AGE, GROWTH, AND MORTALITY OF CHANNEL CATFISH, *ICTALURUS PUNCTATUS,* IN INDIANA RESERVOIRS

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Abstract

Thesis: Age, Growth, and Mortality of Channel Catfish, *Ictalurus punctatus,* in Indiana Reservoirs

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Eagle Creek, Monroe, Patoka, Brookville, and Cecil M. Harden are Indiana reservoirs ranging in size from 546 to 4,343 hectares, and are primarily managed for flood control and recreation. Channel Catfish, *Ictalurus punctatus*, is a valuable part of the recreational fishery in these reservoirs, but unfortunately, scant information is known about their current status. Our objectives for this study were: 1. determine age and growth of channel catfish, 2. compare population demographics such as length and age frequency distributions, and 3. determine mortality. A total of 1,022 fish was collected up to age-10. Hierarchical growth population models using Bayesian statistics showed growth rates and mortality rates were not statistically different among reservoirs. Growth rates ranged from 0.07 to 0.12, and mean total annual mortality rates ranged from 0.21 to 0.26. Low instantaneous fishing mortality rates, 0.06 to 0.08, suggested the Channel Catfish fishery was under-used and should be promoted to Indiana anglers.

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Introduction:

Catfish, *Ictalurus* species, are popular sport fishes for ease of access and constant availability, making them one of the most important species in sport fishing across the country. Over 7 million people fish for catfish every year, which is approximately 26% of all active anglers in the United States (USFWS 2011). In Indiana, 188,000 people ages 16 and older fished for catfish in 2011, ranking them third in popularity behind crappie and bass species. Fishing for catfish species accounted for 13% of all days spent fishing in Indiana . Channel Catfish, *Ictalurus punctatus,* are one of the most popular species of catfish in Indiana, and are seen as a healthy fish option, with lean meat and a good flavor desired by anglers (FAO, 2015; IDNR, 1997; Pool, 2007).

Indiana has 580 lakes and reservoirs, totaling over 28,732 ha, which provide suitable habitat for Channel Catfish and popular fishing locations for anglers (IDNR, 1997). Lakes and reservoirs are more popular for anglers since they are on public land, which reduces the potential issue of fishing on private property in rivers and streams (Chizinski, 2012). Reservoirs in Indiana have been constructed for a variety of reasons, including but not limited to: recreation, water supply, and flood control (IDNR, 1997). The habitats provided by reservoirs range from deep, clear waters to shallow and turbid. Many reservoirs have extensive amounts of aquatic vegetation, and range in size from 0.1 ha to 4350 ha. Channel Catfish typically maintain stable populations in larger reservoirs, but are rarely self-sustaining in small reservoirs, lakes and ponds due to lack of habitat suitable for reproduction (IDNR, 1997).

Historically, studies of Channel Catfish were common (Carlander, 1969), but more often conducted on river populations (Chizinski, 2012). Few studies have been conducted on more recent (constructed after 1960) and large Midwestern reservoirs (Klaassen, 1973; Miranda, 1999). Although reservoirs are relatively new environments for Channel Catfish (Miranda, 1999), these fish are habitat generalists and can readily flourish in the large range of biotic and abiotic conditions that typify these waters (Miranda, 1999; Holley, 2006). Channel Catfish may be under-used or overfished in these reservoirs, depending on the quality of the fishery and the current management efforts, such as length and bag limits (Miranda, 1999). Strategies to achieve optimum or maximum sustainable yield (Ricker, 1975) can be determined only by a specific assessment of a particular reservoir's fishery.

The Federal government began stocking Channel Catfish in 1922 in Indiana as a result of weak recruitment, possibly due to lack of appropriate habitat and predation by Largemouth Bass (Kingsley, 1987). The Indiana Department of Natural Resources (IDNR) took over stocking in the mid-1970s (Kingsley, 1987). In 1982, the IDNR recommended that lake and reservoir stockings of Channel Catfish be on a biannual schedule and with a minimum size of 10 inches. Between 1983 and 1987, about 114,000 Channel Catfish were stocked yearly in nearly 230 lakes around Indiana (IDNR, 1989). Stockings continued yearly, with varying numbers of catfish stocked in lakes around the state thought to have no established populations. In 2010, a record 161,105 Channel Catfish were stocked in 155 lakes in Indiana (S. Clark-Kolaks, personal communication, IDNR). Indiana Department of Natural Resources continues to stock Channel Catfish in lakes and reservoirs to enhance the fishery where populations are exploited or recruitment is not meeting angler demand.

Management agencies spend less time and money on Channel Catfish management than other sport fish species such as bass and crappie (Bodine et al., 2013). The IDNR historically has had few management plans for Channel Catfish, with the latest in 1997 as part of the Impoundments Strategic Plan. This plan addressed issues such as lack of known population characteristics, lack of fishing opportunity due to small populations, and low utilization/angling effort (IDNR, 1997); however, little management activity was directed towards reaching these objectives. As a result, an explicit management plan for Channel Catfish has not been established and followed. Currently, there is no size limit on lakes and reservoirs, though a bag limit of 10 is enforced everywhere except for Turtle Creek Reservoir (IDNR, 2013). Despite the extensive stocking efforts in the past 30 years, little effort has been made to evaluate the Channel Catfish populations. This lack of evaluation could possibly be due to the difficulty of sampling catfishes, which has been experienced across the country (Michaletz and Sullivan, 2002; Holley, 2006). Age, growth, and size at recruitment of naturally reproducing populations need to be studied to determine whether or not stocking is necessary to maintain the population.

Fish population demographics help management agencies enact and enforce regulations to manage the fishery. Age and size metrics allow biologists to evaluate strength in year classes, resource use, and effectiveness of current management strategies (Isely and Grabowski, 2007). Accurate age information of a species is necessary to effectively manage the population (Crumpton et al., 1987), while determining growth is vital to understanding a population and on an individual level (Isely and Grabowski, 2007). Channel Catfish typically have the greatest relative growth in the first several years (up to 100 mm/year), with decreasing growth with age (De Roth, 1965). Maximum fish length can be greater than 900 mm (Pool, 2013) with weights of over 10 kg common (IDNR, 1989). Further, by defining these metrics in Indiana waters, a regional baseline understanding and standard for age and growth will be created. Ultimately, this information will enable fisheries managers in Indiana to more effective management decisions, particularly those related to stocking and fishing regulations.

Mortality describes the rate at which individuals in a population are lost (Miranda and Bettoli, 2007), and determining fish mortality is key to effectively managing the population. Unfortunately, mortality is partitioned into several types, including, annual, natural, and fishing, among others, and each requires specific data requirements which can be difficult to obtain (Miranda and Bettoli, 2007). All species have their own patterns of mortality over their lifetimes and age groups (Miranda and Bettoli, 2007), and mortality can vary within a species, depending on geographic region, as fish tend to be slower growing and longer living in northern latitudes when compared to southern latitudes (Willis, 2005). Channel Catfish annual mortality nationwide has a wide range, from 0.13 to 0.88, and varies with sample size and aging techniques (Hubert, 1999). The methods to calculate annual mortality are often compromised due to inaccurate aging techniques and small sample sizes, ultimately making natural and fishing mortalities problematic to determine. This data limitation is why natural and fishing mortalities are reported less often than annual mortality (Hubert, 1999).

Condition factor provides information for the overall well-being of fishes individually, within, and among populations (Pope and Kruse, 2007). Fish considered to be in good condition should exhibit higher growth rates and survival when compared to individuals in poor condition (Pope and Kruse, 2007). Relative weight (W_r) is one measure of condition factor and is specifically based upon a length-specific standard weight for each species and can be simpler to interpret than other demographics; that is, patterns of W_r can be assessed by looking at individual W_r values for each fish plotted against length (L). This metric may also provide evidence of competition or resource use in a population (Neumann et al. 2012).

A lack of knowledge about the efficacy of statewide Channel Catfish stockings, as well as the low awareness of this fish as an angler resource was identified for several large reservoirs (IDNR, 1989). In this study, we evaluated several population demographic metrics, both within and among the reservoirs. None of the reservoirs have been stocked with Channel Catfish since the 1980s, effectively making the existing populations naturally reproducing. There were four objectives in this study: First, compare age and length frequencies, second, determine condition factor as an indicator of well-being, third, determine age and growth, and finally, determine mortality. We hypothesized that these population metrics would be different among reservoirs. We also expected the data would indicate how the fishery at each reservoir is being used and give direction for future management efforts.

Methods

Study Areas

The reservoirs in this study were located in Central and Southern Indiana. They ranged in size from 546 ha to 4350 ha, with maximum depths of 35 m and drainage areas of up to 1142 km^2. All recreational activities at these reservoirs are under the management of IDNR, while the flood control and water levels are managed by US Army Corps of Engineers Louisville District. Each reservoir boasts high visitor counts and a wide range of activities including boating, camping, and fishing.

Eagle Creek Reservoir is a 546 ha, man-made reservoir in Indianapolis IN, 16 km northwest of the city's center. It has a drainage area of 419 km^2, with a mean depth of 5.5 m and a max depth of 12 m. It was built in 1968 and has since been a part of the water supply for Indianapolis and Speedway (Wisener, 2002).

Brookville Reservoir was constructed in 1974, is located north of Brookville IN, and is a part of the Whitewater Memorial State Park Complex (IDNR, 2014). Its primary purpose was flood control and storm water management (USACE, 2014, Brookville Lake; IDNR, 2014) and is fed by the Whitewater River, among other smaller tributaries (IDNR, 2011). The reservoir is 2128 ha in size, has a drainage area of 981 km^2, a mean depth of 9 m, and a maximum depth of 35 m.

Monroe Reservoir is 32 km southeast of Bloomington, IN and is 4350 ha, the largest lake in Indiana. It was completed in 1965 and was constructed to be the main water source for Bloomington, and flood control. The reservoir is fed by Salt Creek and several minor tributaries covering a watershed area of 1142 km^2 (IDNR, 2011,Monroe Lake). The reservoir has a mean depth of 7 m and a maximum depth of 16 m.

Cecil M. Harden Reservoir is located in Rockville, IN and was constructed by the Army Corps of Engineers in 1960. The dam is located on Big Raccoon Creek and provides flood control in the Big Raccoon Creek and Lower Wabash River watersheds (USACE, 2014). The reservoir has a drainage area of 559 km^2 , a surface area of 853 ha, a mean depth of 7 m and a maximum depth of 19 m.

Patoka Reservoir is the second largest reservoir in the state and was constructed by the Army Corps of Engineers for flood control on the Patoka River. It has a drainage area of 435 km^2, a surface area of 3561 ha, a mean depth of 6 m, and a maximum depth of 15 m. Patoka Lake is currently managed jointly by the US Army Corps of Engineers Louisville District and the IDNR (USACE, 2014, Patoka Lake).

Collection and Processing:

All reservoirs in the study were sampled for fish with hoop net series and gill nets from May through August 2014. Sampling locations in each reservoir were determined by IDNR or Ball State University personnel using IDNR general lake survey protocols. Hoop-net samplers were made by tying together three hoop nets (91-cm diameter with 50-mm stretch mesh and two throats) in series following Michaletz and Sullivan (2002). Each net was baited with 1.5 kg of soybean cake (Greensburg Soy Processors, Greensburg, IN), placed in mesh bags, and suspended in the net throat. The series were set at depths between 2 and 3 m on sandy substrate and allowed to fish for 72 hr. Experimental gill nets with three each 15.2-m alternative panels of stretch mesh sizes of 19, 32, and 51 mm (nine panels total) were also set on each reservoir in the morning and fished for 12 hrs. Upon net retrieval, Channel Catfish were removed and held in tubs of lake water until processed, which included measuring total lengths (mm) and weights (g). The left pectoral spine was removed for aging as outlined by Quist et al. (2012) and placed in a labeled scale envelope. Pectoral spines are the preferred hard part for aging catfish, because they allow for large-scale surveys to be conducted without sacrificing the fishes (Crumpton et al., 1987). Otoliths were thought to be the most accurate hard part for aging, but numerous studies found no difference between pectoral spines and otoliths for age and growth studies (Carlander, 1969; Michaletz et al., 2009; Colombo et al., 2010). All catfish were returned to the water alive following processing. Non-channel catfish species were immediately returned to the water when the nets were pulled.

Some additional fish sampling occurred at Eagle Creek Reservoir in May 2013 and 2014. Gill and hoop nets were fished as described above, but in addition, double front frame trap nets with four rear hoops and 12 mm square measure knotless nylon were fished in shallow, sandy areas just off of the bank on the north and south ends of the reservoir. These latter nets were fished for 24 hours with fishes processed as above.

In the laboratory, spines were boiled in water for five minutes and cleaned with a toothbrush to remove excess flesh in preparation for sectioning. A 0.5 mm cross-section from the mid-spine, starting below the basal recess and above the dentations was cut using a Buehler Isomet low-speed diamond blade saw (Sneed, 1951; Marzolf, 1955). Crumpton et al. (1987) found no difference in ages between sections taken from the basal recess, articulating process, or the mid-spine. Cross-sections were then mounted on microscope slides by placing three consecutive cross-sections in a row, and then taping them down using clear packing tape. Slides were then observed on a microscope under 20x magnification and aged. Photographs of the sections used PacScan software and annual rings were denoted and measured for growth analysis on each photo.

Data Analysis

Age and Growth:

Length and age frequency distributions for each reservoir were calculated. Length frequency distributions were quantified by counting the number of fish that occurred in each 10 mm length bin from 100 mm to > 700 mm, and then plotting the frequencies as a percentage. Age frequency distributions for each reservoir were calculated using the method above, but sorting by ages from 1-12.

Fish back calculated lengths were obtained using the software program Fish B.C. and used to calculated age and growth. Only fish of ages 1-6 were used in the von Bertalanffy growth model due to the low number of older fish collected, which created problems with model conversion. Fish included in the analysis totaled 816. However, all fish were used for length and age frequency descriptions. .

The von Bertalanffy growth model allows biologists to describe growth in a population and make comparisons among populations:

$$L_t = L_\infty\left[1 - e^{-K(t-t_0)}\right] \qquad (1)$$

Growth for Channel Catfish at all reservoirs was determined using a nonlinear hierarchical growth function with a von Bertalanffy equation fit with lengths-at-age:

$$L_j \ = \ L_{\infty i}\left[1 - e^{-k_i(T_j - t_{0i})}\right] + \ \varepsilon_j \qquad (2)$$

where L_j = length at last annulus of individual j; $T_j =$ age of individual j ; L_∞ = asymptotic length at reservoir i ; k = Brody growth coefficient at reservoir i; t_{0i} = hypothetical age when length = 0 at reservoir i ; and ε_j = within-group random error assumed to be normally distributed (Helser and Lai 2004). Reservoir was treated as a random effect where each parameter was assumed to come from a multivariate normal distribution following Helser and Lai (2004).

Condition factor was calculated using methods and equations outlined by Neumann et al. (2012) for relative weight (W_r). A single factor analysis of variance (ANOVA) was used to determine whether W_r (response variable) differed among reservoir (predictor variable) populations. The ANOVA test allowed us to compare our reservoirs as categorical variables and produced a straightforward way to determine if differences between the reservoirs existed. A Tukey Honest Significant Difference test was used to determine which means from the ANOVA differed from one another.

Lee's phenomenon occurs with differing mortalities within age classes of heavily exploited populations, typically as faster growing fish having a higher mortality and slower growing fish having a lower mortality (Ricker, 1975). This metric is typically evaluated using back-calculated length increments within a particular age class. In this study, we compared back-calculated length increments at age-4 and age-6 for all fish among all reservoirs using an ANOVA to test for differences in lengths of individual fishes. A Tukey Honest Significant Difference test was performed to test for significance in mean length differences.

Mortality:

Hierarchical catch-curve regressions were used to estimate mortality at each reservoir. Models were calculated using methods outlined by Doll and Lauer (2014). The slope of the catch-curve, also known as the instantaneous total mortality rate (Z) was obtained via Equation (3):

$$C_i = C_0 e^{-Z*age} \qquad (3)$$

where C_i = catch at age i and C_0 = initial catch. The natural log is taken of both sides of Equation (2) to linearize the catch-curve, resulting in Equation (4):

$$\ln(C) = \ln(\alpha) - Z * age \qquad (4)$$

To determine the parameters of the model, the index of the catch-curve, C_{ij}, for individual fishes in each reservoir j and age is modeled using a generalized linear model (GLM) with a Poisson distribution and log link, resulting in Equations (5) and (6):

$$C_{ij} \middle| \lambda_{ij} \sim Poisson(\lambda_{ij}) \qquad (5)$$

$$\ln(\lambda_{ij}) = \alpha_j - Z_j * age_{ij} \qquad (6)$$

where λ_{ij} = Poisson mean catch of individual fishes for reservoir j at age i, α_j = reservoir specific intercept, Z_j = reservoir specific slope, and age_{ij} = age i of the individual fish for reservoir j. The Poisson distribution was used, as it cannot assume negative values (biological impossibility) in contrast to a normal distribution which can. Further, a binomial distribution may have been an option, but it requires an additional parameter (probability of observing an individual) which we did not have in our data. Instantaneous total mortality (Z) for each reservoir j can be inferred from the catch-curve model individually. However, this is often an imprecise estimate for reservoirs with small sample sizes. In order to minimize the uncertainty at each reservoir, the hierarchical method of the catch-curve is used in Equation (7):

$$\alpha_j \sim normal(\alpha_0, \sigma_0^2) and\ Z_j \sim normal(\beta_1, \sigma_1^2) \qquad (7)$$

where α_0 = overall intercept and β_1 = slope among reservoirs, σ_0^2 and σ_1^2 = amount of variation in the intercept and slope among reservoirs. Total annual survival (S) is calculated as e^{-z} and total annual mortality (A) is calculated as $1- e^{-z}$. Instantaneous total mortality (Z) can be divided into instantaneous natural mortality (M) and instantaneous fishing mortality (F) as demonstrated by Equation (8) (Ricker, 1975):

$$Z = F + M \qquad (8)$$

Natural mortality can be estimated through six methods (Pauly, 1980; Hoening, 1983; Peterson and Wroblewski, 1984; Chen and Watanabe, 1989; Jensen, 1996; Quinn and Deriso, 1999). Two of the six methods were chosen for our study based on the ages of fish collected. The first (Equation 9), was based on Jensen (1996) and suggested the relationship between L∞ and K in the von Bertalanffy equation:

$$M = 1.50 * K \qquad (9)$$

The second method (Peterson and Wroblewski 1984) derived their equation based upon the function of weight and growth rate in relation to predation and metabolic rate. This resulted in a size-dependent mortality rate, where WT represents W∞ in Equation (10):

$$M = 1.92*(WT^{-0.25}) \qquad (10)$$

Instantaneous natural mortality was calculated using Equations (9) and (10) for all five reservoirs. The results of both equations were averaged to get one M for each reservoir. Instantaneous fishing mortality was then calculated using Equation (8).

All models (age and growth, mortality, and length-weight) were fit using Bayesian inference in R 3.1.1 (R Core Team 2014) using JAGS 3.4 (Plummer 2003) and rjags 3.13 (Plummer 2014). All parameters were given non-informative priors. Three concurrent MCMC chains were run for all models. The von Bertalanffy model consisted of 250,000 saved steps thinning every 50 steps and discarding the first 50,000 steps. Convergence of the MCMC chains was checked using the Brooks-Gelman-Rubin (BGR) scale-reduction factor (Brooks and Gelman 1998). The BGR factor is the ratio of between-chain variability to within-chain variability. The chains have converged when the upper limits of the BGR factor are close to one, with values less than 1.15 suggesting the MCMC chains have converged. Posterior distribution of the parameter estimates were describe with their median and 95% credible interval. Complete model specification using JAGS code is available upon request.

Results

A total of 802 Channel Catfish was used in the study. At Eagle Creek Reservoir, lengths ranged from 132 mm to 645 mm, with weights from 20 g to 3,030 g and ages 1-11 . At Brookville Reservoir, total length ranged from 198 mm to 668 mm, with weights from 86 g to 2,494 g and ages 1-7. At Monroe Reservoir, lengths ranged from 182 mm to 741 mm, with weights from 31 g to 4,309 g and ages 1-10 . At Cecil M. Harden Reservoir, lengths ranged from 223 mm to 612 mm, with weights from 90 g to 2,381 g and ages 3-12 . At Patoka Reservoir, lengths ranged from 221 mm to 716 mm, with weights from 281 g to 3,855 g and ages 2-9 . Back-calculated lengths for all reservoirs can be found in Appendix A.

Age and Growth:

Age and length frequency abundance suggested sampling gear bias for ages 1 and 2 Channel Catfish, which was expected (Hubert et al. 2012). Fish appeared to be fully recruited to the gear by age-2 at all reservoirs (Figures 1-5) except for Cecil M. Harden and Patoka (Figures 4 and 5) where ages 1 and 2 fish appeared to be missing or in reduced abundance. Fish appeared to be fully recruited to the gear at 250 mm at all reservoirs (Figures 6-10) except for Patoka based on the length frequency distribution (Figure 10). Although length frequency distributions indicate some fluctuating cohort abundance from year to year, overall there was consistent recruitment on a population level basis at each reservoir (Figures 6-10).

Von Bertalanffy growth curves did not differ among reservoirs. Combined Channel Catfish from all reservoirs had a median length at age-1 = 172 mm, age-2 = 229 mm, age-3 = 282 mm, age-4 = 331 mm, age-5 = 375 mm, and age-6 = 416 mm. Median length at age-1 = 119 (40, 200) mm and age-6 = 390 (310, 470) mm for Eagle Creek Reservoir (Figure 11). Median

(C.I.) length at age for Brookville Reservoir ranged from 185 (105, 266) mm at age-1 to 427 (348, 506) mm at age- 6 (Figure 12). At Monroe Reservoir, median length at age ranged from 187 (105, 268) mm at age-1 to 470 (391, 549) mm at age-6 (Figure 13). Median length at age for Cecil M. Harden Reservoir age-1 = 183 (97, 268) mm and age-6 = 335 (256, 414) (Figure 14). At Patoka Reservoir, median length at age ranged from 142 (46, 233) mm at age-1 to 478 (399, 557) mm at age 6 (Figure 15). Eagle Creek and Patoka reservoirs curves did not reach an asymptote (Figures 11 and 15). Median length at age did not differ among reservoirs (Figure 16). The median growth rate (K) derived from the von Bertalanffy model in the five reservoirs ranged from 0.07 to 0.12. However, growth rates among reservoirs did not differ statistically as the credible intervals for each reservoir overlapped (Figure 17). Length at L_∞, or the theoretical maximum length (Quist et. al. 2012), ranged from 681 mm to 1254 mm among the five reservoirs. Length at L_∞did not differ among reservoirs (Figure 18), although Patoka Reservoir had a larger credible interval likely due to the high number of age 4-6 fish collected, causing L_∞ to increase.

Channel Catfish relative weight (W_r) ranged from 54 to 137 at Brookville Reservoir, 66 to 117 at Patoka Reservoir, 67 to 146 at Eagle Creek Reservoir, 64 to 143 at Cecil M. Harden Reservoir, and 57 to 144 at Monroe Reservoir. Mean W_r ranged from 86-95 among reservoirs. Patoka Reservoir mean W_r differed significantly (F = 14.5, df = 4, P <0.001) from the other four reservoirs and was 6 less than W_r at Brookville Reservoir (P <0.001), 9 less than W_r at Eagle Creek Reservoir (P <0.001), 9 less than W_r at Cecil M. Harden Reservoir (P <0.001), and 8 less than W_r at Monroe Reservoir (P <0.001).

No evidence of Lee's phenomenon was found at any of the reservoirs in our study. No significant differences in growth rates within age-4 and age-6 classes occurred at Eagle Creek (F = 1.7, df = 7, *P* >0.05), Brookville (F = 8.7, df = 3, *P* >0.05), Patoka (F = 4.0, df = 5, *P*> 0.05), Monroe (F = 9.7, df = 6, *P*> 0.05), and Cecil M. Harden (F = 2.6, df = 8, *P*> 0.05).

Mortality:

Total annual mortality was calculated for all five reservoirs, whereas natural and fishing mortalities were calculated for Brookville, Cecil M. Harden, and Monroe reservoirs only due to data limitations. Total annual mortality (A) at each reservoir ranged from 21% to 26%, with the mean total annual mortality (A) among all reservoirs being 21% (Table 3). Mortality estimates from Eagle Creek Reservoir could not be included in the results because constant mortality could not be assumed across year classes based on the age frequency distribution (Figure 11) and the von Bertalanffy model (Figure 3). The sample sizes across age groups were too small, which did not allow the catch-curve model to be fitted correctly. Patoka Reservoir mortality estimates were also problematic and excluded based on the paucity of younger fish and year classes captured. At the three remaining reservoirs, instantaneous fishing mortality (F) ranged from 0.06 to 0.08, and instantaneous natural mortality (M) ranged from 0.18 to 0.22 (Table 4).

Discussion

Several Channel Catfish population demographic metrics were defined, but the results did not support our original hypotheses. We expected to find differences among the reservoirs. However, age and length frequency distributions, growth rates, and median length at age and length at L_∞ did not differ, nor did total annual mortality, natural mortality, and fishing mortality. Condition factor at Patoka Reservoir was lower when compared to the other populations.

Few direct age and growth comparisons to Midwestern reservoirs are available for Channel Catfish. Ages of Channel Catfish at each individual reservoir were in the range reported by Carlander (1969) for reservoirs in Midwestern States, and back-calculated mean length at ages were consistent with Carlander (1969) and Hubert (1999) for reservoirs in Midwestern states. This supported our results of no differences for age and growth among reservoirs.

The Von Bertalanffy growth model is a popular growth functions used in fisheries today (Quist et al. 2012). Although back calculated lengths could have been used to determine growth, few age 1-2 fish were caught which made determining age and growth for those years difficult. Unfortunately, Channel Catfish recruitment to the gear did not occur until lengths reached 250 mm which approximated age-2, with one exception. Age-2 fish at Patoka were absent, which likely meant the 2012 year class was weak or non-existent. Gill-nets may underrepresent fish <250 mm, which could account for the lack of age-1 and age-2 fish seen in the reservoirs (Bodine et al., 2013). Holley (2006) identified that current sampling methodologies for juvenile catfish in reservoir habitats are typically insufficient. This could account for the lower proportion of < age 3 fish collected among our five reservoirs.

Despite gaps in length frequency distributions at all reservoirs, the populations appeared to be stable. Fluctuations in year classes were evident at all reservoirs based on the length frequency distributions, with varying levels of weak or missing cohorts. Hubert (1999) explained that the constant recruitment assumption is difficult to make in catch-curve analysis for Channel Catfish, due to variable year-class strength which is common in the species. Though all reservoirs were located in the same eco-region, each reservoir experienced differing air temperatures, varying levels of rainfall, depths, thermal stratification, and available habitat (IDNR, 2011; IDNR, 2014). Years of drought, flood, and extreme temperatures may contribute to the fluctuation in recruitment of Channel Catfish, and could account for the length class gaps at all reservoirs in the study (Carlander, 1969; Hubert, 1999).

Channel Catfish growth rates are variable within populations (Hubert, 1999); hence, this may explain the lack of differences among our populations. Growth rates (K) were similar in all five reservoirs and to those reported by Shrader et al. (2003; K = 0.11) and Holley et al. (2009; K = 0.14), despite these latter studies out of the Midwestern US. Factors influencing growth rates were not well understood historically and the impact of temperature, growing season, and geographic location have not always be congruent (Carlander, 1969; Gerhardt and Hubert 1991; Hubert, 1999; Miranda, 1999; Durham et al., 2005). Even though all reservoirs were located in the same eco-region, we predicted that differences in depth, size, and angler use would impact growth rates. Since no significant differences in growth rates were detected, it is unlikely that these characteristics sufficiently varied to be important in impacting Channel Catfish growth.

Although mean W_r varied among reservoirs, all values fell within mean W_r ranges reported by Brown et al. (1995; 92-104) and by Eder and McDannold (1987; 84-100). The lower values at Patoka Reservoir may be the result of high densities of older fish. Often, a reduction in condition factor suggests density dependency is influencing growth (Stevens, 2013). Patoka Reservoir had the greatest number of ≥ age 4 fish collected in the study, which could indicate large numbers of adult fish competing for food resources, explaining the lower W_r (Blank, 2012). In addition, Patoka's slower growth rate (K), while not significantly different from the other reservoirs, was at the low end of the range. The significantly lower W_r at Patoka supports this slower growth rate trend, indicating a lower well-being of the Channel Catfish at this reservoir. In this case, relative weight as a measure of condition factor may better indicate health than the growth rate. Relative weight and the growth rate combined help support the evidence of competition among older fishes for resources.

The range of $L\infty$ in our study was similar to Shrader et al. (2003) except for Patoka Reservoir. This reservoir had a higher $L\infty$, likely due to the few number of age 1 and 2 fish collected, which caused $L\infty$ to be calculated based upon a straight line in the von Bertalanffy model rather than a curved asymptotic line. This high $L\infty$ may be a result of sampling bias, as different IDNR biologists collected data from each reservoir, and used different combinations of the gear types described in the methods. While gill-nets are the most common sampling method, and considered the most efficient (Santucci, 1999) in reservoirs (Michaletz and Dillard, 1999), there are general difficulties and inconsistencies with sampling catfishes across the country. Michaletz and Dillard (1999) listed "inadequate sampling" as the third-most major constraint against catfish management in the United States and Canada. Bodine et al. (2013) outlined the increased effort needed to sample Channel Catfish with gill-nets, which were the primary gear in our study. Sampling strains make comparative catfish studies, particularly related to age and growth metrics, difficult for statewide managers to conduct with precision and accuracy.

Though there were no differences in mortality among reservoirs, we suggest that mortality estimates indicate that Channel Catfish are under- or lightly-exploited. Our mean total annual mortality rate (A) (21%) was similar to a lightly exploited Channel Catfish population in Wyoming with an A of 23% (Gerhardt and Hubert, 1991), but less than Holley (2006) reported of 33%, a low to moderate range of mortality for the species. Hubert (1999) reported rates of Channel Catfish total annual mortality between 13% and 88%. Two of our A estimates could not be reported due to inadequate numbers of age 1-2 fish. More age and growth data was needed in order to validate the constant recruitment and mortality assumptions for Eagle Creek and Patoka reservoirs. This low exploitation was substantiated by a lack of evidence for Lee's phenomenon, a metric that appears with over-exploitation. Absence of Lee’s phenomenon, combined with our mortality rates, further supports that the reservoirs are under-exploited.

Instantaneous natural mortality (M) is an estimate of natural mortality rates based upon total annual mortality. Instantaneous natural mortality at the three remaining reservoirs was low (0.18 to 0.22) compared with Shrader et al. (2003) (0.62 and 0.73). Our M rates were consistent with Holley (2006), but at the lower end of his range. High population density often leads to lower mortality, due to the fish being slower to mature and fewer resources. Stable environmental conditions within the species range such as temperature and water levels may also result in lower mortalities, for the fish experience less stress and risk-taking behavior (Carlander 1969; Hubert 1999; Eder, 2014).

Instantaneous fishing mortality (F) was low at our three reservoirs compared to Shrader et al. (2003) and Gerhardt and Hubert (1991), somewhat surprising in Indiana, Channel Catfish are third in angler popularity behind crappie and bass species. Low angler interest is considered the number one ranked constraint of catfish management by Michaletz and Dillard (1999), which appears to be similar at the three reservoirs. At Brookville, Cecil M. Harden, and Monroe reservoirs, only 4% of anglers preferred fishing for Channel Catfish which had average harvest rate of 0.02 fish per hour, suggesting that the fishery is not being targeted by anglers (Wisener,1999; Schoenung, 2000; Carnahan, 2007). In contrast, Miranda (1999) reported 40% of anglers targeting catfish in Midwestern reservoirs, and a USFW (2011) Indiana survey listed 26% of anglers targeting catfish. Hence, our findings indicated that while channel catfish are sought after in Indiana, reservoir exploitation and harvest are low.

Management Implications:

Management plans for Channel Catfish in Indiana impoundments have historically been restricted to stocking and bag limits. At the current rate, about 150 state lakes and reservoirs are stocked per year, and none of the reservoirs in our study are stocked with Channel Catfish. In a 1998-99 survey by Michaletz and Dillard (1999), Indiana managers rated catfish as "medium" importance, which was reflected in their management strategies. The current bag limit of 10 channel catfish/day does not appear to limit or negatively influence the fishery. Based on the mortalities identified in this study, the current Indiana bag limit could be relaxed at our reservoirs, and would be a reasonable consideration for the other reservoirs in the state.

Because the Channel Catfish fishery is under-used, the fishery would benefit with additional promotion of catfish angling and harvest, a stance supported by Miranda (1999) in Midwestern reservoirs. Low angler preference, harvest rate, and fishing mortality suggest the angling public would benefit from fishing promotion and additional exploitation without harm to the Channel Catfish populations. This fishery has a great potential for Indiana anglers, as demonstrated by the urban GoFishIN program, which stocks hatchery raised Channel Catfish in urban ponds as a method to increase angler interest in urban areas (IDNR, Go FishIN 2014).

Fishing tournaments, flyers, and general species information have the potential to increase angler interest. Some anglers may be unaware of methods to clean or catch a Channel Catfish. By providing the public this free information, the state would be encouraging anglers of all ages to explore a new avenue in their fishing. Partnering with local fishing clubs such as the Indiana Catfish Association for fishing tournaments and workshops could increase angler comfort with the species. The promotion of fishing events through social media would give the state a unique opportunity to market to a younger generation that may not have had significant exposure to local fisheries. Social media is incredibly popular, and these announcements would provide the opportunity to reach exponentially more people. By encouraging people to try something new, this could bring increased attention knowledge of state parks and nature preserves and make the public more aware of available fish resources. With Increasing visitor numbers and purchases of items such as fishing licenses, the state will have more money for managing the resources at hand. All of these activities and promotions have the potential to increase use and exploitation of the fishery.

Exploitation, as well as age and growth at these reservoirs should be monitored by IDNR managers in the future to assess whether bag or length limits are necessary to the fishery. Fishery promotion and increased exploitation can indicate a resource is being actively used, but the fishery must be maintained in a sustaining manner. Proper observation, sampling, and surveying of Channel Catfish and anglers can ensure that managers are making informed decisions about the resources at hand. Long-term age and growth studies may provide additional information, forming a more complete picture of age, growth, and mortality among reservoirs in Indiana.

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Table 1. Estimates of Median Total Annual Mortality (A) in percentages with credible intervals in parentheses, Instantaneous Fishing Mortality (F) and Instantaneous Natural Mortality (M) for Brookville, Cecil M. Harden, and Monroe reservoirs.

Reservoir	Median Total Annual Mortality (A)	Instantaneous Fishing Mortality (F)	Instantaneous Natural Mortality (M)
Brookville	26 (0.18, 0.39)	0.08	0.22
Cecil M. Harden	23 (0.16, 0.31)	0.07	0.19
Monroe	21 (0.15, 0.28)	0.06	0.18

Table 2. Differences in mean W_r among reservoirs as determined by Tukey HSD.

Reservoir	Difference (%)	Lower C.I.	Upper C.I.	*P*-value
Patoka-Brookville	-5.9	-9.5	-2.2	<0.001
E.C.-Patoka	9.1	5.5	12.7	0
Harden-Patoka	9.1	4.8	13.3	<0.001
Monroe-Patoka	7.9	4.1	11.7	<0.001
E.C.-Brookville	3.3	-0.1	6.6	0.06
Harden-Brookville	3.2	-0.8	7.2	0.2
Monroe-Brookville	2	-1.5	5.6	0.5
Harden-E.C.	-0.1	-4	3.9	0.9
Monroe-E.C.	1.2	-4.8	2.3	0.9
Monroe-Harden	-1.2	-5.3	3	0.9

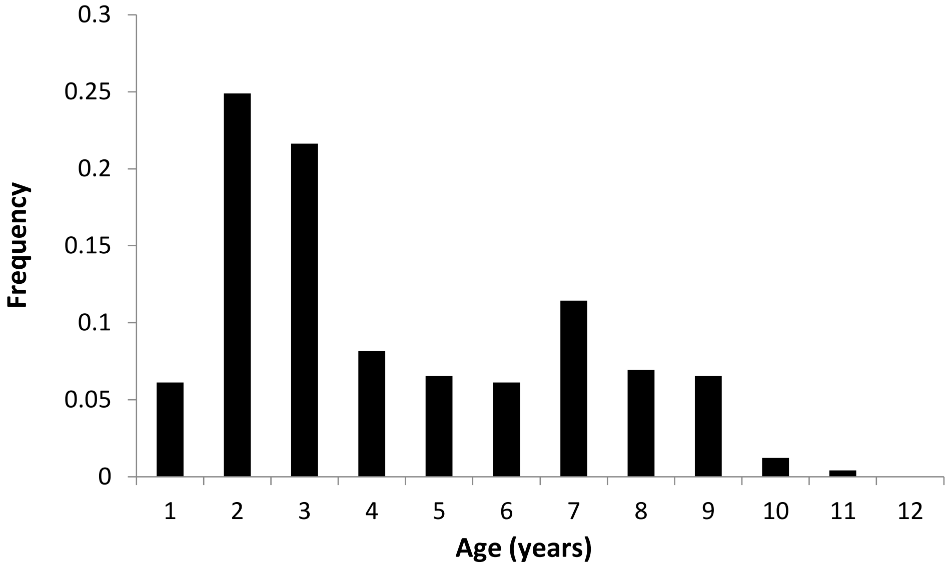

Figure 1. Age frequency distribution of Channel Catfish at Eagle Creek Reservoir

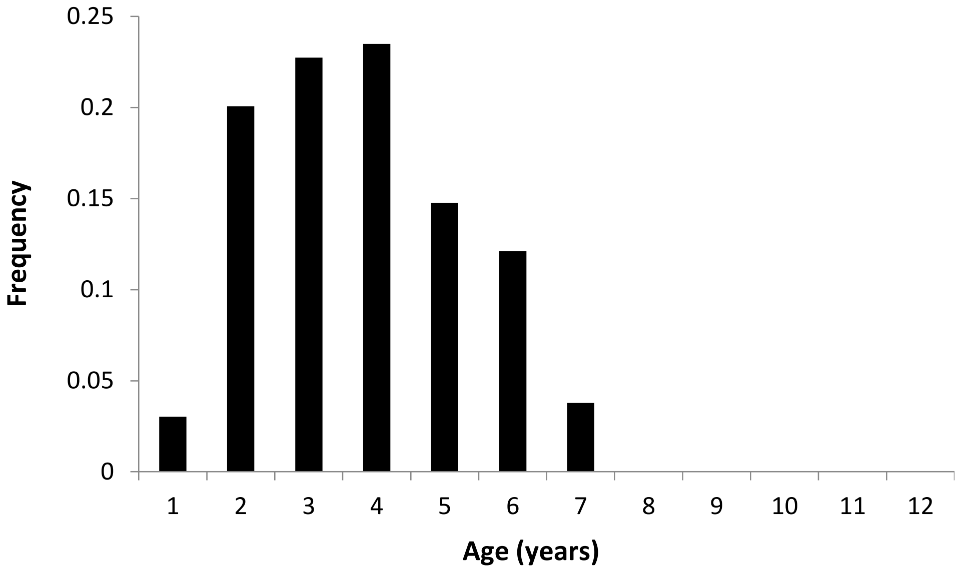

Figure 2. Age frequency distribution of Channel Catfish at Brookville Reservoir.

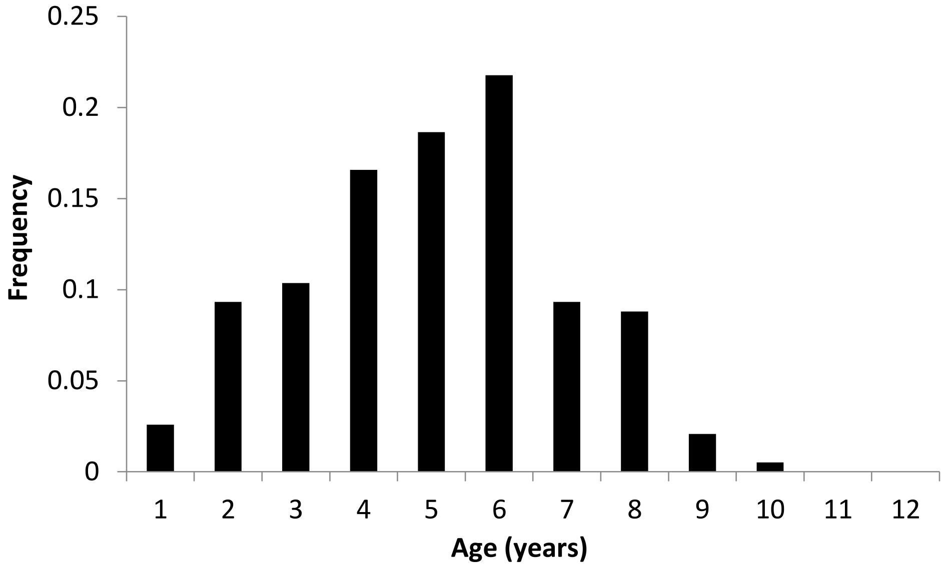

Figure 3. Age frequency distribution of Channel Catfish at Monroe Reservoir.

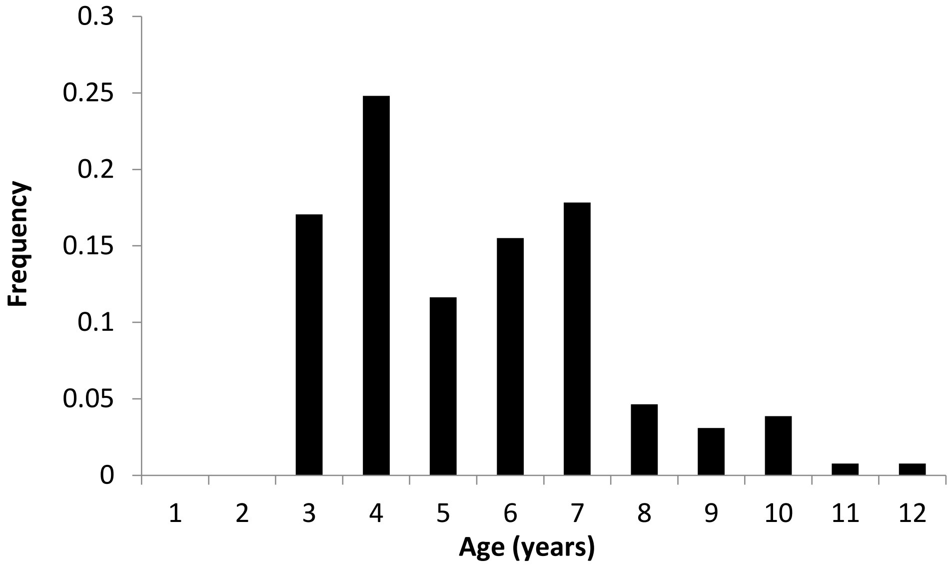

Figure 4. Age frequency distribution of Channel Catfish at Cecil M. Harden Reservoir.

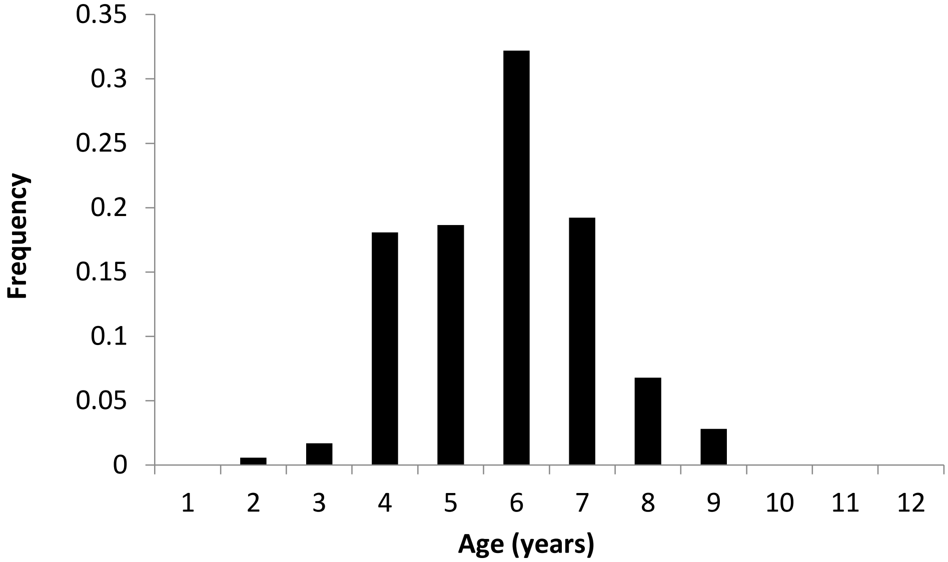

Figure 5. Age frequency distribution of Channel Catfish at Patoka Reservoir.

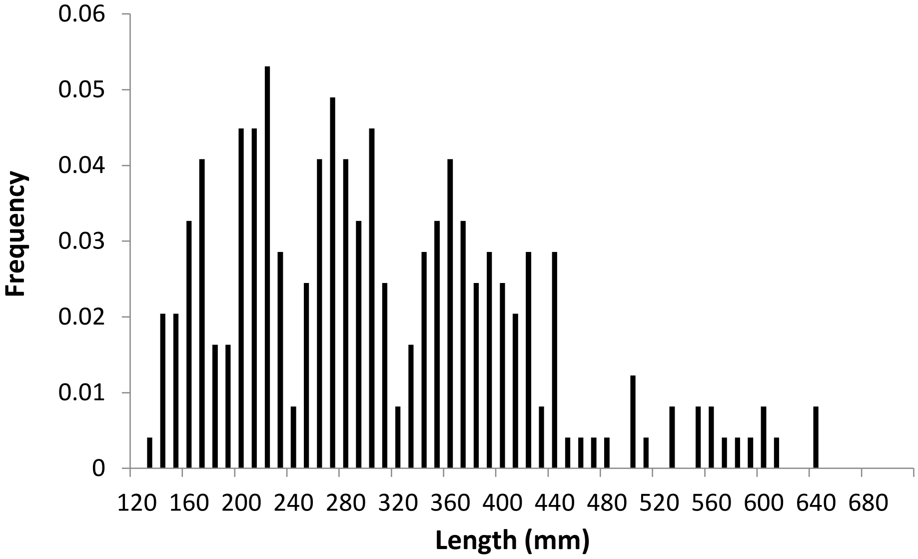

Figure 6. Length frequency distribution of Channel Catfish at Eagle Creek Reservoir.

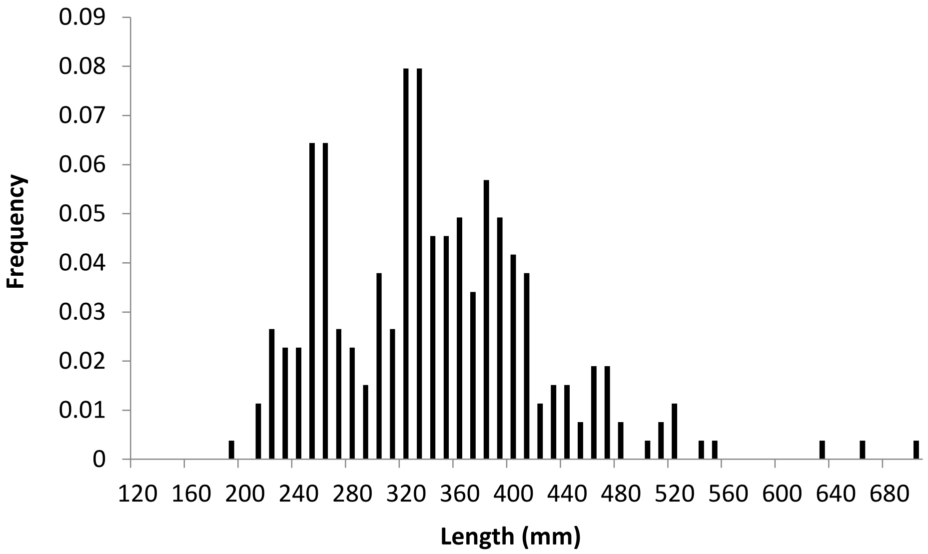

Figure 7. Length frequency distribution of Channel Catfish at Brookville Reservoir.

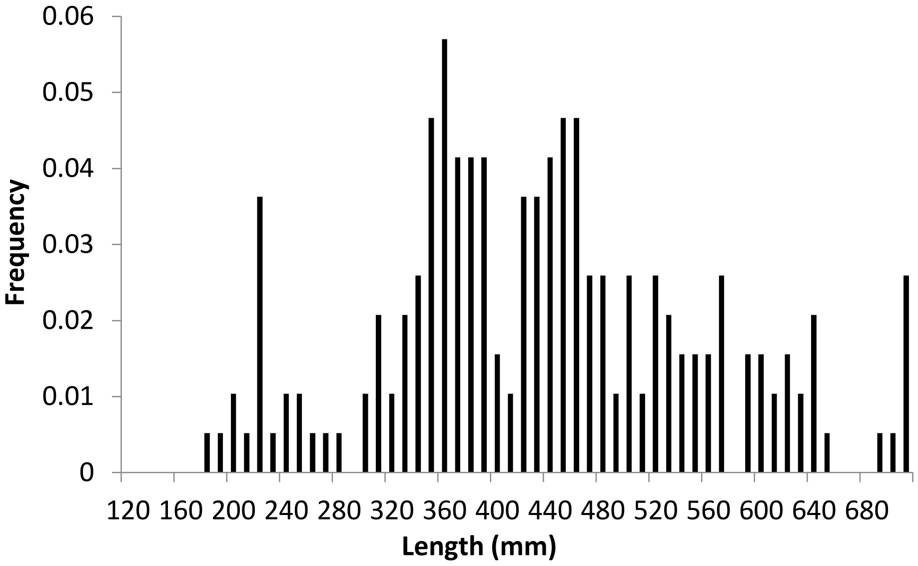

Figure 8. Length frequency distribution of Channel Catfish at Monroe Reservoir.

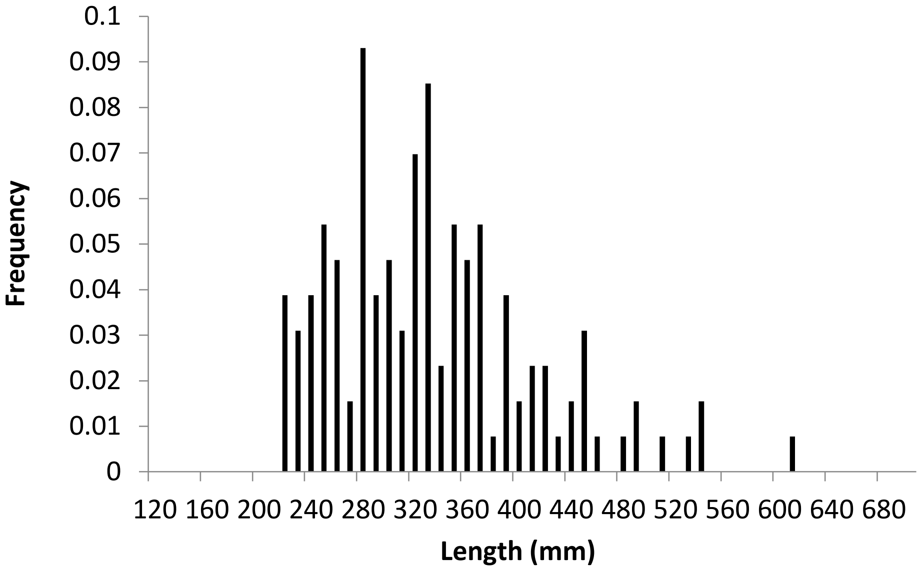

Figure 9. Length frequency distribution of Channel Catfish at Cecil M. Harden Reservoir.

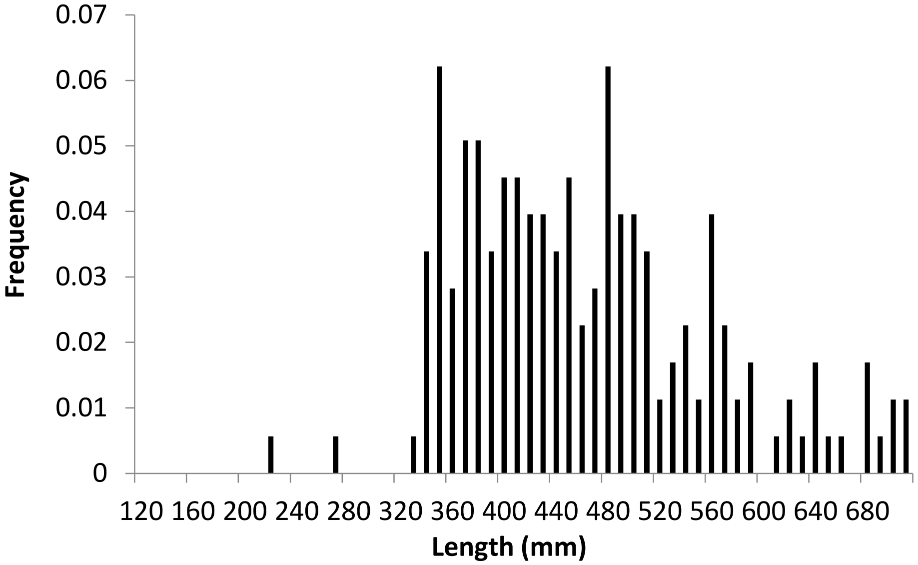

Figure 10. Length frequency distribution of Channel Catfish at Patoka Reservoir.

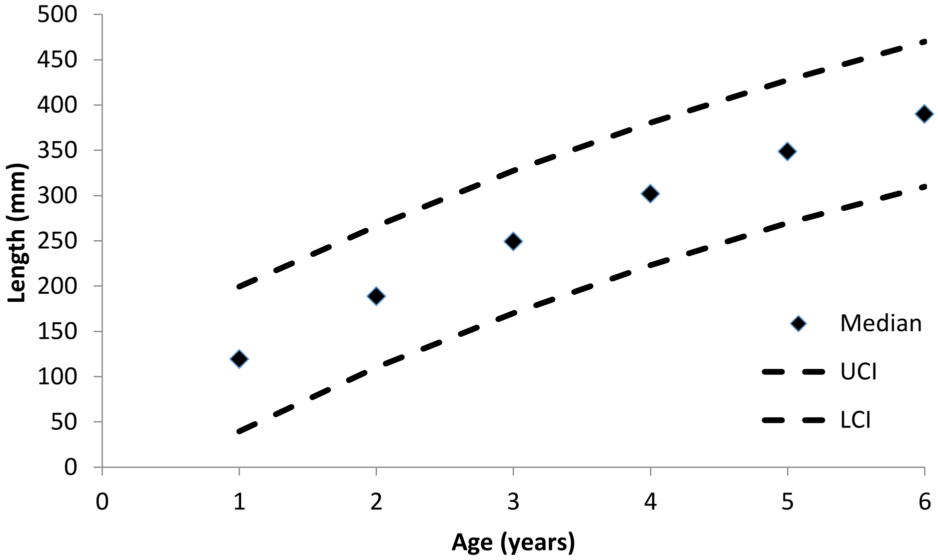

Figure 11. Von Bertalanffy growth curve of Channel Catfish at Eagle Creek Reservoir. Diamonds are median length at age and dashed lines are credible intervals.

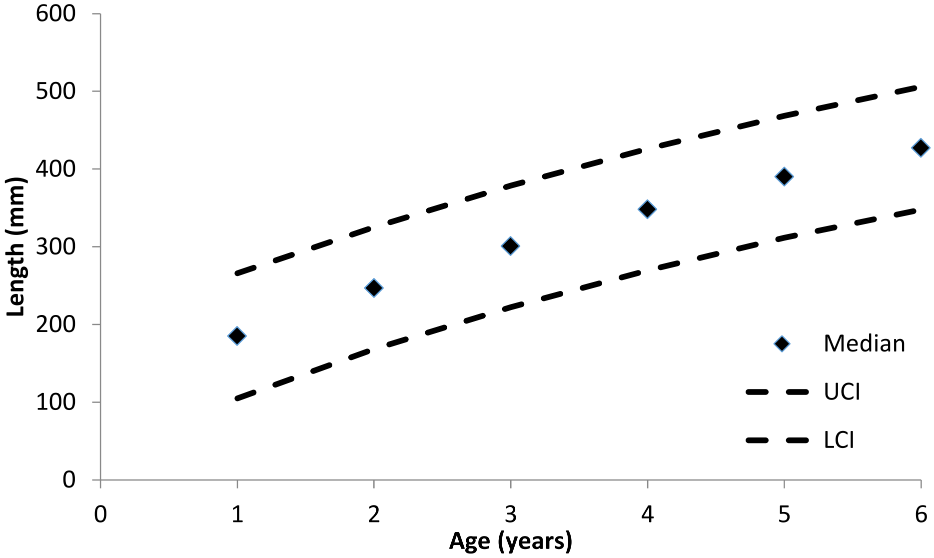

Figure 12. Von Bertalanffy growth curve of Channel Catfish at Brookville Reservoir. Diamonds are median length at age and dashed lines are credible intervals.

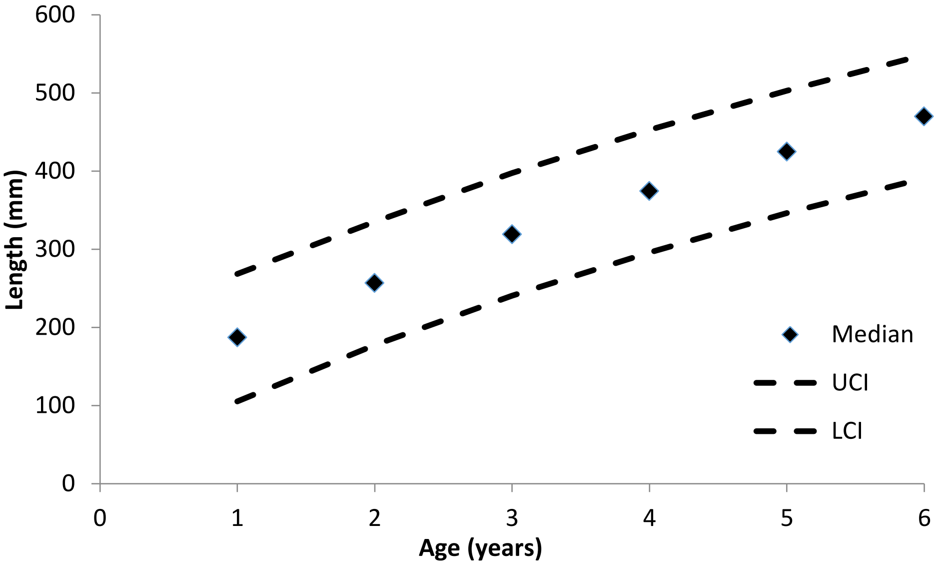

Figure 13. Von Bertalanffy growth curve of Channel Catfish at Monroe Reservoir. Diamonds are median length at age and dashed lines are credible intervals.

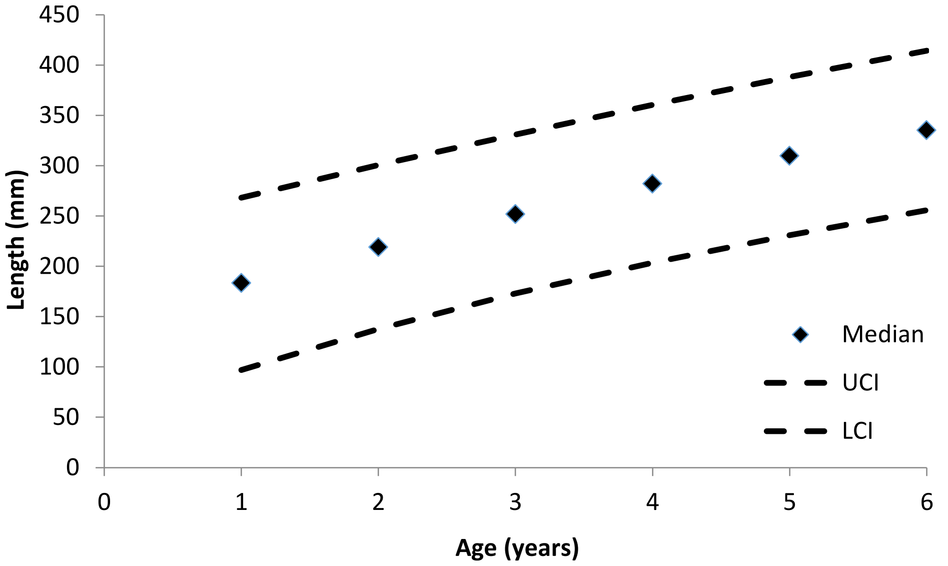

Figure 14. Von Bertalanffy growth curve of Channel Catfish at Cecil M. Harden Reservoir.

Diamonds are median length at age and dashed lines are credible intervals.

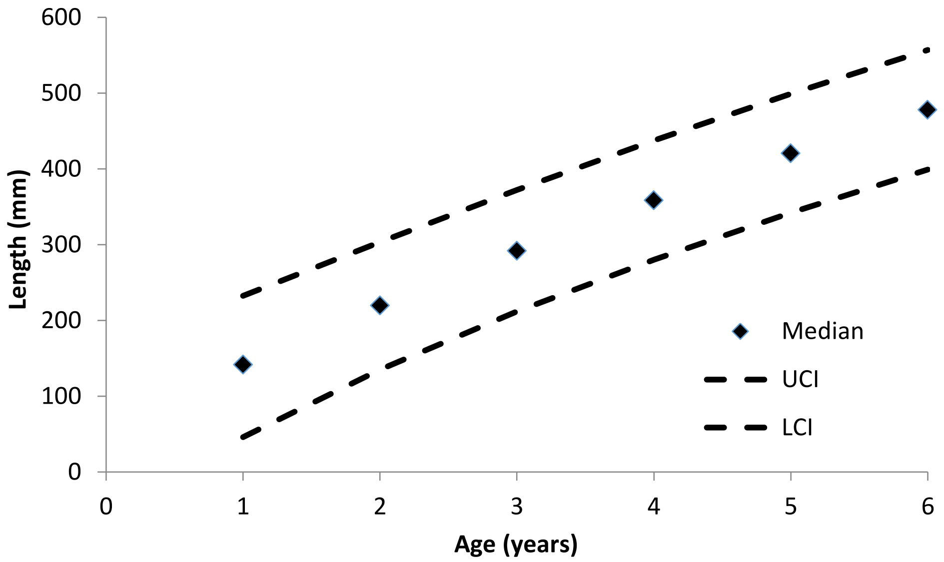

Figure 15. Von Bertalanffy growth curve of Channel Catfish at Patoka Reservoir. Diamonds are median length at age and dashed lines are credible intervals.

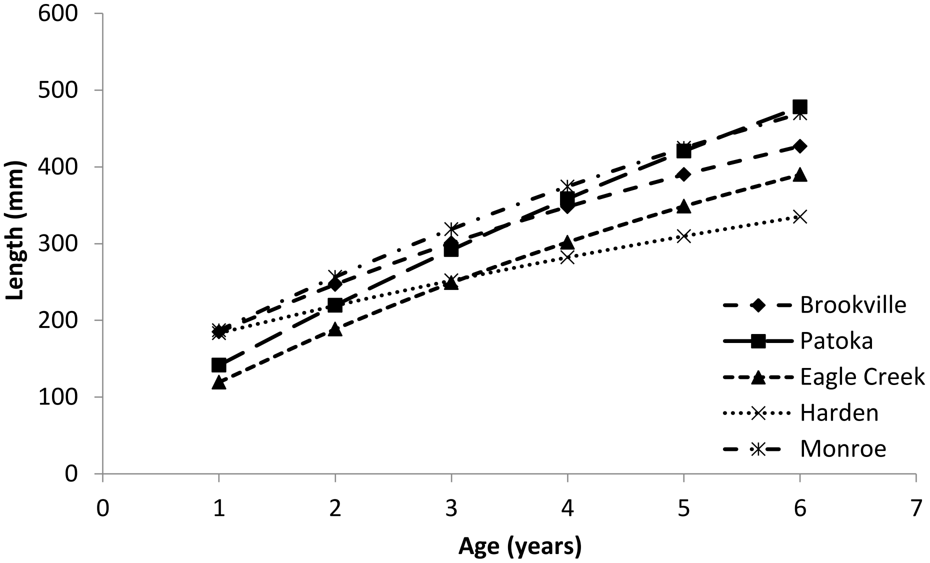

Figure 16. Median Length at age of Channel Catfish among reservoirs.

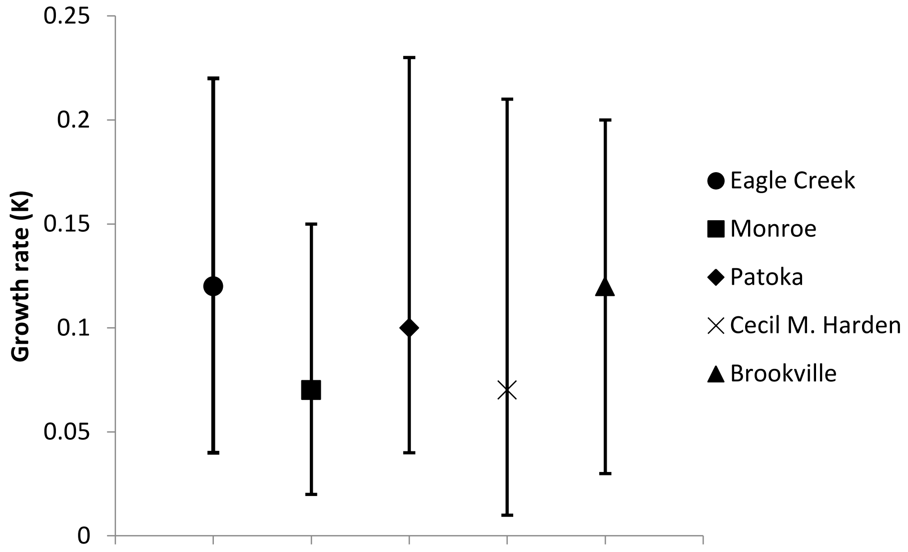

Figure 17. Comparison of growth rate (k) of Channel Catfish among reservoirs. Mean (k) are the differing symbols and black lines are the credible intervals.

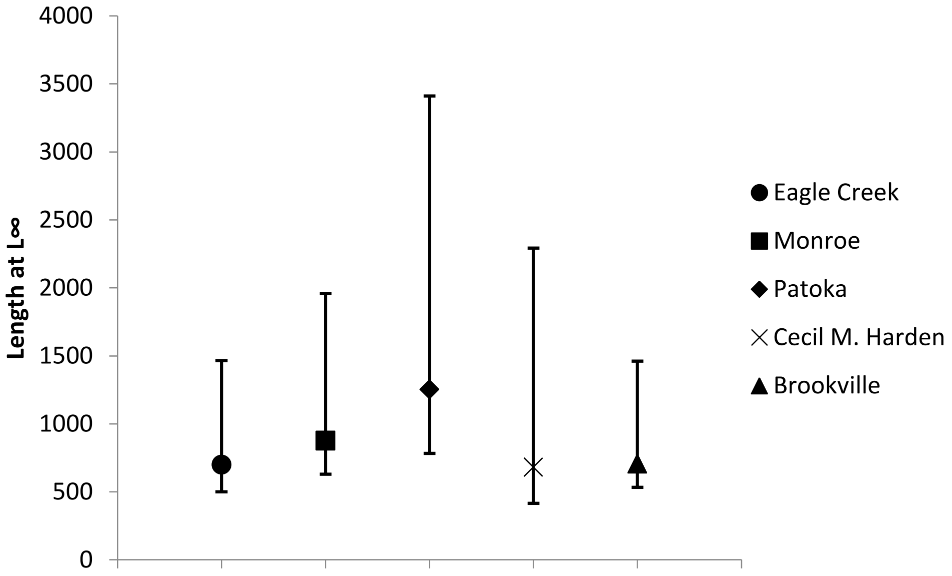

Figure 18. Comparison of length at L∞ of Channel Catfish among reservoirs. Mean L∞ are the differing symbols and the black lines are the credible intervals.

Appendix

Back-calculated lengths at age were obtained from the program Fish B.C. This program uses the Fraser-Lee method, a common method of back-calculating lengths in fisheries sciences (Quist et al. 2012). Tables 1-10 are a summary of the back-calculated lengths at age for each reservoir in the study, with corresponding standard error tables.

Appendix 1. Average back-calculated lengths for each age class at Brookville Reservoir in 2014.

Year Class	Age	n							
2013	1	8	185						
2012	2	53	168	243					
2011	3	60	162	251	302				
2010	4	62	183	268	323	356			
2009	5	39	176	266	315	352	383		
2008	6	32	172	266	317	358	396	425	
2007	7	10	205	300	361	410	452	490	523
N		264	264	256	203	143	81	42	10
All Classes			174	259	316	359	397	440	523

Appendix 2. Standard error of average back-calculated lengths for each age class at Brookville Reservoir in 2014.

Year Class	Age	n							
2013	1	8	7						
2012	2	53	4	2					
2011	3	60	4	4	4				
2010	4	62	5	5	5	5			
2009	5	39	6	4	6	6	6		
2008	6	32	7	8	9	11	11	12	
2007	7	10	18	15	17	19	20	22	25
All Classes			2	2	3	4	6	11	25

Appendix 3. Average back-calculated lengths for each age class at Eagle Creek Reservoir in 2014.

Year Class	Age	n											
2013	1	15	122										
2012	2	61	87	180									
2011	3	53	126	219	264								
2010	4	20	98	194	259	294							
2009	5	16	159	227	271	309	338						
2008	6	15	159	237	290	332	364	391					
2007	7	28	137	211	259	296	331	364	389				
2006	8	17	144	218	264	304	341	375	413	440			
2005	9	16	127	214	267	311	35	393	428	460	487		
2004	10	3	153	230	280	331	369	410	446	485	514	532	
2003	11	1	139	243	300	322	347	403	439	485	522	581	640
N		245	245	230	169	116	96	80	65	37	20	4	1
All Classes			121	207	266	306	344	380	408	453	493	545	640

Appendix 4. Standard error of average back-calculated lengths for each age class at Eagle Creek Reservoir in 2014.

Year Class	Age	n											
2013	1	15	13										
2012	2	61	4	3									
2011	3	53	6	4	4								
2010	4	20	10	7	5	6							
2009	5	16	7	7	8	9	9						
2008	6	15	14	17	18	20	21	21					
2007	7	28	4	5	5	5	6	6	6				
2006	8	17	11	10	11	14	14	15	17	19			
2005	9	16	5	8	11	13	12	13	16	17	18		
2004	10	3	34	18	23	33	40	40	46	52	53	54	
2003	11	1	0	0	0	0	0	0	0	0	0	0	0
All Classes			3	2	3	4	5	6	7	12	16	40	0

Appendix 5. Average back-calculated lengths for each age class at Cecil M. Harden Reservoir in 2014.

Year Class	Age	n												
2013	1	0	0											
2012	2	0	0	0										
2011	3	22	129	206	258									
2010	4	32	104	200	236	273								
2009	5	15	131	215	258	293	319							
2008	6	20	120	221	258	284	313	336						
2007	7	23	130	220	263	299	335	360	378					
2006	8	6	131	218	256	298	338	369	395	416				
2005	9	4	146	222	263	302	349	390	431	462	489			
2004	10	5	140	221	255	284	323	369	403	432	455	483		
2003	11	1	154	250	320	365	394	409	433	465	508	548	603	
2002	12	1	115	204	287	344	386	409	437	451	470	490	516	539
N		129	129	129	129	107	75	60	40	17	11	7	2	1
All Classes			123	212	254	288	328	357	392	436	473	493	560	539

Appendix 6. Standard error of average back-calculated lengths for each age class at Cecil M. Harden Reservoir in 2014.

Year Class	Age	n												
2013	1	0	0											
2012	2	0	0	0										
2011	3	22	10	8	8									
2010	4	32	8	5	6	6								
2009	5	15	10	6	5	7	8							
2008	6	20	9	5	5	5	6	7						
2007	7	23	7	6	7	7	8	8	8					
2006	8	6	11	8	7	8	12	12	10	11				
2005	9	4	11	12	14	13	10	3	7	9	13			
2004	10	5	16	13	16	15	14	10	10	10	13	16		
2003	11	1	0	0	0	0	0	0	0	0	0	0	0	
2002	12	1	0	0	0	0	0	0	0	0	0	0	0	0
All Classes			4	3	3	3	4	5	6	7	9	14	43	0

Appendix 7. Average back-calculated lengths for each age class at Monroe Reservoir in 2014.

Year Class	Age	n										
2013	1	5	193									
2012	2	18	152	239								
2011	3	20	193	289	340							
2010	4	32	170	283	338	370						
2009	5	36	180	290	351	394	425					
2008	6	42	188	294	357	407	445	469				
2007	7	18	223	342	418	473	519	553	579			
2006	8	17	213	332	423	482	523	560	591	613		
2005	9	4	165	328	439	501	553	589	621	651	668	
2004	10	1	175	316	418	465	516	580	613	644	670	696
N		193	193	188	170	150	118	82	40	22	5	1
All Classes			186	294	366	415	466	514	589	622	669	696

Appendix 8. Standard error of average back-calculated lengths for each age class at Monroe Reservoir in 2014.

Year Class	Age	n										
2013	1	5	4									
2012	2	18	11	10								
2011	3	20	10	6	6							
2010	4	32	11	7	6	7						
2009	5	36	7	6	6	6	7					
2008	6	42	7	7	7	7	7	7				
2007	7	18	11	11	13	14	15	16	17			
2006	8	17	11	10	9	11	12	12	12	12		
2005	9	4	15	10	20	20	31	32	32	32	32	
2004	10	1	0	0	0	0	0	0	0	0	0	0
All Classes			4	3	4	5	6	8	10	11	24	0

Appendix 9. Average back-calculated lengths for each age class at Patoka Reservoir in 2014.

Year Class	Age	n									
2013	1	0	0								
2012	2	1	176	219							
2011	3	3	177	295	332						
2010	4	32	162	264	320	359					
2009	5	33	207	287	334	374	405				
2008	6	57	216	317	378	420	457	485			
2007	7	34	234	330	383	426	465	495	520		
2006	8	12	207	330	404	457	496	534	567	599	
2005	9	5	245	383	456	510	558	589	622	652	680
N		177	177	177	176	173	141	108	51	17	5
All Classes			207	306	363	406	453	498	541	614	680

Appendix 10. Standard error of average back-calculated lengths for each age class at Patoka Reservoir in 2014.

Year Class	Age	n									
2013	1	0	0								
2012	2	1	0	0							
2011	3	3	43	26	33						
2010	4	32	10	5	4	4					
2009	5	33	6	5	5	5	5				
2008	6	57	5	6	7	8	8	9			
2007	7	34	9	12	13	13	134	14	14		
2006	8	12	10	10	12	14	16	16	18	18	
2005	9	5	17	9	3	11	12	11	10	7	4
All Classes			4	4	4	5	6	7	11	14	4