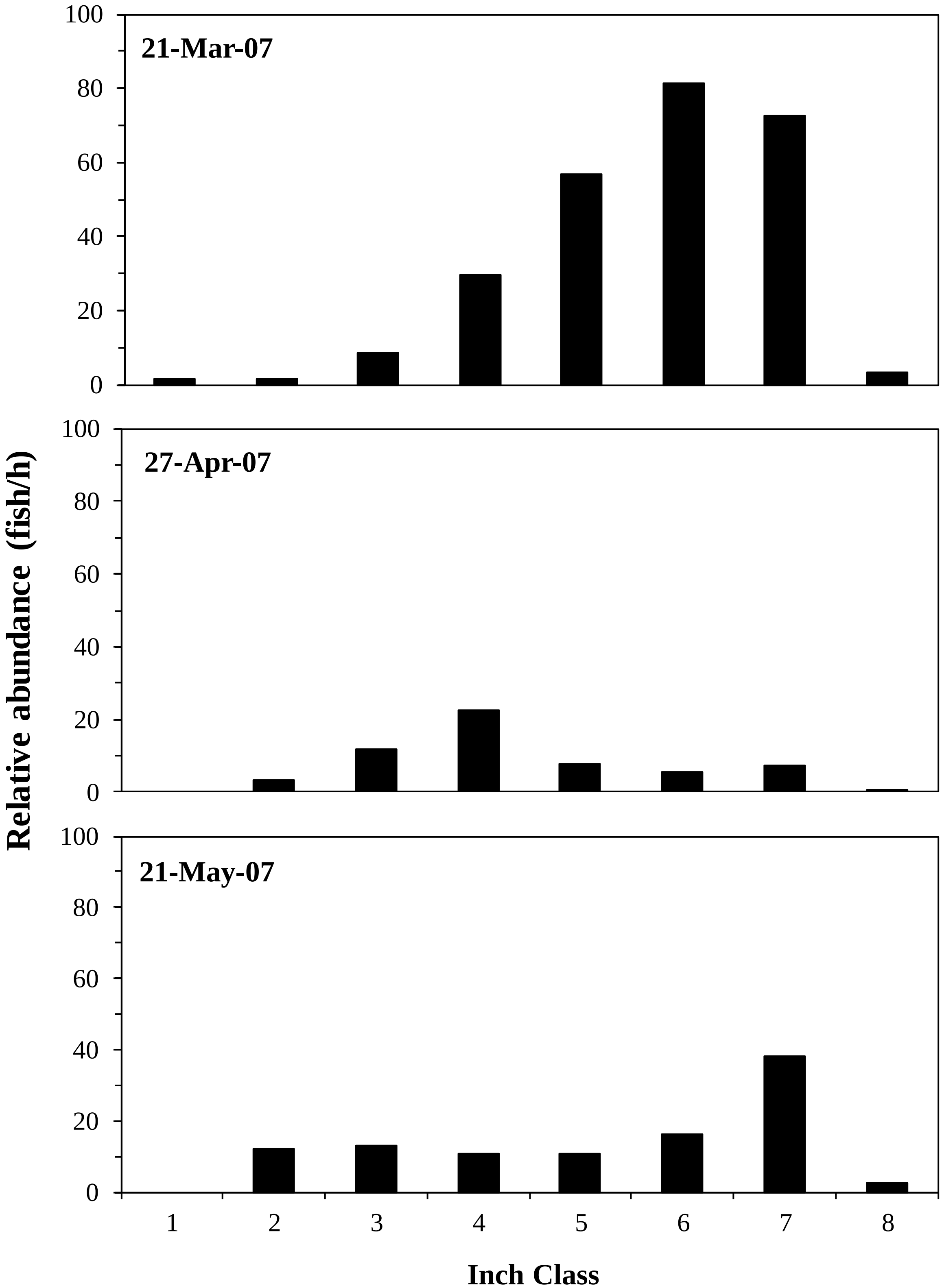

Figure 4. Relative abundance (fish/h) of bluegill collected by diurnal electrofishing of Beaver Lake on three dates in 2007.

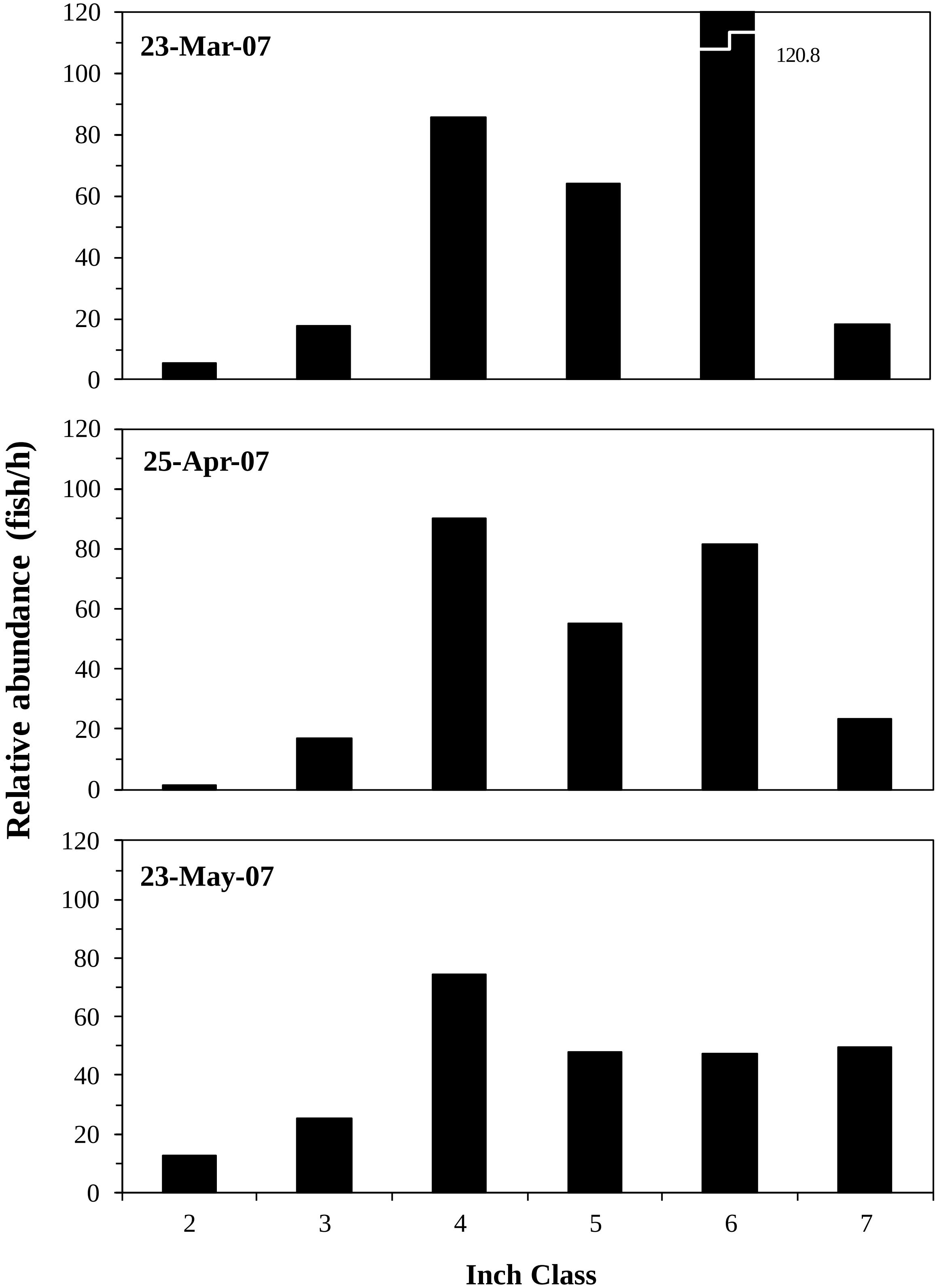

Figure 5. Relative abundance (fish/h) of bluegill collected by diurnal electrofishing of Corinth Lake on three dates in 2007.

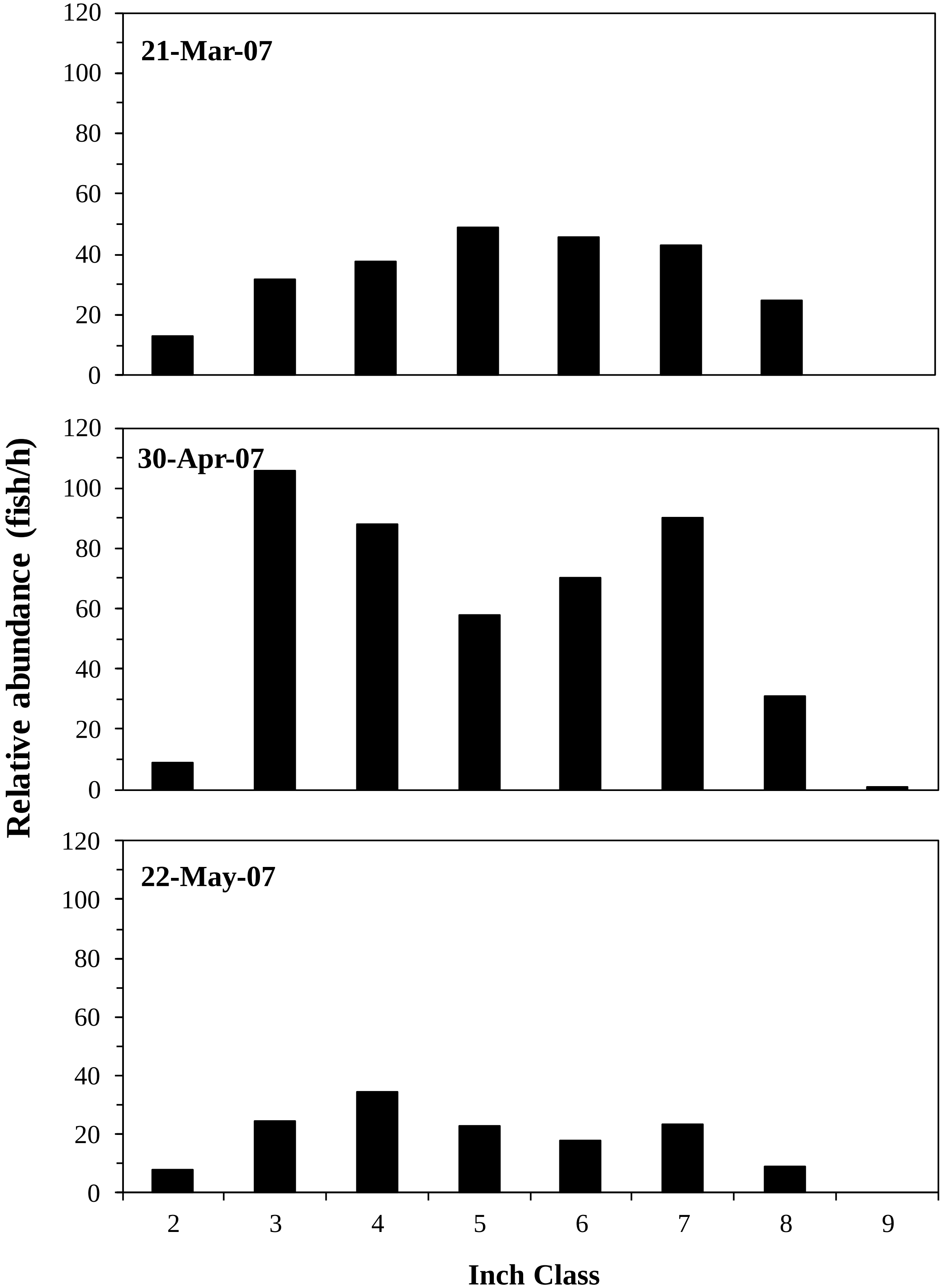

Figure 6. Relative abundance (fish/h) of bluegill collected by diurnal electrofishing of Elmer Davis Lake on three dates in 2007.

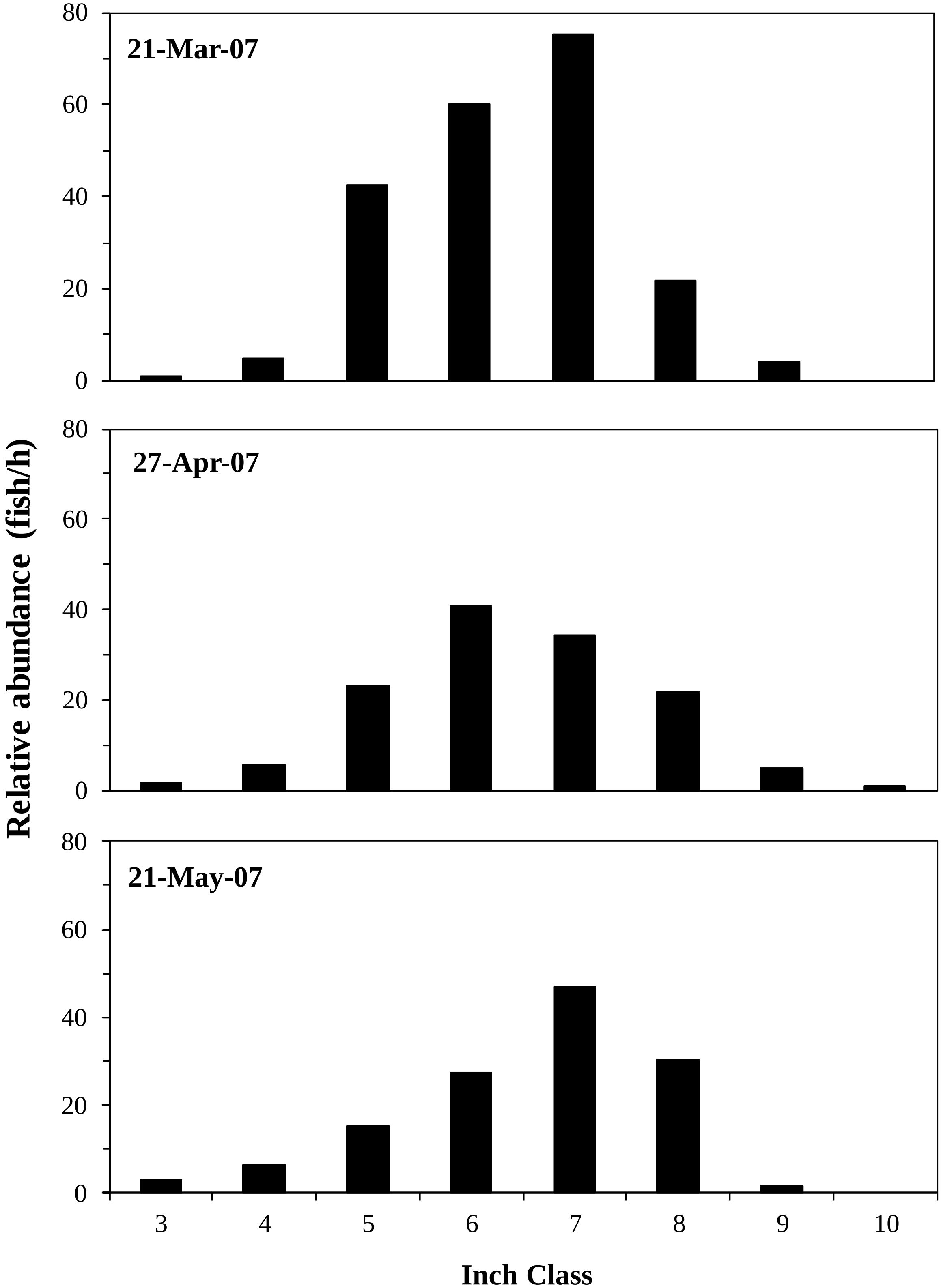

Figure 7. Relative abundance (fish/h) of redear sunfish collected by diurnal electrofishing of Beaver Lake on three dates in 2007.

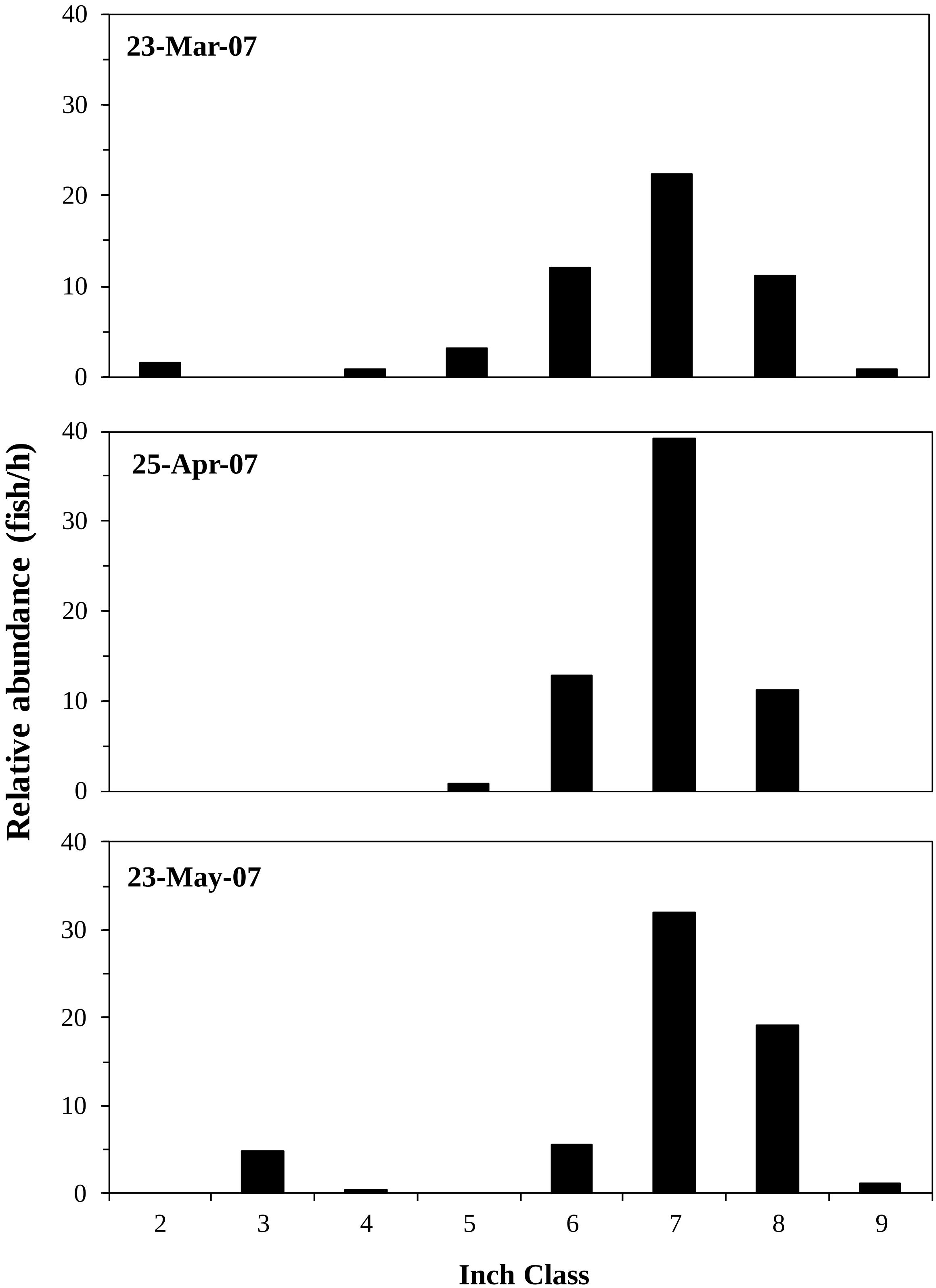

Figure 8. Relative abundance (fish/h) of redear sunfish collected by diurnal electrofishing of Corinth Lake on three dates in 2007.

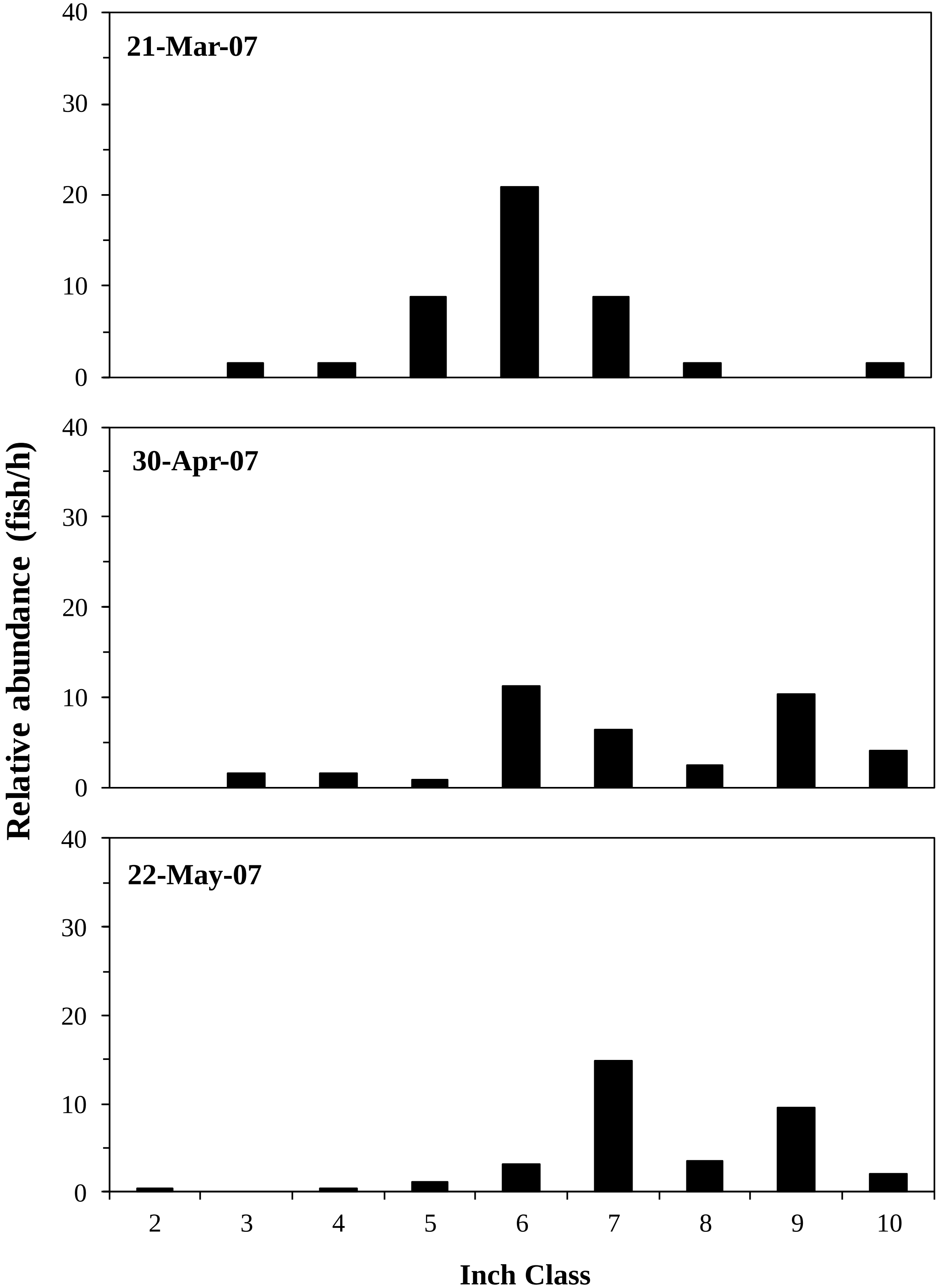

Figure 9. Relative abundance (fish/h) of redear sunfish collected by diurnal electrofishing of Elmer Davis Lake on three dates in 2007.

Appendix

Appendix Table 1. Backcalculated lengths (mm) at age from otoliths of bluegill collected from Beaver Lake in spring 2007-2011 and resulting von Bertalanffy growth parameters, L_{inf} is the maximum theoretical length (mm), K is the growth coefficient, and t_o is the time in years when length would theoretically equal zero.

	Backcalculated Length (mm) at Age									von Bertalanffy Growth Parameters		
Year	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	L_{inf} (mm)	K	t_o
2007	61	107	152	173	183	193	198	206		211	0.436	0.247
2008	51	102	145	168	173	188	191	193	203	203	0.455	0.379
2009	66	117	152	175	183	191	198	201	211	209	0.446	0.148
2010	58	107	152	178	185	191	196	203	211	210	0.462	0.321
2011	58	114	163	183	191	198	206	213		214	0.506	0.386

Appendix Table 2. Backcalculated lengths (mm) at age from otoliths of bluegill collected from Corinth Lake in spring 2007-2011 and resulting von Bertalanffy growth parameters, L_{inf} is the maximum theoretical length (mm), K is the growth coefficient, and t_o is the time in years when length would theoretically equal zero.

	Backcalculated Length (mm) at Age								von Bertalanffy Growth Parameters		
Year	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	L_{inf} (mm)	K	t_o
2007	66	114	145	168	178	178	185	191	193	0.502	0.173
2008	58	112	147	165	175	168			179	0.661	0.417
2009	71	119	150	173	180	191			203	0.461	0.070
2010	58	107	142	160	175	170	180	188	188	0.503	0.271
2011	58	112	145	165	173	173			182	0.606	0.373

Appendix Table 3. Backcalculated lengths (mm) at age from otoliths of bluegill collected from Elmer Davis Lake in spring 2007-2011 and resulting von Bertalanffy growth parameters, L_{inf} is the maximum theoretical length (mm), K is the growth coefficient, and t_o is the time in years when length would theoretically equal zero.

	Backcalculated (mm) Length at Age										von Bertalanffy Growth Parameters		
Year	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	L_{inf} (mm)	K	t_o
2007	61	114	165	188	198	206	221				229	0.448	0.331
2008	64	114	160	185	191	201	203	211	211	213	214	0.492	0.313
2009	61	109	155	188							375	0.175	-0.008
2010	58	112	163	180	188	203					215	0.490	0.375
2011	61	114	163	185	193	196	201				208	0.561	0.412

Appendix Table 4. Backcalculated lengths (mm) at age from otoliths of redear sunfish collected from Beaver Lake in spring 2007-2011 and resulting von Bertalanffy growth parameters, L_{inf} is the maximum theoretical length (mm), K is the growth coefficient, and t_o is the time in years when length would theoretically equal zero.

	Backcalculated Length (mm) at Age								von Bertalanffy Growth Parameters		
Year	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	L_{inf} (mm)	K	t_o
2007	71	122	170	201	221	241	236		267	0.358	0.174
2008	61	114	160	185	208	224	218	216	232	0.447	0.360
2009	71	122	168	193	211	226	239		264	0.332	0.066
2010	64	124	178	203	221	236	246		264	0.398	0.323
2011	71	137	188	218	231	241	241		254	0.508	0.377

Appendix Table 5. Backcalculated lengths (mm) at age from otoliths of redear sunfish collected from Corinth Lake in spring 2007-2011 and resulting von Bertalanffy growth parameters, L_{inf} is the maximum theoretical length (mm), K is the growth coefficient, and t_o is the time in years when length would theoretically equal zero.

	Backcalculated Length (mm) at Age								von Bertalanffy Growth Parameters		
Year	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	L_{inf} (mm)	K	t_o
2007	89	157	193	206	224				232	0.639	0.237
2008	86	150	188	203	221	226			235	0.553	0.171
2009	84	155	191	206	224	231	229		235	0.610	0.269
2010	76	142	183	206	226	231	241		250	0.470	0.224
2011	76	152	196	208	211	211	226	236	226	0.712	0.418

Appendix Table 6. Backcalculated lengths (mm) at age from otoliths of redear sunfish collected from Elmer Davis Lake in spring 2007-2011 and resulting von Bertalanffy growth parameters, L_{inf} is the maximum theoretical length (mm), K is the growth coefficient, and t_o is the time in years when length would theoretically equal zero.

	Backcalculated Length (mm) at Age								von Bertalanffy Growth Parameters		
Year	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	L_{inf} (mm)	K	t_o
2007	84	170	221	249	257				275	0.626	0.424
2008	84	168	224	246	259	269			279	0.598	0.409
2009	79	155	201	213	231	251	264		270	0.454	0.207
2010	79	165	211	229	244	257	267	274	273	0.531	0.335
2011	84	170	224	249	244				260	0.745	0.488

Appendix Table 7. Log_{10} transformed weight-length regression coefficients for bluegill and redear sunfish from Beaver, Corinth, and Elmer Davis Lakes. Length (mm) and weight (g) data collected in the fall from 2007-2011 was pooled.

	Bluegill			Redear Sunfish		
Lake	Intercept	Slope	r^2	Intercept	Slope	r^2
Beaver Lake	-5.351	3.273	0.953	-5.457	3.316	0.975
Corinth Lake	-4.653	2.952	0.941	-5.058	3.136	0.976
Elmer Davis Lake	-4.929	3.099	0.941	-5.204	3.222	0.962