AN EVALUATION OF THE CATFISH FISHERY IN WILSON RESERVOIR, ALABAMA

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AN EVALUATION OF THE CATFISH FISHERY IN WILSON RESERVOIR, ALABAMA

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A Thesis

Submitted to

the Graduate Faculty of

Auburn University

in Partial Fulfillment of the

Requirements for the

Degree of

Master of Science

Auburn, Alabama
December 15, 2006

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VITA

Michael Paul Holley, son of Paul Holley and Diane (Leverton) Holley, was born October 20, 1978 in Gadsden, Alabama. He graduated from Etowah High School in Attalla, Alabama in 1997. He received his Bachelor of Science degree in Fisheries Management from Auburn University in December, 2001, and began working as a Research Assistant II in the Department of Fisheries at Auburn University in February 2002. In August 2004, he entered the Graduate School at Auburn University in the Department of Fisheries.

THESIS ABSTRACT

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Master of Science December 15, 2006
(B.S., Auburn University, 2001)

106 Typed Pages

Directed by Michael J. Maceina

On Lake Wilson, Alabama, a popular recreational and commercial catfish fishery exists and this study was initiated to assess population metrics and estimate exploitation. Currently, creel or length limits are not used to manage this fishery. Blue catfish *Ictalurus furcatus*, channel catfish *I. punctatus*, and flathead catfish *Pylodictis olivaris* were collected using low-pulse (15 mHz) DC electrofishing, and a sub sample of fish were aged with otoliths to describe longevity, growth and survival. Growth increments from back-calculated length at age and catch-curve residuals were used to compare annual growth variation and year-class strength to discharge from Wheeler Dam into Lake Wilson. Average discharge was computed for each year and month from 1985 to

2004 and various temporal time periods were used to assess the influence of discharge on growth and year-class strength. Fish greater than 300 mm total length (TL) were tagged with Carlin dangler tags and exploitation estimates were made based on angler returns that provided a reward. In addition, exploitation for blue catfish was estimated by examining differences in natural mortality and total annual mortality estimates. For blue catfish, simulation modeling was conducted to explore the impacts of variable minimum length limits and exploitation on yield, and number of fish that could potentially be harvested with implications for supporting a trophy fishery.

Male blue catfish and channel catfish grew faster than females, and no difference was observed between growth of male and female flathead catfish. The time to reach harvestable size (30 cm) was 2.3, 3.0, and 3.7 years for channel catfish, blue catfish, and flathead catfish, respectively. Maximum ages for channel catfish, blue catfish and flathead catfish were 12, 25, and 34 years and average annual survival rates based on linear catch-curve regressions were 73, 67, and 85%, respectively.

Age accounted for the majority of the variation in growth of all species of catfish, and less than 1% of the variation in growth was explained by various temporal windows of discharge from Wheeler Dam. Year-class strength was positively related to average discharge from Wheeler Dam prior to spawning period for channel catfish (January-April) and flathead catfish (March-May), and greater blue catfish year-class strength was weakly associated to higher average discharge into Lake Wilson in July.

For blue catfish, I observed length-dependent differences in mortality using a piecewise non-linear model, as total annual mortality was 41% for fish less than 760 mm

TL (10.3 years old) and only 16% for fish greater than this length. However, exploitation estimates from tag returns ranged from 5% to 15% for blue catfish when adjusted for non-reporting, and were similar to estimates obtained from linear catch-curve analysis (13-18%), but lower than the maximum exploitation rate of 28% computed for small blue catfish from the non-linear catch-curve regression. From linear catch curve analysis, estimates of natural mortality, and angler tag returns, exploitation ranged from 5 to 20% for channel catfish and flathead catfish. Growth overfishing for blue catfish would likely occur if exploitation was greater than 20%, but fishing mortality likely did not exceed natural mortality. The production of angler-memorable size (813 mm TL) blue catfish at an exploitation rate of 15% would increase 29% with a 457 mm minimum length limit compared to a 305 mm minimum length limit, but yield would only increase 17%. However, the number of fish available for harvest would decline 32% with the more restrictive minimum length limit (457 mm TL), compared with baseline conditions or a 305 mm minimum length limit. Based on electrofishing tag returns (< 1%), blue catfish abundance appears high in Lake Wilson. This, coupled with low to moderate exploitation rates, which did not exceed natural mortality, indicated that restrictive length or bag limits are not warranted for this blue catfish fishery at this time.

ACKNOWLEDGEMENTS

The author would like to thank many people who helped with this project. I would like to thank my advisor, Dr. Mike Maceina, for his guidance and help throughout graduate school, and providing his statistical and fishery biology expertise to me anytime I had questions. I would also like to thank my committee members, Dr. Elise Irwin and Dr. Rusty Wright, for their help and guidance along the way. Thanks to Ryan Hunter, Matt Marshall, Ben Ricks, Steve Sammons, Michael Shephard and David Stormer for field work support, and they all deserve recognition for avoiding being tossed out of the chase boat during the pursuit of many surfacing catfish. Julia Warren (Tennessee Valley Authority) provided hydrology data from Wheeler Dam. I owe a special thanks to my family for their continued support. Funding for this project was provided by the Alabama Division of Wildlife and Freshwater Fisheries through Federal Aid in Sport Fish Restoration funds (F-40).

Style manual or journal used North American Journal of Fisheries Management

Computer software used WordPerfect 12.0, SAS 9.1, FAST 2.1, Microsoft Excel 2000, SigmaPlot 9.0

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INTRODUCTION

Management of freshwater fisheries has been successful in recent years and has relied in part on accurate population data. Until recently, population assessments to assist in the management of catfishes (Ictaluridae) have been rare (Irwin et al. 1999; Miranda 1999). In Alabama, about 36% of anglers fish for catfishes, and 28% of the total freshwater anglers effort is directed towards these fish (USFWS 2001). Alabama does not regulate recreational or commercial fishing for catfishes with creel or length limits, and exploitation rates have not been estimated for catfish fisheries in Alabama. Blue catfish *Ictalurus furcatus*, channel catfish *I. punctatus*, and flathead catfish *Pylodictus olivaris* are all native species in the Alabama portions of the Tennessee River and the Mobile Basin drainage, and provide important commercial and recreational fisheries in this region (Boschung and Mayden 2004).

Increased popularity of catfish angling and tournament activity, where trophy sized catfish are sought, has raised concern for maintaining quality catfish fisheries (Irwin et al. 1999; Jackson 1999). Recent advancements in aging techniques for catfishes using otoliths (Nash and Irwin 1999; Buckmeier et al. 2002; Kwak et al. 2006) indicated that catfishes live longer, grow slower, and probably have lower natural mortality rates than previously reported when ages were estimated from pectoral spines.

A literature review by Hubert (1999) indicated that exploitation of channel catfish varied from 1 to 30%, and annual natural mortality ranged from 13 to 88%. Few attempts have been made to estimate natural mortality of channel catfish; therefore, most estimates were computed from estimates of the difference between annual mortality and exploitation. Blue catfish and channel catfish exploitation was 17 and 11%, respectively, in Kentucky Lake (Timmons 1999). In Missouri, Graham and DeiSanti (1999) reported exploitation rates of 32 and 28% for blue catfish and channel catfish, respectively. Annual mortality for blue catfish has ranged from 12 to 63% (Graham 1999), and estimates of natural mortality were uncertain in these populations. Grussing et al. (1999) observed annual mortality rates of blue catfish ranging from 27 to 57% from catch-curve analysis in four Alabama reservoirs. Mortality estimates of flathead catfish are rare in their native range (Kwak et al. 2006). However, Quinn (1993) estimated annual fishing mortality was 14-25% for an introduced population of flathead catfish in Georgia, and Kwak et al. (2006) reported similar estimates (16-20%) for introduced populations in North Carolina. Sakaris et al. (*In press*) reported conditional natural mortality and total annual mortality was 13 and 14%, respectively, for native flathead catfish in the Coosa River, Alabama.

Graham and DeiSanti (1999) stated that fishing effort for catfish was 20-50 times higher in the tailrace, compared to other areas of Truman Lake, Missouri. Jackson and Dillard (1991) reported that catfish anglers preferred to fish in the tailwaters of Aberdeen and Columbus lakes in Mississippi. In Coosa River tailwaters, Alabama, catfish were more abundant, larger, and in better condition than in other areas of the reservoirs (Jolley

2003). If exploitation is high, particularly in tailwaters, and the size harvested by anglers is small, managing for trophy catfish fisheries could be impossible without implementation of restrictive harvest regulations.

Implementation of restrictive harvest has been used with success to manage catfish populations. Pitlo (1997) reported that an increase in the minimum length limit from 33 to 38 cm for commercial harvest of channel catfish on the upper Mississippi River improved recruitment, and the number of fish available to anglers. Before the restriction that was implemented in 1985, a significant decrease in commercial harvest was observed, and smaller fish made up a large proportion of the commercial harvest (Pitlo 1997). Slipke et al. (2002) used simulation modeling to explore growth and recruitment overfishing of the upper Mississippi River channel catfish fishery. Modeling predicted that the spawning potential ratio (SPR) under the 33 cm minimum length limit ranged from 3-12%, and would increase to 10-20% under the 38 cm minimum length limit. In this fishery, the predicted increase in SPR corresponded with increased recruitment (Slipke et al. 2002). Therefore, the decline in commercial harvest was attributed to recruitment overfishing (Slipke et al. 2002).

Catfish populations have responded positively after commercial fishing ceased. The Missouri River was closed to commercial fishing in 1992 to increase the number of catfish available to recreational anglers (Stanovick 1999). The removal of commercial fishing led to increased harvest rates, release rates, and average lengths of blue catfish, channel catfish, and flathead catfish based on recreational angler survey data in Missouri (Stanovick 1999). Travnichek and Clemons (2001), used tournament data to assess the impact of banning commercial harvest on the Missouri River by looking at pre-regulation and post-regulation data. Fish weight required to place first, second, and third in tournaments increased during post-regulation, and the mean weight of the largest fish weighed-in tournaments also increased. Mestl (1999) reported that mean length and percentage of channel catfish > 410 mm increased, and age structure improved after a commercial fishing ban on the Missouri River, Nebraska.

Recently, the Tennessee Wildlife Resources Agency (TWRA) implemented a restriction that prohibited the daily harvest of more than one catfish greater than 813 mm. The regulation was not implemented based on biological data, but TWRA felt this regulation was necessary due to possible transport of large catfish, particularly blue catfish, out of the state (Tim Churchill; TWRA; personal communication). Anecdotal evidence also exists in Alabama, and suggested that large blue catfish were being removed from Tennessee River reservoirs, and hauled live out of the state of Alabama.

Recruitment of fishes is necessary to sustain any fishery where fish are not stocked, thus identifying strong and weak year classes is useful to assess the future of any fishery (Sammons et al. 2002). Residuals associated with catch curve regressions can represent variable recruitment in fish populations (Maceina 1997). Various factors can influence year-class strength, and in reservoirs, discharge was identified as an important variable related to sportfish recruitment (Ploskey 1986; Maceina 1992; Sammons et al. 1999; Bonvechio and Allen 2005). High discharge prior to spawning led to increased year-class abundance of crappies *Pomoxis spp.* in tributary storage impoundments in Tennessee (Sammons et al. 2002). However, an inverse relation between discharge and year-class abundance was observed in mainstem impoundments in Tennessee (Sammons et al. 2002) . A negative relation between smallmouth bass *Micropterus dolomieu* year-class strength and discharge during and right after spawning was evident on Lake Pickwick, Alabama (Slipke et al. 1998). Bonvechio and Allen (2005) found negative relations between black bass *Micropterus spp.* year-class strength and spring median flow rates in Florida Rivers. However, Bonvechio and Allen (2005) warned that relations may not be cause and effect, and habitat changes with flow should be incorporated to better understand system hydrology and fish recruitment. Conversely, white bass *Morone chrysops* year-class strength was positively related to high spring inflows in Virginia reservoirs (Dicenzo and Duval 2002). The production of young channel catfish was negatively effected by high discharge in a navigation pool of the upper Mississippi River when spawning was protracted due to increased or variable flow (Holland-Bartels and Duval 1988).

In 1990, 43% of all fishing effort was directed at catfishes, and nearly 100,000 kg of catfish were harvested in the Wheeler Dam tailwater of Lake Wilson (Janssen and Bain 1995). Blue catfish and channel catfish represented 63 and 34% of the total catfish harvest respectively, and harvest of flathead catfish was negligible (Janssen and Bain 1995). A trophy blue catfish fishery currently exists on Lake Wilson, but Janssen and Bain (1995) suggested that catfish exploitation could be high around the Wheeler Dam tailwater. If exploitation is indeed high, then maintaining a trophy fishery for blue catfish could be difficult without imposing restrictive regulations, especially if anglers harvest small fish that are unable to reach their reproductive and growth potential. In addition, high exploitation of small catfish could lead to reduced yield and growth overfishing.

The objectives of this project were to estimate population metrics and exploitation rates for blue catfish, channel catfish, and flathead catfish in Lake Wilson, Alabama. In addition, I computed stock density indices, relative weight, and estimated fishing and natural mortality rates of the three species of catfish. I also quantified annual growth variation, and related this to reservoir hydrology. Using age structure data and catch curve analysis, variation in year-class formation was described and related to reservoir hydrology. Finally, simulation modeling was used to explore the impacts of exploitation on the trophy blue catfish fishery, and evaluate the potential impact of creel and length limits.

STUDY AREA

This study was conducted on Lake Wilson, Alabama, a 6,400 ha mainstem impoundment of the Tennessee River that was impounded in 1924 (Figure 1). The reservoir is operated by the Tennessee Valley Authority (TVA), and provides hydropower and navigation. Lake Wilson flooded the once treacherous shoals reach of the Tennessee River, which once blocked navigation. The reservoir is approximately 26 km long, stretching from Wheeler Dam to Wilson Dam, and contains 269 km of shoreline. Lake Wilson has a mean annual discharge of approximately 1,500 m^3/s, and at full pool, elevation is 155 m above sea level. Lake Wilson supports a popular sport and commercial fishery for catfishes, especially in the tailwater below Wheeler Dam. Sampling locations consisted primarily of the tailwaters below Wheeler Dam, but also included locations that offered suitable habitat throughout the reservoir.

METHODS

Collection and processing

Channel catfish, blue catfish, and flathead catfish were collected from various locations, including the tailwater area below Wheeler Dam and main reservoir locations, using a Smith Root (7.5 GPP) electrofisher with low pulse frequency (15 pulses/s), and direct current (100-1000V). Additionally, a chase boat was employed in close proximity to capture catfishes as they rose to the surface. Pedal time was recorded in s, and the GPS location of each station was geo-referenced. Fish were collected in areas that were conducive to high catch rates and 14 to 24 replicate samples were taken during each sampling trip. Electrofishing was conducted during October 2004 and 2005, May 2005 and 2006, and July-August 2005.

Upon collection, all fish were placed in a 400 L live well, and total length (TL) was measured to the nearest mm, and for fish less than 5.0 kg, weight was recorded to the nearest 1 g. Fish larger than 5.0 kg were weighed to the nearest 10 g. Carlin dangler tags were inserted below the first dorsal fin and between the dorsal pterygiophores on all fish $\geq$ 300mm TL to assess harvest of catfish based on angler tag returns. Each tag had an individual number, stated that a reward was offered, and had the name, address, and phone number of the Fisheries Department at Auburn University. The adipose fin of all tagged fish was clipped to identify that they had been tagged in case of recapture with sampling gear, and to determine if tags had been shed. In addition, catfish were collected and tagged in June 2006 (see later section in methods) and checked for tag recaptures.

For each species of catfish, about 150 fish were sacrificed for age determination. Samples included fish $\geq$ 200 mm TL to the maximum length collected. Upon capture, fish were placed in a 300 mg/L solution of MS-222 until they expired. Length and weight were recorded, sagittal otoliths removed, and sex determined for all sacrificed fish.

Stock density, relative weight, and relative abundance

Stock density indices were calculated according to Anderson and Neuman (1996) and included proportional stock density (PSD) and relative stock density (RSD) values. Relative weight was calculated for blue catfish according to the standard weight equation proposed by Muoneke and Pope (1999). Flathead catfish relative weight was calculated based on the equation reported by Bister et al. (2000), and the channel catfish standard weight equation was obtained from Anderson and Nuemann (1996). Differences in relative weight among sampling months were tested using ANOVA, and post-hoc comparisons were made using Student-Neuman-Keuls (SNK) multiple range tests. The weight-to-length relation for all three species was determined by regressing $\log_{10}$(WT) against $\log_{10}$(TL) and the slope and intercept values were tested against coefficients from the standard weight equations. The slope and intercept from the weight-to-length relation regression were used in the modeling software developed by Slipke and Maceina (2000).

Catch per effort (CPE) was determined by computing the number of fish caught per hour for each species. To test for differences in catch rates, fish were placed into stock size categories (Anderson and Nuemann 1996), then analysis of variance (ANOVA) was used to test for differences in catch per hour for each species among collection months, and each size group among species over the sampling period. Catch-per-effort values were $\log_{10}$ transformed to meet assumptions of ANOVA. Post-hoc comparisons were made using (SNK) multiple range tests.

Age and Growth

Otoliths were used to age fish by counting successive annuli, and distances between annuli were measured to back-calculate length at age using an Image Pro Digitizer and software (Image Pro 2002). Procedures for sectioning an examining otoliths consisted of mounting the otoliths perpendicular on a glass microscope slide with crystal bond cement, hand sanding the otolith to the core, then examining the section under 40X magnification with reflected light (Buckmeier et al. 2002).

Growth was described for each species using the von Bertalanffy equation:

$$L_t = L_{inf}\left[1 - e^{-k(t - to)}\right]$$

where L_t = length at time t, L_{inf} = the maximum theoretical length, k = growth coefficient, t = time in years or age, and t_o = theoretical time at age 0. For my analysis, I constrained L_{inf} to the largest fish collected. To test for sex specific growth differences, the slope of the TL to $\log_{10}$age regressions were compared using analysis of covariance (ANCOVA).

The direct proportion method for estimating back-calculated mean lengths-at-age was used as recommended by Schramm et al. (1992) for otoliths:

$$Li = \frac{ODi_{*}Lc}{OR}$$

where L_i = back calculated length at age_i, OD = otolith distance at age_i, L_c = length at capture and OR = otolith radius. Annual variation in growth was examined by assessing the influence of Wheeler Dam discharge (DIS) on growth increments after the effect of age was accounted for using multiple regression (Maceina 1992):

$$TLINC = b_0 - b_1\,AGE \pm b_2{*}(HYD)$$

where TLINC= total length increment between ages. Hence, ages represent 0.5 year intervals (i.e. 0.5, 1.5, 2.5, etc.). Average discharge (m^3/s) from Wheeler Dam was computed each year and month with data provided by the Tennessee Valley Authority (Figure 2). Discharge represented climatic conditions over time, and average monthly discharge was pooled among months to represent hydrologic windows that corresponded to seasonal time periods prior to and during reproductive activity for all species. Additionally, the residuals computed from catch-curve regressions were also used as an index of year-class strength and entered into the multiple regression equation to examine possible density-dependent effects on growth (Maceina 1997).

Exploitation and mortality

Exploitation of tagged fish was calculated as:

$$\mu = \frac{(N_h)}{[(N_t)*(1-P_{nr})(1-P_t)]}$$

where N_h = number of tagged fish reported as harvested, N_t = number of tagged fish at large, P_{nr} = angler non-reporting rate, and P_t = tag loss rate (31.4% / year). In order to promote the study and encourage anglers to return tags, fliers were posted at boat ramps, local tackle shops, and convenience stores. Postage paid envelopes were available at local businesses, which contained an information card for anglers to complete. Anglers were asked whether or not they were recreational or commercial fisherman, the date the fish was caught, location the fish was caught, the type of gear used to capture the fish, whether or not the fish was released or harvested, and their address for payment of rewards. Rewards were randomly assigned values of $5, $10, $20, or $50 U.S. dollars to entice anglers to return tags. Offering rewards for returned tags improves angler compliance, however, non-reporting rates must still be included in exploitation estimates (Zale and Bain 1994; Pegg et al 1996; Maceina et al. 1998; Miranda et al 2002). Although angler non-reporting was not directly estimated in this study, I estimated exploitation by including low and high angler non-reporting rates of 20 and 70% based on previous studies (Larson et al. 1991; Zale and Bain 1994; Maceina et al. 1998; Schultz and Robinson 2002). Carlin Dangler tags typically eliminate the uncertainty associated with tag loss; Graham (1999) reported that after one year, all tags were recovered from 30 blue catfish that were held in a 0.20 ha pond, and Travnichek (2004) evaluated 38 flathead catfish held in a hatchery pond for one 1 year with no tag loss. However, Carlin dangler tag loss has been estimated as high as 15.7% over a six-month period (Kevin Sullivan; Missouri Department of Conservation; personal communication). The number of fish at large each month was computed by removing the number harvested and the number of tags lost from the total tagged, as fish were being tagged throughout the study. Exploitation accounting for tag loss was calculated monthly from November 2004 to April 2006. Monthly estimates of exploitation were summed for the 18 month period, then adjusted to estimate average annual exploitation over a one-year period, and included 20 and 70% angler non-reporting rates. However for blue catfish, 2 of 7 fish were harvested by anglers in winter 2005. Thus, average annual exploitation was estimated for data collected from May 2005 to April 2006.

Catch-curve regressions were used to estimate instantaneous annual mortality (Z) by regressing the natural log-at-age against number. Unaged fish were assigned ages using a length-age key (Miranda and Bettoli 2001). Only ages that recruited to the harvestable length (300 mm TL) were included in the analysis. Residuals associated with catch-curve regressions can represent variable recruitment in fish populations (Maceina 1997). Maceina (2004) verified that residuals computed from catch curves served as a quantitative index of juvenile crappie and largemouth bass abundance, and were used in this study as an index of recruitment variability for three species of catfish. For blue catfish, total annual mortality was also estimated using piecewise non-linear regression to account for size related differences in mortality (Maceina 2007). The model was fit to the data:

$$\log_e(N_i) = b_o - (b_1 + b_2)\, t_i + \epsilon$$

where $b_1 = b_1$* when $t_i \leq$ knot, 0 otherwise, $b_2 = b_1 - b_2$* when $t_i >$ knot, 0 otherwise, ϵ = error, and b_1* and b_2* are estimated by the model. In this model Ni = number of fish at the ith age, and ti = age. Through iteration, a least squares fit to the data was solved for this age structure model to estimate two slope or Z values on either side of the knot or the change in the slope of this relation. Uncertainty associated with angler tag return estimates of exploitation inclined me to estimate natural mortality as another way to compute exploitation. The instantaneous natural mortality rates (M) were estimated from empirical and theoretical equations presented by Pauly (1980), Hoenig (1983), Peterson and Wroblewski (1984), Chen and Watanabe (1989), Jensen (1996) and Quinn and Deriso (1999) and were used to conduct simulation modeling for blue catfish. These values of M were averaged and the instantaneous fishing mortality rate (F) was derived by subtracting M from Z. In addition to using Carlin dangler tag returns to estimate exploitation, estimates of exploitation (μ) were also estimated from data generated from catch-curve regressions:

$$\mu = \frac{F}{Z} * AM$$

where AM = annual mortality determined from catch-curve analysis.

The influence of average monthly discharge (DIS) from Wheeler Dam on recruitment variation after the effects of age were accounted for were evaluated by multiple regression (Maceina 1997):

$$\log_e(\text{Number}) = b_0 - b_1(\text{Age}) \pm b_2(\text{DIS}).$$

Discharge was assumed to be related to climatic conditions (rainfall), and monthly and seasonal temporal time periods were calculated (i.e. July discharge, spring discharge) from average discharge using the same data that was used to assess the influence of Wheeler Dam discharge on growth. For these analyses, ages 3-17, 2-10, and 4-25 were examined for blue catfish, channel catfish and flathead catfish respectively, as older fish were rare and could bias the results.

Recapture rates of blue catfish

The number of blue catfish tagged and recaptured using electrofishing was recorded from November 2004 to June 2006. I used these data to estimate recapture rates, which I expected to increase over time as the number of tagged fish at large increased. Similar to the methods I used to estimate exploitation, I adjusted the number-at-large over time using a tag loss rate of 31.4%/year and also subtracted angler harvested fish from the total number of fish-at-large.

Simulation Modeling

Blue catfish population response and production of angler-memorable (819 mm TL) size fish to different management scenarios in Wilson Reservoir was simulated using Fishery Analysis and Simulation Tools (FAST) software (Slipke and Maceina 2005). Janssen and Bain (1992) reported that 63% of the catfish harvest was comprised of blue catfish and my observations of the fishery indicated most catfish anglers targeted blue catfish. Using estimates obtained from natural and fishing mortality, and age and growth, the population was modeled to predict yield and the number of fish recruiting to the fishery over a range of exploitation and different minimum lengths (305, 356, 406, 457 mm). For blue catfish, management options to sustain a trophy fishery were explored.

RESULTS

Collection

A total of 3,307 catfish were collected from October 2004 to May 2006 during electrofishing surveys, of which, 1,887 were blue catfish, 805 were flathead catfish and 615 were channel catfish. Of the blue catfish captured, 173 were sacrificed for age determination, 1,149 were tagged and released, and 565 were measured and released. For flathead catfish captured, 164 were sacrificed for age determination, 433 were tagged and released, and 208 were measured and released. Of the channel catfish collected, 127 were sacrificed for age determination, 266 were tagged and released and 222 were measured an released. An additional 42 fish were collected from tournaments held during March 2005 and March 2006, of which 40 blue catfish and 2 channel catfish were tagged and released.

Catch per effort

Blue catfish CPE averaged 52 fish/h over the study period, and the highest CPE (mean = 159/h) occurred in May 2006 (Table 1). Catch was significantly ($P < 0.10$) higher in May 2006 than in other months collection, and CPE was also higher in June 2005 (mean = 45/h), August 2005 (53/h) and October 2005 (mean = 44/h), than in May 2005 (mean = 12/h) and October 2004 (mean = 0.9/h; $P < 0.10$; Table 1).

Catch of channel catfish averaged 11 fish/h over the course of the study, and the highest CPE occurred in October 2005 (mean = 25/h, Table 1). In October 2005, catch was significantly higher ($P < 0.10$) than all other months of collection, and the CPE in May 2005 (mean = 16/h) was higher than October 2004 (mean = 5/h) and August 2005 (mean = 2/h; $P < 0.10$).

Catch of flathead catfish averaged 19 fish/h, and catch rates were highest in October 2005. Flathead catfish were not targeted for collection in May 2006. Statistically, CPE in October 2005 (mean = 35/h) was higher than all other months with the exception of June 2005 (mean = 21/h), and CPE was lower in August (mean = 5/h) than in all other months of collection ($P < 0.10$; Table 1).

Catch rates of memorable size and larger flathead catfish and blue catfish were over a magnitude lower compared to smaller size fish (Table 1). Trophy size flathead catfish and blue catfish were relatively rare in electrofishing surveys; mean CPE ranged from 0 to 0.7 fish/h.

Length frequency analyses

The length-frequency distribution of blue catfish was highly truncated toward smaller fish, and PSD, RSD-P (preferred), and RSD-M (memorable) values were 14, 4 and 2%, respectively (Figure 3). PSD and RSD-P for channel catfish was 46% and 2%, respectively, however, and no memorable or trophy size channel catfish were collected during the study (Figure 3). Flathead catfish PSD, RSD-P and RSD-M values were 43, 17 and 6%, respectively (Figure 3).

Weight-to-length relations and relative weight

The intercept of the regression of double $\log_{10}$ transformed weight-to-length for blue catfish (Table 2) was lower ($t = 2.53$; $P < 0.10$), but the slope was similar ($t = 0.66$; $P > 0.10$) to the standard weight equation reported by (Muoneke and Pope 1999). For channel catfish, no differences in the slope ($t = -0.819$; $P > 0.10$) or intercept ($t = -0.258$; $P > 0.10$) in the weight-to-length relation were evident when compared to the standard weight equation presented by Anderson and Neuman (1996). The slope and intercept of the weight-to-length regression for flathead catfish (Table 2) were higher ($t = 4.45$; $P < 0.10$) and lower ($t = 6.08$; $P < 0.10$), respectively, from the standard weight equation computed by Bister et al. (2000).

Relative weight of blue catfish was similar ($P > 0.10$) during all months of collection for quality, preferred, memorable and trophy size fish (Table 3). Relative weight for stock-size blue catfish was higher ($P < 0.10$) in August 2005 (mean = 91) than in all other months of collection, and was also higher ($P < 0.10$) in June 2005 (mean = 89) and October 2005 (mean = 87), than in May 2005 (mean = 84) and May 2006 (mean = 84; Table 3). Blue catfish collected in October 2004 were excluded from the analysis due to small sample size.

Relative weights of channel catfish did not differ over the sampling periods for stock, quality, or preferred size fish ($P > 0.10$; Table 3).

Flathead catfish relative weights did not differ ($P > 0.10$) over time for preferred or trophy size fish. Relative weights were higher ($P < 0.10$) in August 2005 than in May 2005, June 2005, and October 2005 for stock-size fish, and higher in May 2005 and

October 2005 than in June 2005 (Table 3). Quality-size flathead catfish also expressed higher relative weights in May 2005 than all other months of collection ($P < 0.10$), but differences ($P > 0.10$) were not observed among other months (Table 3). Relative weights for memorable-size fish were higher in May 2005 than in October 2005, but differences ($P > 0.10$) were not detected between May 2005 and June 2005, or June 2005 and October 2005, and memorable-size fish were not collected in August 2005 ($P < 0.10$). Flathead catfish were not collected in May 2006, and data from October 2004 was eliminated from the analysis due to small sample size.

Age and growth

The maximum ages observed were 18 and 25 years for female and male blue catfish, respectively, and the longest total lengths collected were 1,165 mm TL for females and 1,291 mm TL for males. To date, 25 is the oldest recorded age for blue catfish, and the longest fish collected during this project (1,291 mm TL) was 19 years old. The von Bertalanffy equation predicted that blue catfish reached harvestable size (305 mm TL) in 3.0 years, and angler-memorable size (813 mm TL) in 11.5 years (Figure 4). Time to reach memorable (890 mm TL) and trophy size (1,140 mm TL) was 15.5 and 24.9 years, respectively. Sex-specific differences in growth rates were evident for blue catfish. The slopes of the TL to $\log_{10}$ transformed age regressions were different between sexes (ANCOVA; $t = -4.96$; $P < 0.01$). Male blue catfish reached harvestable size (305 mm TL) in 3.2 years and angler-memorable size in 10.7 years (Figure 5). Female blue catfish reached harvestable size in approximately the same time (2.9 years), but females took almost five years longer (15.0 years) to reach angler-memorable size (Figure 5).

The maximum ages for female and male channel catfish were 12 and 9 years, respectively, and the longest lengths observed were 646 mm TL for females and 623 mm TL for males. The von Bertalanffy equation predicted that channel catfish reach harvestable (305 mm TL) size in 2.3 years (Figure 6). Male channel catfish grew faster than female channel catfish (ANCOVA; $t = -2.02$; $P < 0.05$). Male and female channel catfish reached harvestable size at 2.6 and 2.3 years respectively (Figure 7). However, female growth was slower after age 3 (Figure 7).

The oldest flathead catfish collected was a male that was 34 years old and 1,100 mm TL. However, the longest male flathead catfish collected was 1,145 mm TL and was only 16 years old. The oldest female flathead catfish collected was 29 years old, and the maximum length for all females collected was 1,110 mm TL. Flathead catfish grew slower than blue catfish and channel catfish, hence, they reached harvestable size (305 mm TL) in 3.7 years (Figure 8). No difference in male and female growth was evident (ANCOVA; $t = -0.45$; $P = 0.6593$). The von Bertalanffy equation predicted flathead catfish took 22.0 and 35.9 years to reach memorable size (860 mm TL) and trophy size (1020 mm TL), although some individual fish reached this length in less than half this time (Figure 8).

Incremental growth variation

Incremental growth of blue catfish from back-calculated mean length at age decreased with age for age 1 to 17 year old fish from the 1988 to 2004 year classes (Figure 9). Mean length increments were negatively correlated with age ($r = -0.763$; $P < 0.01$), and $\log_{10}$ transformation of age improved the fit between age and incremental growth (TLINC). To assess the effects of age on growth, the following simple linear regression was computed:

$$\text{TLINC} = 106.2 - 60.2(\log_{10}\text{Age})$$

which explained 84% of the variation in incremental growth of blue catfish ($F = 800.96$; $r^2 = 0.84$; $P < 0.01$). A host of temporal discharge periods using monthly data from Wheeler Dam were entered into the simple linear regression and analyzed to examine the effects of discharge (see Figure 2) on growth of blue catfish, but none explained more than 1% of the variation in incremental growth after the effects of age were accounted for. Also, year-class strength was evaluated as a predictor of growth by entering catch-curve residuals into the regression, but no statistical relationships ($P > 0.10$) with growth were evident after accounting for age effects on growth increments. Therefore, variation in growth did not appear to be influenced by discharge from Wheeler Dam or density-dependent mechanisms for blue catfish in Lake Wilson.

Channel catfish growth increments decreased with age, and were negatively correlated with age ($r = -0.82$; $P < 0.01$; Figure 10). Transformation of age to $\log_{10}$ values improved the fit, as 84% of the variation in mean growth increments were explained by $\log_{10}$ age ($F = 338.87$; $r^2 = 0.84$; $P < 0.01$), and was computed:

$$\text{TLINC} = 101.5 - 79.8(\log_{10}\text{AGE}).$$

The relation improved by reducing the year classes in the regression to include only those that contained sufficient sample sizes ($N \geq 5$), which were year classes produced from1997 through 2004. With only these year classes included, $\log_{10}$ age explained 96% of the variation in mean growth increments ($F = 751.32$; $r^2 = 0.96$; $P < 0.01$):

$$\text{TLINC} = 111.7 - 94.1(\log_{10}\text{Age}).$$

Monthly and seasonal periods of average discharge from Wheeler Dam and year-class strength (catch-curve residuals) showed no statistical improvement ($P > 0.10$) to the model, thus density-dependence and discharge from Wheeler Dam were not significant predictors of channel catfish growth after accounting for the effects of age.

Flathead catfish growth increments were correlated with age ($r = -0.70$; $P < 0.01$), and increments decreased over time (Figure 11). Simple linear regression was computed:

$$\text{TLINC} = 78.3 - 41.8(\log_{10}\text{Age})$$

which explained 76% of the variation in mean growth increments ($F = 1060.24$; $r^2 = 0.76$;

$P < 0.01$). The relation improved when older year classes (≤ 1984) were deleted due to low sample sizes, and 80% of the variation in mean growth increments were explained by $\log_{10}$ age ($F = 729.83$; $r^2 = 0.80$; $P < 0.01$):

$$\text{TLINC} = 85.0 - 48.7(\log_{10}\text{Age}).$$

Climatic conditions did not appear to influence growth of flathead catfish, as many temporal periods of average discharge were included into the simple linear regression and did not improve fit. Also, year-class strength had no effect ($P > 0.10$) on growth of flathead catfish after accounting for the effects of age.

Mortality and exploitation

For age 3 to 25 year old blue catfish, total annual mortality based on linear catch-curve analysis was 27% ($Z = -0.315$). However, fish older than 17 years old were rare, and when these data were removed from the catch-curve, total annual mortality of blue catfish was 32% ($Z = -0.388$; $r^2 = 0.81$; $P < 0.01$; Figure 12). Estimates of instantaneous natural mortality (M) ranged from 0.13 to 0.20, and averaged 0.17 from the six empirical and theoretical equations used (Table 4). I estimated exploitation was about 13 to 18% for blue catfish from the difference in total annual mortality estimates and the average natural mortality rate.

The plot of $\log_e$ number-at-age against age strongly suggested that the relation between the two variables was not linear. The piecewise non linear regression was computed

$$\log_e(N_i) = 8.137 - 0.528(t_i) + 0.351(t_i)$$

where $b_2 = [-0.528 - 0.351]$ when $t_i > 10.3$ (in years) which is the knot where the spline regression between $\log_e(N_i)$ and t_i met. The model was highly significant ($F = 303$; $P < 0.0001$) and provided a slightly better fit ($r^2 = 0.94$) than the linear catch-curve regression ($r^2 = 0.90$). Thus, for age 3 to 10 year old fish, $Z = -0.528$ and $AM = 0.41$, and for age 11 to 25 year old fish, $Z = -0.177$ ($-0.528 - 0.351$) and $AM = 0.16$ (Figure 13). The knot at 10.3 years old conferred a length of about 760 mm TL in the piecewise non-linear regression and was derived from the von Bertalanffy equation (Figure 4). This suggested that exploitation could be as high as 28% for fish less than 11 years old if $M = 0.17$. Estimates of annual exploitation of blue catfish from angler tag returns of harvested fish ranged from 5 to 15% over a one-year period, which extended from May 2005 to April 2006 and included tag loss and a high rate of angler non-reporting (Table 5).

For age 3 to 12 year old channel catfish, total annual mortality based on catch-curve analysis was 33%. However, fish older than age 9 were rare and the annual mortality rate was 31% for age-3 to age-9 fish ($Z = -0.37$; $r^2 = 0.67$; $P < 0.01$; Figure 12). Estimates of instantaneous natural mortality (M) ranged from 0.22 to 0.38 and averaged 0.30 (Table 4). From differences in total annual mortality and natural mortality, I estimated exploitation was about 6 to 8% for channel catfish. However, estimates of annual exploitation of channel catfish from angler tag returns ranged from 6 to 21%

(Table 6).

Catch-curve analysis for flathead catfish estimated an annual mortality rate of 16% (Figure 12), which indicated a high survival rate of 85% ($Z = -0.17$; $r^2 = 0.81$; $P < 0.01$). Estimates of flathead catfish instantaneous natural mortality (M) ranged from 0.09 to 0.16, and averaged 0.13. Thus, the difference in Z and M suggested that exploitation was about 4%. However, angler tag returns of harvested flathead catfish indicated annual exploitation ranged from 5 to 16% (Table 7).

Recruitment variation

Catch-curve residuals computed from blue catfish age structure data were positively correlated to average discharge during July ($r = 0.53$: $P < 0.05$; Figure 14). After the effects of age were accounted for, average July discharge (DIS = m^3/s) accounted for an additional 3% of the variation in year-class strength of blue catfish ($F = 40.68$; $r^2 = 0.87$; $P < 0.01$), and was a significant term in the multiple regression equation:

$$\log_e(\text{Number}) = 6.485 - 0.444(\text{Age}) + 0.000927(\text{DIS}).$$

Semi-partial squared correlation coefficients (spr^2) suggested that age ($spr^2 = 0.86$) was the major determinant of year class strength, and average July discharge was a weak ($P < 0.10$) variable ($spr^2 = 0.21$) that accounted for variation in year-class strength of blue catfish.

Catch-curve residuals for channel catfish were positively correlated ($r = 0.77$; $P < 0.05$) with average discharge (DIS) prior to the spawning season (January-April; Figure 15). Average pre-spawn discharge was a significant term ($P < 0.01$) when entered into the catch-curve regression:

$$\log_e(\text{Number}) = 3.772 - 0.431(\text{Age}) + 0.00120(\text{DIS})$$

and discharge explained an additional 25% of the variation in year-class strength after the effects of age were accounted for ($F = 31.36$; $r^2 = 0.91$; $P < 0.01$). Thus, for channel catfish, stronger year classes were associated with higher discharge during the pre-spawn period (Figure 14). Age was the best determinant of abundance-at-age as semi-partial squared correlation coefficients (spr^2) were 0.90 and 0.74 for age and average pre-spawn discharge, respectively.

Catch-curve residuals generated for flathead catfish were positively correlated with average spring (March-May) discharge (DIS) ($r = 0.48$; $P < 0.05$; Figure 16). Average spring discharge ($\log_{10}$ transformed) was entered into the catch-curve regression and the multiple regression equation was computed:

$$\log_e(\text{Number}) = -0.956 - 0.166(\text{Age}) + 1.399(\log_{10}\text{DIS})$$

which explained an additional 6% of the variation in year-class strength of flathead catfish after the effects of age were accounted for ($F = 28.57$; $r^2 = 0.75$; $P < 0.01$). Semi-partial squared correlation coefficients showed that average spring discharge ($spr^2 = 0.18$) only slightly improved the model compared to age ($spr^2 = 0.72$)

Recapture rates of blue catfish

During sampling from October 2004 through June 2006, 10 blue catfish were recaptured using electrofishing from a total of 1,189 fish that had been tagged through May 2006 (Table 8). After June 2005, when over 250 tagged blue catfish were at-large, recapture rates were low and ranged from 0.3 to 0.8% when substantial numbers of fish were examined for tags in summer 2005 and 2006. An increase in recapture rate did not occur, even though the number of tagged blue catfish at-large increased.

Blue catfish simulation modeling

Based on the parameters estimated in this study (Table 9), simulation modeling suggested that exploitation of small blue catfish (< 760 mm TL or 11 years old and younger) was 28 - 35% based on calibration of observed and predicted stock density indices when conditional natural mortality was set at 0.16 ($M = 0.17$). However, as fish grew, negative selection or avoidance of electrofishing gear may have occurred. Catch analysis using abundance-at-age data suggested total annual mortality was about 32%, and based on life history traits and growth, estimated exploitation was 13-18%. This estimate was similar to my maximum exploitation rate (15%) from angler returns of tagged fish which assumed a maximum non-reporting rate of 70%.

Growth overfishing was evident when exploitation exceeded 20%, and the maximum yield occurred at exploitation rates of 13-20% for 305 mm, 356 mm, 406mm and 457 mm minimum length limits when M = 0.17 for all ages of fish (Figure 17). Examination of the yield contour plot (Figure 18) indicated that maximum yield would occur at high rates of exploitation (50%) and a high minimum length limit (> 725 mm TL), which, was not desirable as the bulk of the fishery at Lake Wilson targeted smaller fish (Matt Marshall, Auburn University, unpublished creel survey data). Yield would only increase about 17% if the minimum length limit was 457 mm TL compared to the 305 mm minimum length at an exploitation rate of 15% (Figure 17). The production of angler-memorable size fish (813 mm) under the 305 mm minimum length limit would decrease 75% if exploitation was 15%, compared to no fishing mortality, regardless if the minimum length limit varied from 305 mm to 457 mm TL (Figure 19). If exploitation was on the high end of my estimate (35%), I predicted a 92% reduction in the number of fish reaching 813 mm compared to an exploitation rate of 15% with a 305 mm minimum length limit (Figure 18). At an exploitation rate of 15%, approximately 29% more angler-memorable size fish would be available under a 457 mm minimum length limit compared to the 305 mm length limit (Figure 19). Under a 356 mm and a 407 mm minimum length limit, 11% and 19% more angler-memorable size fish would be available, respectively, compared to the 305 mm minimum length limit at an exploiation rate of 15% (Figure 19). At an exploitation rate of 15%, 32% fewer fish would be available to anglers with the more restrictive 457 mm minimum length limit compared to the 305 mm minimum length limit, and approximately 9 and 21% fewer fish would be available to anglers with a 356 mm or 406 mm length limit, respectively (Figure 20).

DISCUSSION

Catch per effort and length frequency analysis

Higher catch rates of all three species of catfish occurred in the tailrace portion of Lake Wilson, and catch rates were much lower in deep (10-25 m) main reservoir locations. After multiple attempts to collect fish from deep main reservoir habitat, I concentrated electrofishing effort on collecting and tagging primarily blue catfish in the tailrace, where the majority of anglers were observed fishing. Hence, electrofishing catch rates for blue catfish increased dramatically after May 2005. I observed most anglers fished offshore in the Wheeler Dam tailrace, where water depths were generally 3 to 7 m. Electrofishing catch rates for blue catfish were highest in these areas, but due to merging of habitats among transects, differences in catch rates between habitats were not analyzed, and would be difficult to compare with previous studies.

In Wheeler Lake, Alabama, catch rates of blue catfish, channel catfish and flathead catfish were not different among habitats (Grussing et al. 1999). In the Coosa River, Alabama, catch rates of blue catfish and channel catfish were not different among habitats, but flathead catfish were more abundant in the tailrace (Jolley 2003). Catch rates were slightly higher for flathead catfish in the Coosa River tailwater than in Lake Wilson; thus Jolley (2003) captured 32 fish/h, compared to 19 fish/h in the present study. Catch rates were higher for blue catfish (52 fish/h) and channel (11 fish/h) catfish in Lake

Wilson, than in the Coosa River where catch rates were 6.5 and 4.4 fish/h for blue catfish and channel catfish, respectively (Jolley 2003). Graham (1999) reported that blue catfish prefer deep swift channels and flowing pools, and that large specimens were often found in tailwaters, which was consistent with my observations. Similarly, blue catfish were found mostly in deep offshore areas of Lake Texoma (Edds et al. 2002). Catch rates were higher in this study for blue catfish than for channel catfish and flathead catfish, primarily due to selection of open water areas in the tailrace to concentrate sampling efforts, as blue catfish were the primary species of interest. The highest catches of channel catfish and flathead catfish occurred below Wheeler Dam around rip rap banks and rock piles in this study. Jackson (1999) provided a comprehensive literature review of flathead catfish, and suggested that they prefer hard bottoms, swift current, revetted banks, and are primarily in tailraces below dams. Channel catfish thrive in a wide range of environmental conditions, and are described as habitat generalists (Hubert 1999). Channel catfish habitat utilization has been described as a function of size, thus larger fish (>500 mm TL) prefer faster water areas where forage may be more abundant, and smaller fish inhabit slower water areas where smaller prey items (aquatic insects) are present (Hubert 1999).

A chase boat was beneficial in this study, as 30 or more catfish could be observed at any one time in an approximate 30 m radius around the electrofishing boat. The majority of the time, I observed that catfish did not remain stunned more than 45 to 120 seconds, and the chase boat collected catfish that may have been missed by the electrofishing boat. Additional manpower and equipment was needed when incorporating a chase boat, which required additional funds, and system specific decisions should be made regarding the use of chase boats (Daugherty and Sutton 2005). I did not quantify catch between boats, but Cunningham (2004) suggested that a chase boat was not necessary to sample flathead catfish in three Oklahoma Reservoirs. In this study, the chase boat improved electrofishing efficiency for all species of catfish, and in reservoirs similar to Lake Wilson, the use of a chase boat is recommended.

I assumed stock-density indices for blue catfish and channel catfish were dependent upon equal catchability of all size groups of fish. However, based on the length-frequency distribution, large blue catfish may have been avoiding or not adequately sampled with the electrofishing gear in Lake Wilson. The habitat preference of larger channel catfish for faster water probably inflated PSD, as many quality size fish or larger were collected immediately below Wheeler Dam in shallow areas where they may have been more vulnerable to electrofishing. I observed many smaller channel catfish escaping from the electric field in deeper open water areas, however, blue catfish and flathead catfish, once stunned and floating in open water areas were generally catchable. A survey of state agencies suggested that a common constraint among resource managers is inadequate sampling of catfishes (Michaletz and Dillard 1999). In the Cape Fear River, North Carolina, electrofishing failed to collect blue catfish and channel catfish larger than 381 mm (Rachels and Ashley 2003). Although I was able to collect a few large (> 1200 mm TL) blue catfish, no channel catfish larger than 646 mm TL were collected. The stock density indices for flathead catfish appeared accurate as a wide and more even distribution of lengths were collected. For all species of catfish, catch rates appeared higher when Wheeler Dam discharges were high, and future efforts to evaluate capture efficiency should incorporate hydrologic conditions as a function of catchability.

Relative Weight

Temporal trends in relative weight were evident for blue catfish. Stock-size blue catfish expressed higher relative weights during the summer (August) than in spring (May) and fall (October). Relative weights for quality-size blue catfish were not significantly different over time, but for quality and preferred-size fish, the lowest relative weights occurred in August, and the highest relative weights occurred in May. Blue catfish spawn from April to June (Boschung and Mayden 2004), which probably corresponded to the higher relative weights observed during this time period. In general, relative weights were higher for memorable-size and larger blue catfish than for stock and quality-size fish. Density-dependent mechanisms could effect condition of smaller blue catfish, as catch rates were highest for these size groups, and competition could limit prey availability (Liao et al. 1995).

Statistically, relative weight did not vary for channel catfish seasonally, however, the highest relative weights observed corresponded with the spawning season, which is usually from April to June (Boschung and Mayden 2004). Relative weights were high in both the fall and the spring for preferred-size channel catfish, but no preferred-size or larger fish were collected during the summer for comparison. Similar to blue catfish, stock-size channel catfish had lower relative weights than quality or preferred-size fish, which may be due to density dependent food limitation.

Relative weight of flathead catfish was high for preferred, memorable and trophy-size fish. Stock-size flathead catfish had higher relative weights during summer and fall than in spring. Contrary to stock-size flathead catfish, quality-size flathead catfish expressed higher relative weights in spring and fall, than during summer. Preferred-size flathead catfish were the only size group that had the highest relative weights during the spawning season, which is generally June through July (Boshung and Mayden 2004).

I detected differences in intercept and slope parameters from $\log_{10}$ transformed weight-to-length regressions for blue catfish and flathead catfish in Lake Wilson, compared to the standard weight equations used in the relative weight analysis. Murphy et al. (1991) questioned the validity of comparing regression parameters and standard weight parameters, since they are dissimilar measurements, because the standard weight equations were derived from a statistical population of biological population means (Murphy et al. 1991). Thus, even though parameters were different, trends in relative weight across lengths appeared valid, but comparison with other populations may not be warranted.

Age and growth

The oldest blue catfish and flathead catfish ever recorded were collected during this study on Lake Wilson, and these fish were 25 and 34 years old respectively. Many previous studies used spines to age catfish, which negated any comparison between systems and regions where spines were used to age catfish. Buckmeier et al. (2002) used three methods to age channel catfish, and otoliths were preferred over basal recess and articulating process sections due to less variability and greater accuracy. Otoliths were preferred for aging flathead catfish from the Tallapoosa River, Alabama, as they produced better accuracy and precision than basal recess and articulating process sections (Nash and Irwin 1999). Sections from pectoral spines consistently underestimate age of older fish due to erosion of the central lumen, which is particularly problematic for older fish and long-lived populations (Kwak et al.2006).

Growth of blue catfish in Lake Wilson was faster than blue catfish in the Coosa River, Alabama. Using von Bertalanffy parameters reported from tailrace habitat by Jolley (2003), it took blue catfish 1 year longer (4.1) to reach harvestable size (305 mm TL), and approximately 12 years longer (24 years) to reach angler-memorable size in the Coosa River compared to Lake Wilson. Growth was also slower for channel catfish in the Coosa River and Tallapoosa River, Alabama, as it took approximately 2 years longer, (4.0 years; Nash 1999, 4.6 years; Jolley 2003), to reach 305 mm TL than it did in Lake Wilson (present study; 2.3 years). Flathead catfish grew faster in Lake Wilson than in the Coosa (Jolley 2003) or Tallapoosa Rivers (Nash 1999); thus time to reach 305 mm TL was 3.7, 3.9 and 4.4 years, respectively. Time to reach preferred-size for flathead catfish was longer in the Coosa (15.5 years) and Tallapoosa Rivers (18.9 years) than in Lake Wilson (14.8 years). Time to reach memorable-size for flathead catfish was 24.1, 30.6, and 22.0 years, for the Coosa (Jolley 2003), Tallapoosa (Nash 1999) and Tennessee Rivers (present study), respectively. Native populations of flathead catfish grow slower than introduced populations (Kwak et al. 2006; Sakaris et al. *In press*). However, most introduced populations are relatively young with respect to the longevity observed in

Wilson Reservoir and the Tallapoosa River (Nash 1999).

Average discharge appeared to have little effect on growth of all three species of catfish. Average discharge using monthly means from Wheeler Dam did not explain much of the variation ($\leq$ 1%) in mean growth increments from back-calculated length-at-age after the effects of age were accounted for. The large amount of variation explained by age (>80%) suggested that growth was likely stable from year-to-year for all three species of catfish in Wilson Reservoir, however prey availability and other environmental conditions should be incorporated into future studies to evaluate variation in growth.

Mortality and exploitation

From catch-curve regressions, the survival rate for flathead catfish was higher than for blue catfish and channel catfish. Empirical and theoretical estimates of natural mortality suggested these values were low for flathead catfish and blue catfish, and highest for channel catfish. From differences in total annual mortality and fishing mortality, exploitation appeared low to moderate for blue catfish and channel catfish, but nil for flathead catfish. Based on observations of the fishery and a aged-based piecewise model, anglers appear to select for smaller blue catfish, and fishing mortality for blue catfish > 760 mm TL was nil. Electrofishing may have shown negative bias in the collection of larger blue catfish, but if catchability of larger fish was constant, then annual mortality (about 16%) was low for these fish. This annual mortality rate was similar to estimates made from empirical and theoretical equations used to estimate M. Additionally, the number of recaptures from electrofishing was low for blue catfish and flathead catfish, and suggested that abundance of these two species in the tailrace was high, which could be directly related to estimates of high survival and low to moderate exploitation.

Estimates of exploitation for blue catfish were highly variable, likely size selective, and depending on approach, ranged from 5 to 28%. However, exploitation likely was less than 15 to 20%. Exploitation estimates for blue catfish were similar to estimates of blue catfish exploitation from Kentucky Lake (17%; Timmons 1999) and lower than from the Truman Lake, Missouri (32%; Graham and DeiSanti 1999). My estimate of exploitation from catch curve-curve analysis (13-18%), and angler tag returns (15%) assuming a high rate of non-reporting were similar. Thus, exploitation likely did not exceed the predicted natural mortality rate. Based on the age-based non-linear regression, exploitation was probably low for large (> 760 mm TL) blue catfish, and appeared higher for smaller blue catfish (< 760 mm TL). From a creel survey on Lake Wilson in 2006, angler harvested fish ranged from 242 - 562 mm TL (median = 330 mm TL; Mathew Marshall; Auburn University; personal communication) which conferred my observations that size related mortality differences existed in the blue catfish fishery. A statewide angler survey in Texas found that catfish anglers expressed more interest in obtaining fish to eat rather than catching a trophy-size catfish (Wilde and Ditton 1999).

Based on angler tag returns, harvest of channel catfish and flathead catfish was similar to blue catfish, and ranged from 5 to 15% and 5 to 16%, respectively. Exploitation for channel catfish was lower than natural mortality (M = 0.30), but flathead catfish exploitation could be higher than natural mortality (M = 0.13). Exploitation was similar for channel catfish in Lake Wilson to estimates reported from Kentucky Lake (11%; Timmons 1999), but lower than from Truman Lake, Missouri (28%; Graham and Deisanti 1999). The flathead catfish fishery appeared minor or non-existent, as catfish anglers were rarely seen fishing with live bait in the tailrace region of Lake Wilson. Flathead catfish are highly piscivorus, and feed exclusively on live prey items (Ashley and Buff 1987; Jackson 1999; Jolley and Irwin 2003; Eggleton and Schramm 2004). Channel catfish were not as abundant as blue catfish or flathead catfish based on electrofishing catch. Anglers fishing for other sportfish possibly caught channel catfish and flathead catfish with artificial lures and live bait, and may have been more inclined to return tags than anglers targeting blue catfish. Thus, estimates of exploitation for channel catfish and flathead catfish based on catch-curve analysis were lower than estimates of angler returns with high non-reporting (70%), but similar if non-reporting was low (20%).

Non-reporting was not directly estimated in this study, but was based on previous exploitation studies of tagged sauger *Stizostedion canadense* in the same area of the Tennessee River, where only 27% of anglers returned a questionnaire which served as a tag surrogate (Maceina et al. 1998). Although uncertainty existed, non-reporting was probably higher for blue catfish. If angler non-reporting was about 70% for blue catfish, then exploitation corresponded to the linear catch-curve estimates for exploitation (13-18%). I used a tag loss rate of 31.4%/year based on recent observations from Missouri, but this estimate could be high, as two previous studies using Carlin dangler tags reported 0% tag loss (Graham 1999; Travnichek 2004). Future efforts to evaluate Carlin dangler tag loss should incorporate fish size effects and wire spacing.

Recruitment variation

Blue catfish recruitment appears to be weakly, but positively related to average discharge during July. Age accounted for most of the variation in year-class strength, but increased discharge during July was associated with slightly stronger year-classes of blue catfish. Little is known about blue catfish recruitment, and my data suggested that discharge into Lake Wilson is only a weak correlate of blue catfish recruitment. In Virginia, high flows after spawning led to strong year-classes of white bass, and may have been related to high nutrient loading or increased spawning substrate availability (Dicenzo and Duval 2002). Allochthonous sources of inorganic and organic material and nutrients associated with increased discharge could boost primary production and increase food availability to larval and juvenile catfish (Ploskey 1986; Maceina 2003). Juvenile sportfish species such as black basses and white bass that hatched in the spring, switch to piscivory by mid to late summer, and an influx of turbid water could hinder predation on juvenile and or larval catfish, or allow refuge in inundated shoreline areas which could also impede predation (Ploskey 1986; Maceina and Bettoli 1998). The catch-curves for blue catfish indicated that recruitment was fairly stable, as r^2 values were relatively high (0.81-0.90), and mechanisms to explain hydrologic conditions in relation to recruitment were only speculative.

Channel catfish and flathead catfish produced stronger year-classes during years of above average flows prior to spawning. High discharge and water levels prior to spawning has led to strong year-classes for other species (Maceina and Stimpert 1998; Sammons et al. 2002; Sammons and Bettoli 2002; Bonvechio and Allen 2005). The influence of increased flows and discharge prior to spawning is not well understood, but could serve as a spawning cue for adults (Maceina and Stimpert 1998; Sammons and Bettoli 2000; Sammons et al. 2002). An influx of nutrients associated with higher flows in the spring could increase primary productivity and lead to increased food availability for larval and juvenile catfish later in the year when these fish were age-0 (Ploskey 1986; Maceina and Stimpert 1998). Channel catfish recruitment appeared more sporadic, than blue catfish and flathead catfish, as only about 67% of the variation in year-class strength was explained by age, and the addition of January to April average discharge from Wheeler Dam explained a relatively high amount of variation (27%) after the effects of age were accounted for. Similar to blue catfish, catch-curve analysis indicated that flathead catfish recruitment was more stable than channel catfish, and average discharge from March to May prior to spawning only accounted for an additional 7% of the variation in year-class strength after the effects of age were accounted for.

Natural recruitment of catfishes is not well understood, and future work is needed to identify sampling methodologies for juvenile catfishes in large river and reservoir systems. Although catch-curve residuals have been verified as indicators of year-class strength for other species (Maceina 2004), electrofishing efficiency for catfishes is not well understood and bias of age and length data may provide erroneous results for mortality and recruitment variation. Therefore, catchability assessment among all sizes of catfishes needs to be conducted.

Blue catfish simulation modeling and management implications

The implementation of length limit and bag limits is not warranted for blue catfish in Lake Wilson. Growth overfishing was likely not occurring, and fishing mortality probably does not currently exceed natural mortality. In addition, less than 2% of all blue catfish with tags were recaptured using electrofishing during a particular sampling trip, which strongly suggested abundance was high, and exploitation may be low. Restrictive harvest and minimum length limits are usually implemented when natural mortality is low, and exploitation rates are moderate to high and exceed natural mortality (Allen and Miranda 1995; Noble and Jones 1999). Maximum yield for blue catfish will not be attainable in this population, as high rates of exploitation and a minimum length limit of 725 mm or larger would be needed if maximum yield was a management goal. Considering that the bulk of the blue catfish fishery in Lake Wilson has been directed at smaller fish, implementation of minimum length limits would have adverse effects on the number of fish available for harvest. For instance, with a 356 minimum length limit, 9% fewer fish would be available to anglers for harvest, and only 11% more angler-memorable size fish would be available to anglers interested in trophy blue catfish angling. Implementation of a 457 mm minimum length limit could increase yield, but the number of fish of fish avialable to anglers would decrease 32%. However, about 29% more angler-memorable size fish would be obtainable in the population. A trade-off existed, as implementation of restrictive minimum length limits would decrease the number of fish avialable for harvest, but increase yield only if exploitation exceeded 10%. To increase abundance of angler-memorable or trophy blue catfish, high minimum size limits would be necessary and would compromise the current fishery.

Although the limit of one catfish over 813 mm per day was not based on biological data in Tennessee, a similar restriction may be warranted only if evidence is found to be true that large blue catfish are being transported out of Alabama. However, preliminary creel survey data indicates that large blue catfish were not targeted by most anglers in Lake Wilson, and a similar restriction may have adverse effects on trophy angler participation. Considering Lake Wilson and other Tennessee River reservoirs host many catfish tournaments annually, a one fish per day bag limit over a specified size is not recommended.

TABLES

Table 1. Mean electrofishing catch-per-effort (N/h) of three species of catfish collected from Wilson Lake. Mean values followed by the same letter were not significantly (P > 0.10) different among sampling dates.

Blue catfish

Season	**All lengths**	**Stock**	**Quality**	**Preferred**	**Memorable**	**Trophy**
October 2004	1 d		0.6 b	0.1 b	0.2 a	0.0
May 2005	12 c	7 d	3.1 ab	2.0 ab	0.8 a	0.1 a
June 2005	45 b	31 bc	1.6 ab	0.0	0.0	0.0
August 2005	53 b	34 b	2.3 ab	0.1 b	0.0	0.1 a
October 2005	44 b	20 c	8.2 a	1.5 ab	1.5 a	0.7 a
May 2006	159 a	90 a	6.5 a	2.5 a	4.2 a	0.1 a
Channel catfish						
October 2004	5 c	0.1	4.6	0.2		
May 2005	16 b	5.6	7.0	0.4		
June 2005	6 bc	0.8	0.2	0.0		
August 2005	2 d	0.2	0.0	0.0		
October 2005	25 a	12.7	3.1	0.0		
May 2006	9 bc	4.2	1.0	0.0		
Flathead catfish						
October 2004	13 b	3 b	2 bc	1.0 ab	0.3 ab	0.1 a
May 2005	19 b	6 b	8 a	3.2 a	2.2 a	0.1 a
June 2005	21 ab	6 b	5 ab	1.4 ab	0.5 ab	0.5 a
August 2005	5 c	3 b	1 c	0.1 b	0.0	0.1 a
October 2005	35 a	20 a	7 a	2.2 a	1.0 ab	0.3 a
May 2006	not collected					

Table 2. Slope (b_0) and intercept (b_1) values for $\log_{10}$weight:$\log_{10}$length regression for three species of catfish collected from Wilson Lake, compared to the intercept and slope values for standard weight (W_S) equations published by Muoneke and Pope (1999) for blue catfish, Anderson and Neuman (1996) for channel catfish, and Bister et al. (1999) for flathead catfish.

		Coefficients	
Species	Equation	b_0	b_1
Blue catfish	Wilson	-6.136	3.407
	W_S	-6.067	3.400
Channel catfish	Wilson	-5.788	3.280
	W_S	-5.800	3.294
Flathead catfish	Wilson	-5.717	3.280
	W_S	-5.542	3.230

Table 3. Relative weights of three species of catfish by different length categories. Mean values for a length category followed by the same letter did not vary significantly (P > 0.10) over time.

Season	Stock	Quality	Preferred	Memorable	Trophy
Blue catfish					
October 2004		87 a	95 a	107 a	
May 2005	84 c	92 a	105 a	110 a	103 a
June 2005	89 b	89 a			
August 2005	91 a	84 a	85 a		107 a
October 2005	87 b	87 a	94 a	102 a	117 a
May 2006	84 c	92 a	101 a	103 a	90 a
Channel catfish					
October 2004	81 a	94 a	107 a		
May 2005	95 a	97 a	103 a		
June 2005	91 a	96 a			
August 2005	84 a				
October 2005	92 a	94 a			
May 2006	92 a	105 a			
Flathead catfish					
October 2004	91 a	97 a	101 a	89 c	103 a
May 2005	84 b	98 a	110 a	114 a	102 a
June 2005	79 c	90 b	117 a	106 ab	100 a
August 2005	91 a	86 b	106 a		96 a
October 2005	85 b	88 b	97 a	95 bc	103 a
May 2006	not collected				

Table 4. Estimates of instantaneous natural mortality (M) from the empirical and theoretical equations presented by authors listed.

Species	Quinn and Deriso (1999)	Hoenig (1983)	Jensen (1996)	Peterson and Wroblewski (1984)	Pauly (1980)	Chen and Watanabe (1989)	**Average**
Blue catfish	0.18	0.17	0.13	0.15	0.20	0.18	**0.17**
Channel catfish	0.38	0.35	0.22	0.27	0.35	0.23	**0.30**
Flathead catfish	0.14	0.12	0.09	0.16	0.16	0.11	**0.13**

Table 5. Monthly exploitation from angler tag returns over a one-year period for blue catfish in Lake Wilson. The number-at-large was adjusted for the number removed and the percentage of tags lost each month.

Year	Month	Number tagged	Number harvested	Number at-large	Exploitation corrected for tag loss
2004	October	7	0	7	0.0
2004	November	0	0	6.8	0.0
2004	December	0	0	6.6	0.0
2005	January	0	1	6.5	15.5
2005	February	0	1	5.3	18.8
2005	March	28	0	31.5	0.0
2005	April	0	0	31.0	0.0
2005	May	69	0	97.0	0.0
2005	June	173	0	263.0	0.0
2005	July	0	6	256.1	2.3
2005	August	357	3	591.2	0.5
2005	September	0	3	572.8	0.5
2005	October	158	2	708.8	0.3
2005	November	0	2	688.3	0.3
2005	December	0	1	668.3	0.2
2006	January	0	0	649.8	0.0
2006	February	0	1	632.8	0.2
2006	March	12	0	627.0	0.0
2006	April	0	2	610.69	0.3
Average annual exploitation for one year period (May 2005 - Apr. 2006)					**4.6**
Average annual exploitation corrected for 20% non-reporting					**5.8**
Average annual exploitation corrected for 70% non-reporting					**15.3**

Table 6. Monthly exploitation from angler tag returns over a one-year period for channel catfish in Lake Wilson. The number at-large was adjusted for the number removed and the percentage of tags lost each month.

Year	Month	Number tagged	Number harvested.	Number at-large	Exploitation corrected for tag loss.
2004	October	59	0	59.0	0.0
2004	November	0	1	57.5	1.7
2004	December	0	0	55.0	0
2005	January	0	1	53.5	1.9
2005	February	0	0	51.2	0
2005	March	2	2	51.8	3.9
2005	April	0	0	48.5	0
2005	May	101	2	145.6	1.4
2005	June	6	1	145.6	0.7
2005	July	0	0	140.9	0.0
2005	August	1	0	138.1	0.0
2005	September	0	0	134.5	0.0
2005	October	75	0	204.0	0.0
2005	November	0	0	198.7	0.0
2005	December	0	0	193.5	0.0
2006	January	0	0	188.4	0.0
2006	February	0	0	183.5	0.0
2006	March	0	0	178.7	0.0
2006	April	0	0	174.0	0.0
Average annual exploitation for one-year period (Nov. 2004 - Apr. 2006)					**6.4**
Average annual exploitation corrected for 20% non-reporting					**8.0**
Average annual exploitation corrected for 70% non-reporting					**21.3**

Table 7. Monthly exploitation from angler tag returns over a one-year period for flathead catfish in Lake Wilson. The number at-large was adjusted for the number removed and the percentage of tags lost each month.

Year	Month	Number tagged	Number harvested.	Number at-large	Exploitation corrected for tag loss
2004	October	62	0	62	0.0
2004	November	0	1	60.4	1.7
2004	December	0	0	57.8	0.0
2005	January	0	0	56.3	0.0
2005	February	0	1	54.8	1.8
2005	March	0	0	52.4	0.0
2005	April	0	0	51.1	0.0
2005	May	97	0	144.2	0.0
2005	June	11	0	151.2	0.0
2005	July	0	0	147.2	0.0
2005	August	27	2	169.6	1.2
2005	September	0	3	163.2	1.8
2005	October	236	1	385.9	0.3
2005	November	0	1	374.8	0.3
2005	December	0	0	364.0	0.0
2006	January	0	0	354.5	0.0
2006	February	0	0	345.2	0.0
2006	March	0	0	336.2	0.0
2006	April	0	1	327.4	0.3
Average annual exploitation for a one year period (Nov. 2004 - Apr. 2006)					**4.9**
Average annual exploitation corrected for 20% non-reporting					**6.1**
Average annual exploitation corrected for 70% non-reporting					**16.3**

Table 8. Recaptures of blue catfish from electrofishing during collection months. The number at large is corrected for tag loss and the number removed by anglers at the end of the previous month before collection occurred.

Year	Month	Number tagged	Number recaptured	Number at-large	Percent recaptured
2004	October	7		7.0	
2004	November	0		6.8	
2004	December	0		6.6	
2005	January	0		6.5	
2005	February	0		5.3	
2005	March	28	0	4.2	0
2005	April	0		31.4	
2005	May	69	0	30.5	0
2005	June	173	0	96.9	0
2005	July	0		262.9	
2005	August	357	2	250.2	0.8
2005	September	0		588.3	
2005	October	158	2	570.0	0.4
2005	November	0		707.0	
2005	December	0		686.6	
2006	January	0		667.6	
2006	February	0		650.2	
2006	March	12	0	632.2	0
2006	April	0		627.3	
2006	May	385	2	608.9	0.3
2006	June	268	4	967.0	0.4

Table 9. Life history parameters used to model the blue catfish population in Lake Wilson, Alabama using the yield-per-recruit model in FAST.

Parameter	Value
von Bertalanffy growth coefficients	L_{inf} = 1291 mm
	k = 0.086
	t_0 = -0.095
Maximum Age	25
Conditional natural mortality (Ages 1 to 25)	0.16
Conditional fishing mortality	0.0 to 0.46
Exploitation	0% to 43%
Log10weight:log10 length coefficients	intercept = -6.136
	slope = 3.407
Minimum length limits (total length)	305 mm
	356 mm
	406 mm
	457 mm

FIGURES

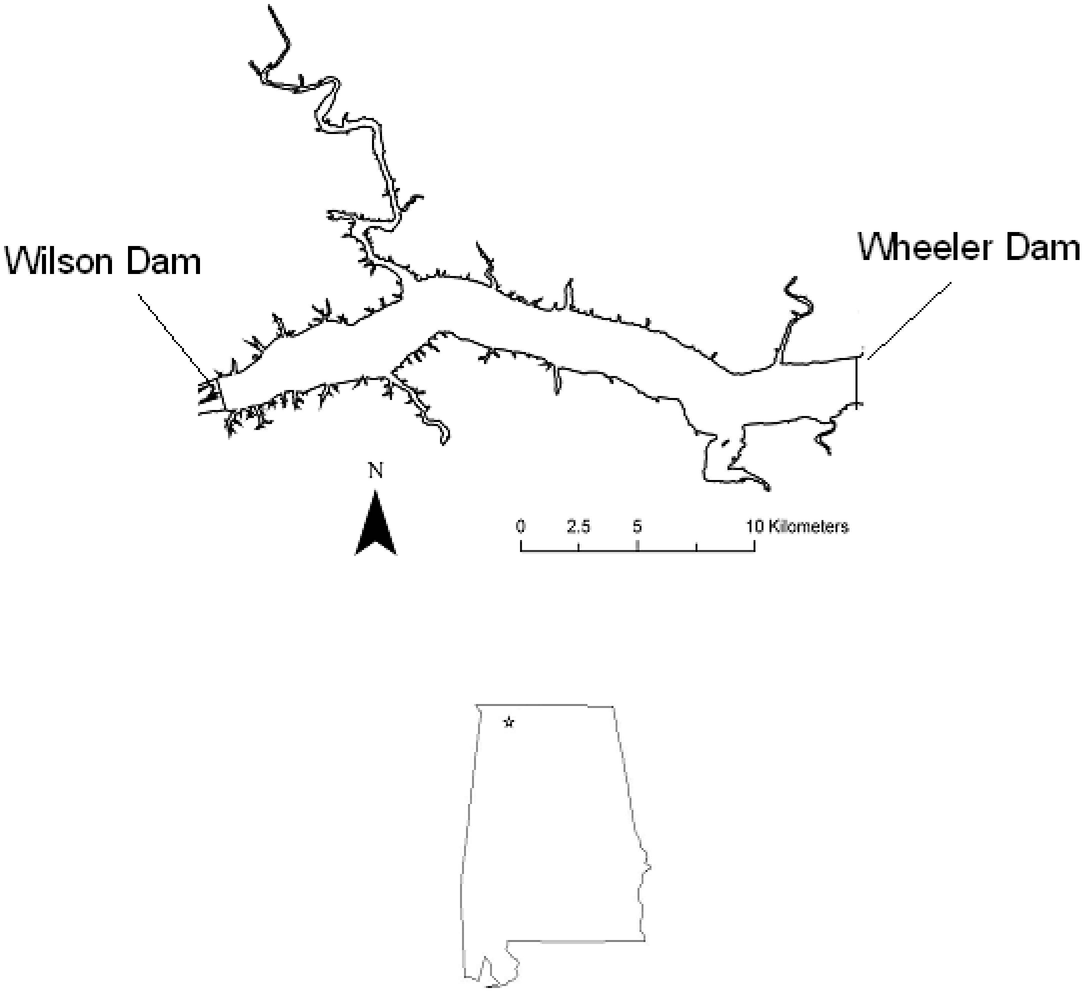

Figure 1. Map of Lake Wilson, and the location of the reservoir in the state of Alabama.

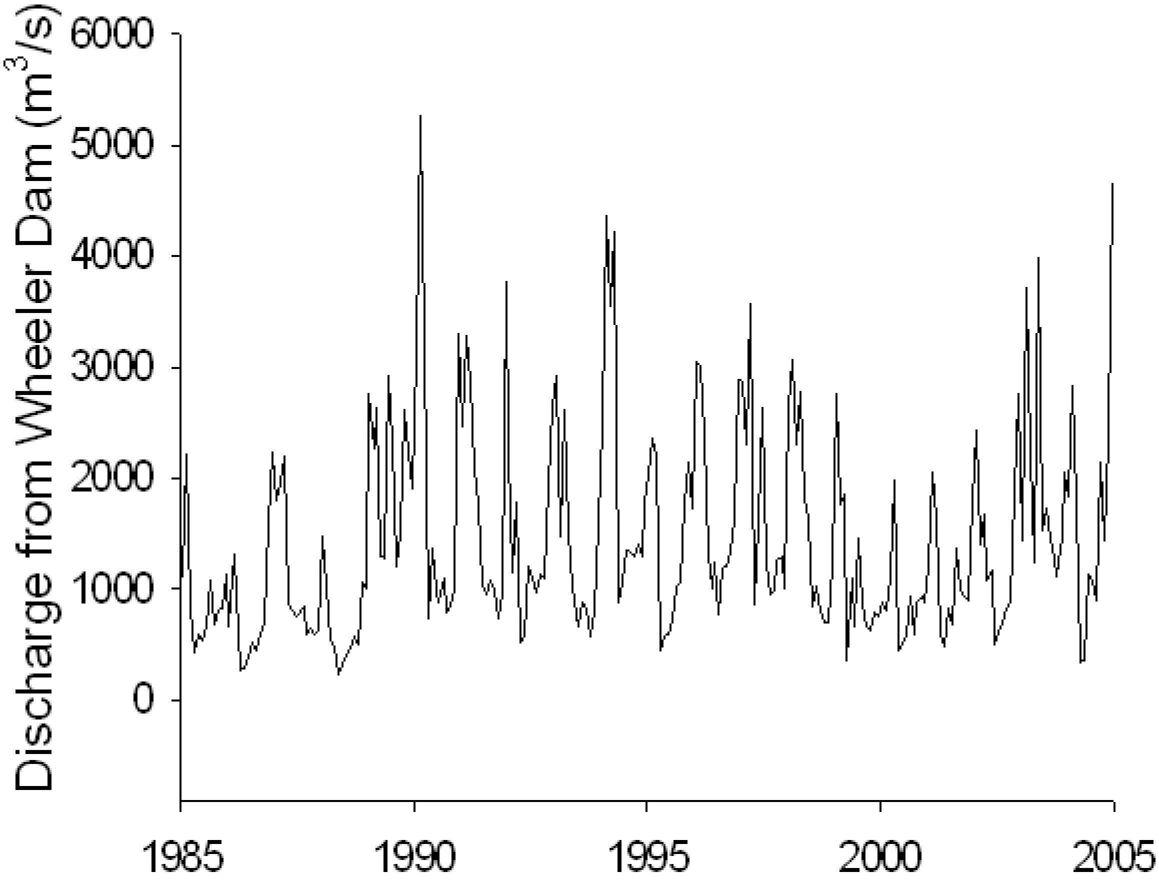

Figure 2. Average monthly discharge from Wheeler Dam from January 1985 to December 2004. The data were used to assess the influence of discharge or climatic condition on catfish growth and recruitment success.

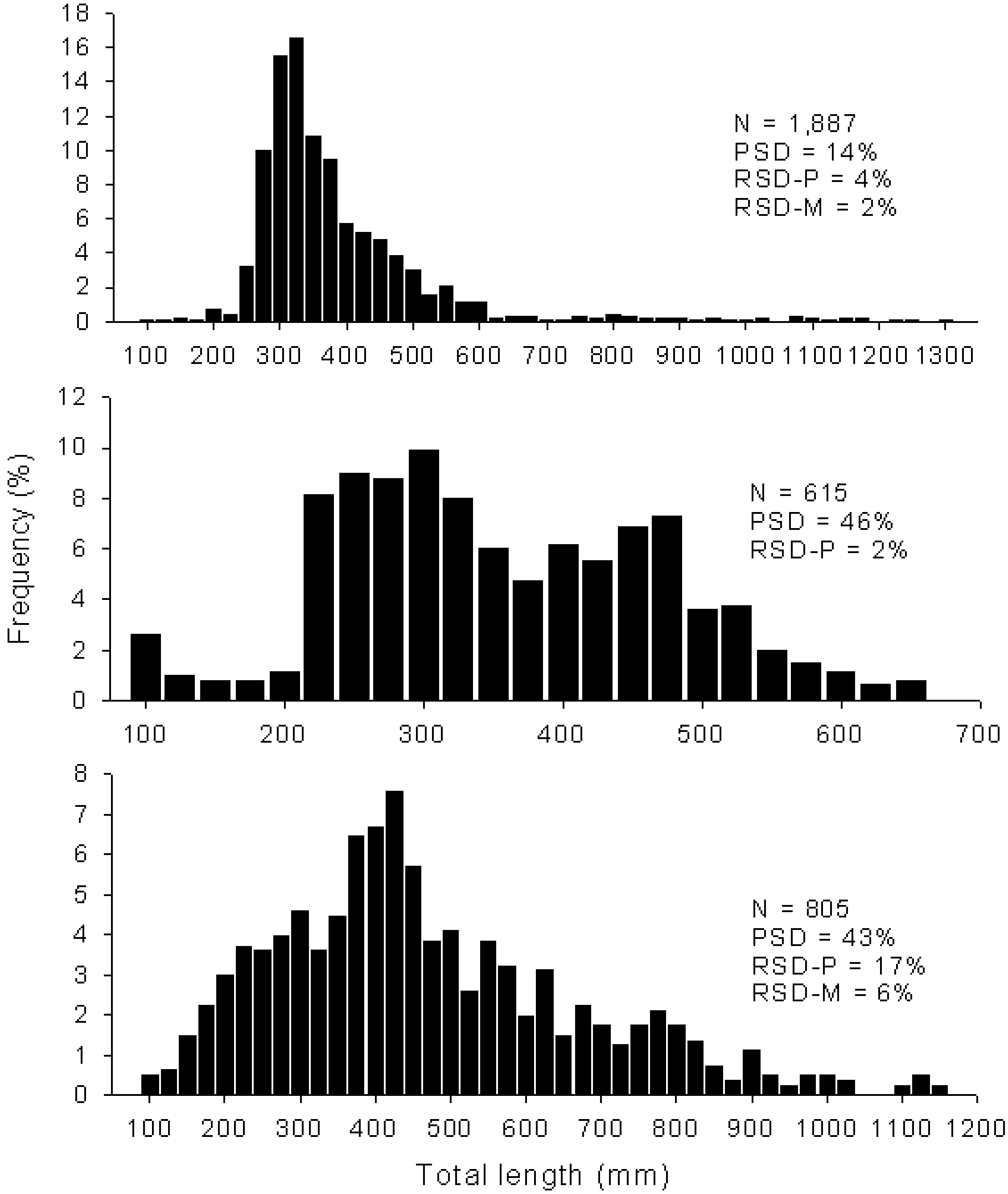

Figure 3. Length frequency histograms and stock density indices for blue catfish (top), channel catfish (middle) and flathead catfish (bottom).

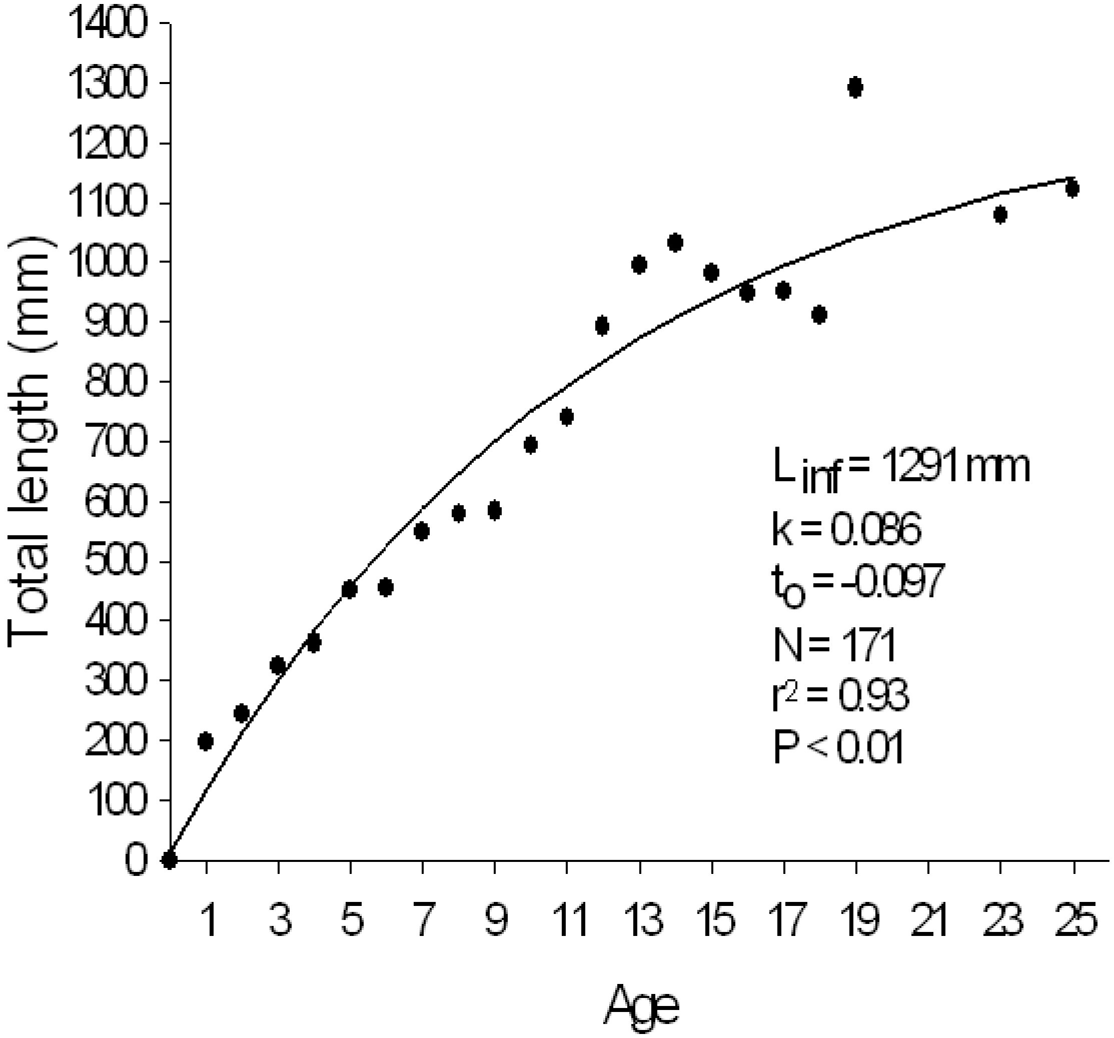

Figure 4. von Bertalanffy growth curve and coefficients for blue catfish. Data plotted are mean lengths-at-age.

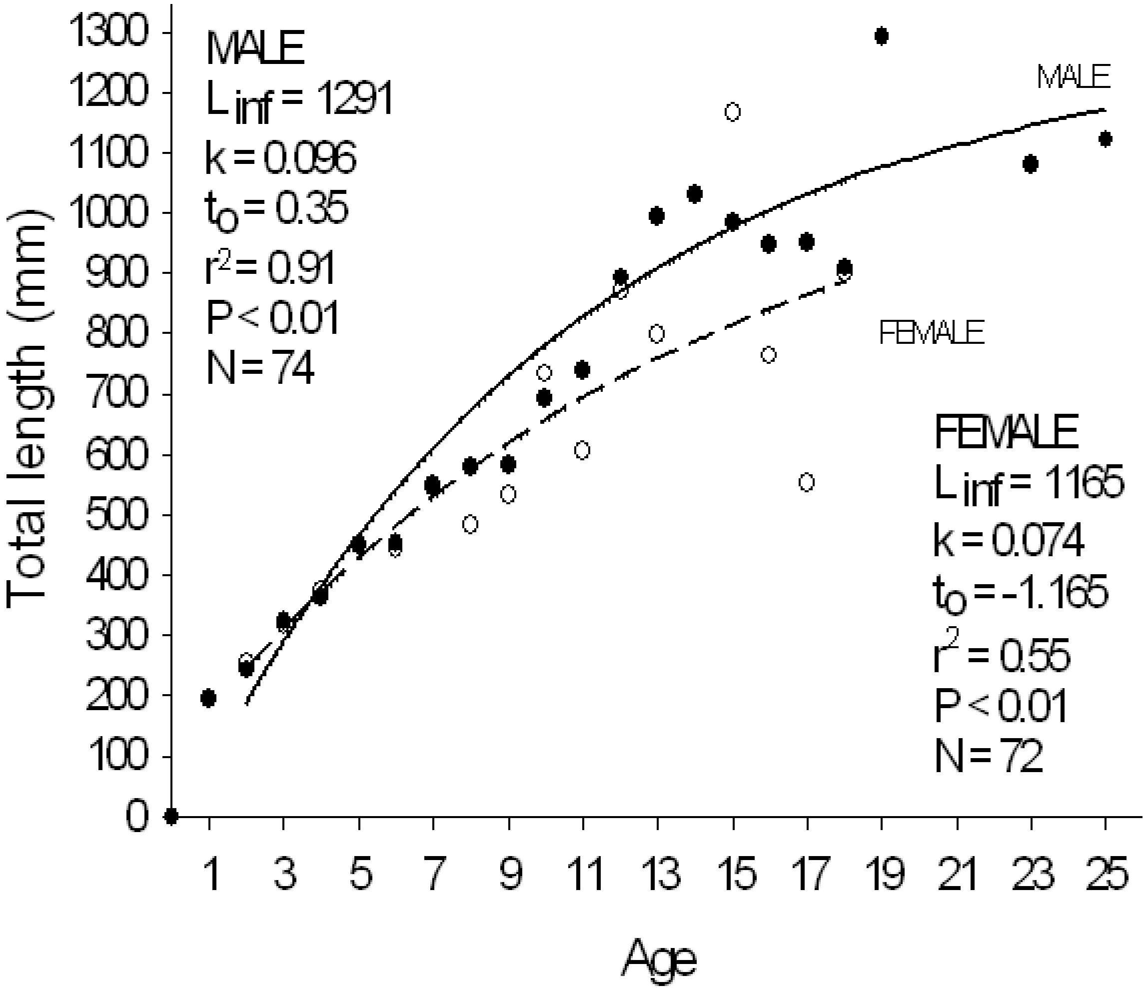

Figure 5. von Bertalanffy growth curves and coefficients for male and female blue catfish. The solid line represents the predicted curve from the von Bertalanffy equation for male blue catfish, and the black circles are mean length-at-age data for males. The dashed line is the predicted line from the von Bertalanffy equation for female blue catfish, and open circles are mean lengths-at-age data for female blue catfish.

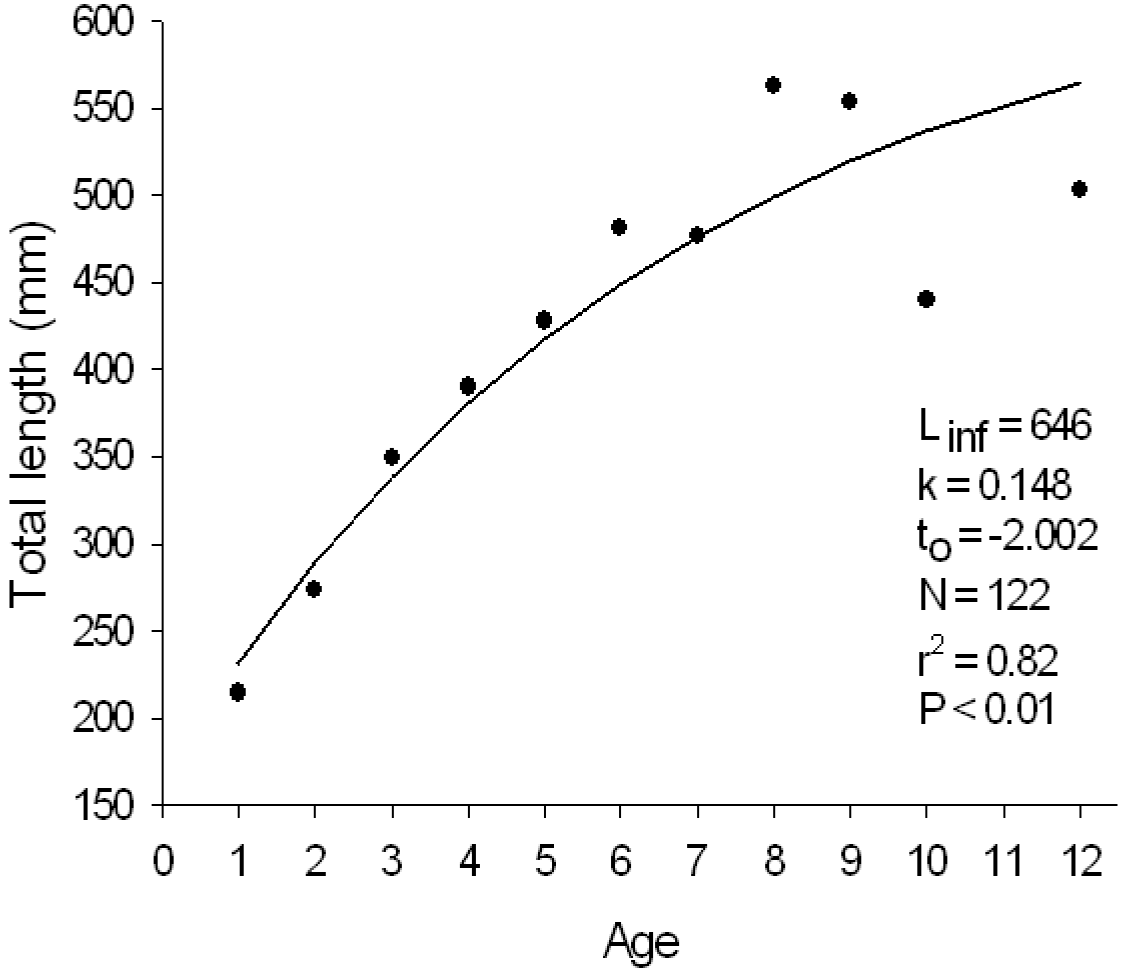

Figure 6. von Bertalanffy growth curve and coefficients for channel catfish. Data plotted are mean lengths-at-age.

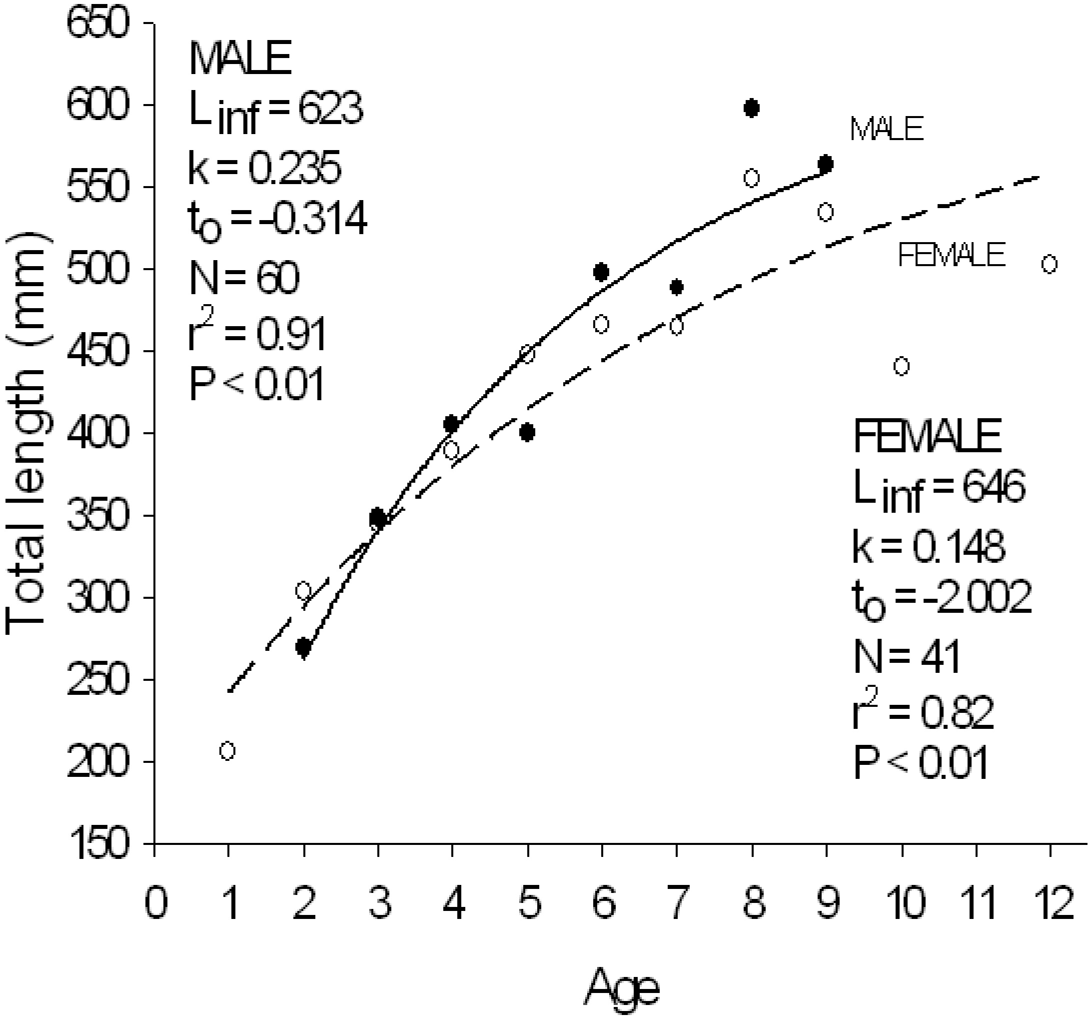

Figure 7. von Bertanffy growth curves and coefficients for male and female channel catfish. The solid line represents the predicted curve from the von Bertalanffy equation for male channel catfish, and the black dots are mean length-at-age data for males. The dashed line is the predicted line from the von Bertalanffy equation for female channel catfish, and the open circles are mean lengths-at-age data for female channel catfish.

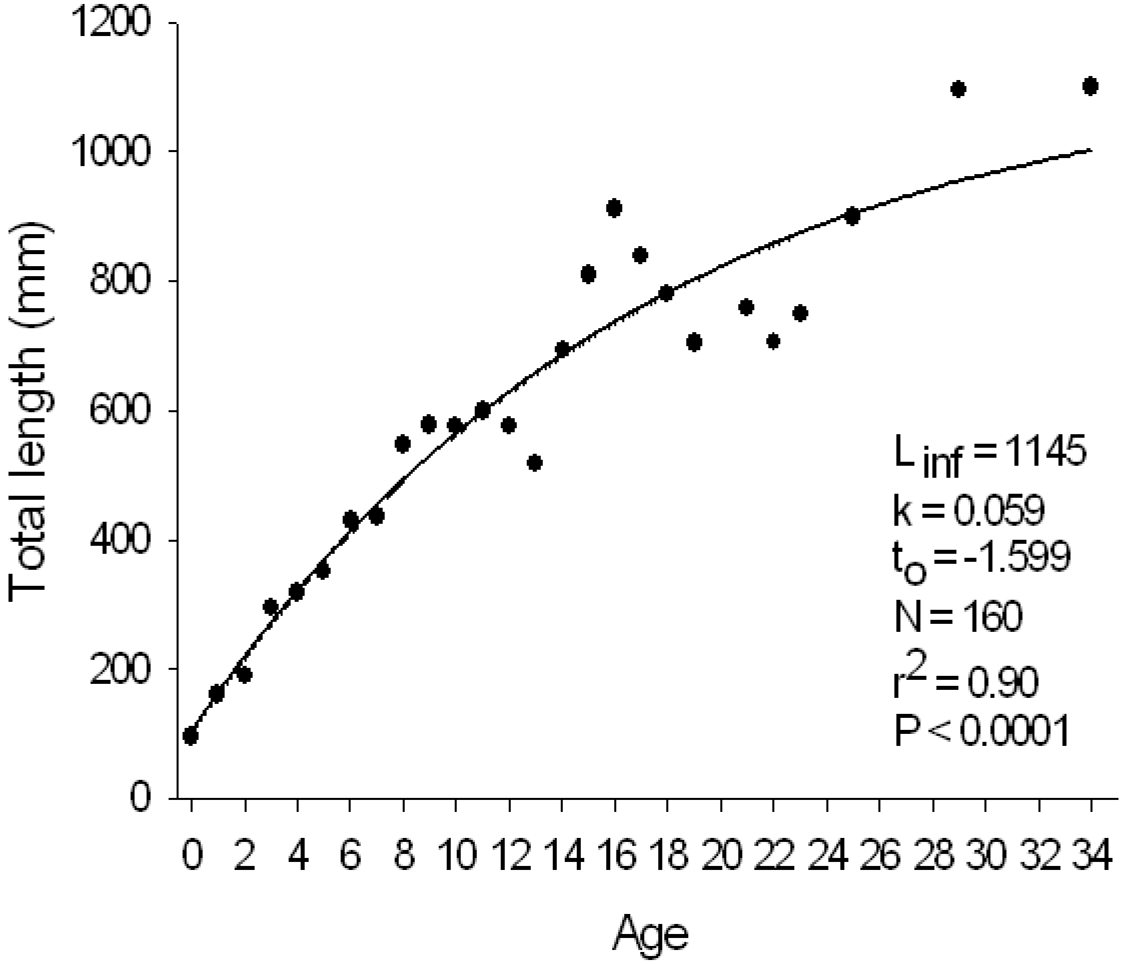

Figure 8. von Bertalanffy growth curve and coefficients for flathead catfish. Data plotted are mean lengths-at-age.

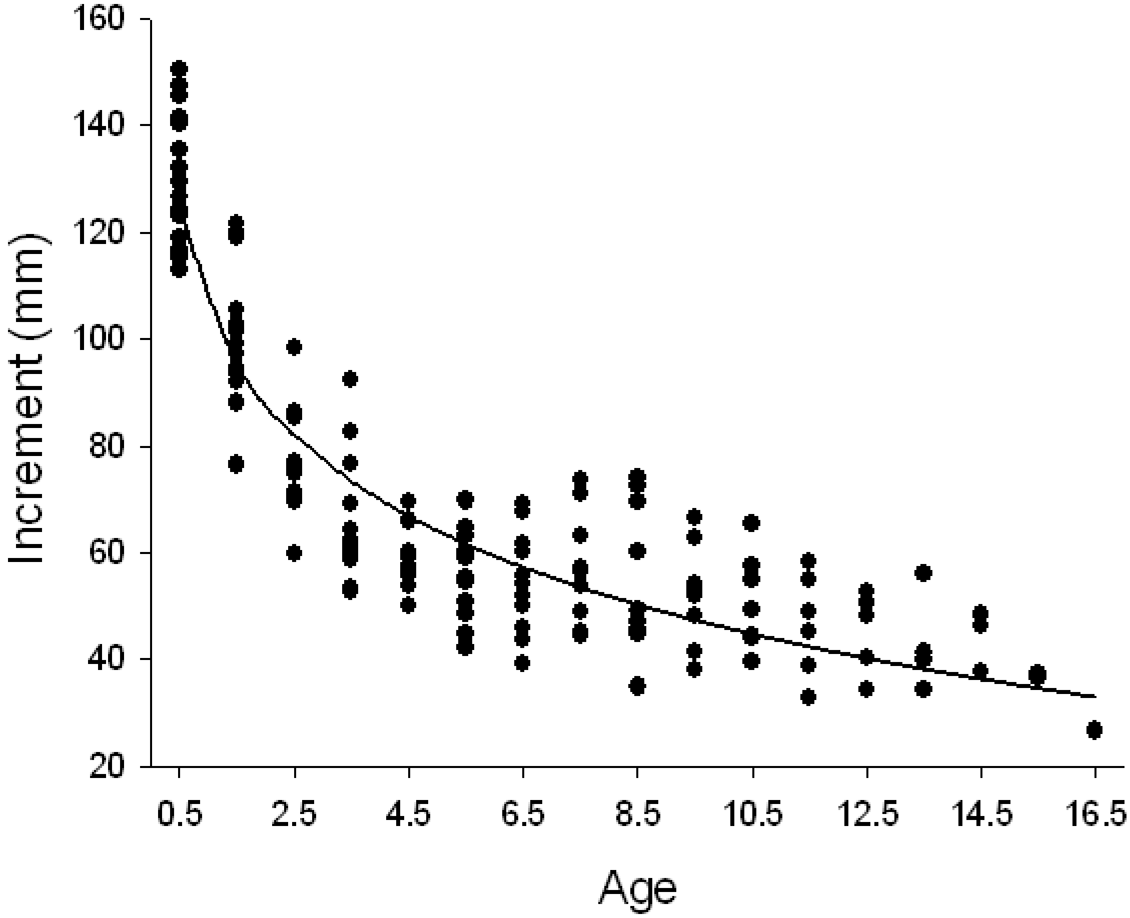

Figure 9. Mean annual growth increments of blue catfish plotted against age. Ages represent mid points between ages from 0 to 17 (i.e. 0.5 represents age 0 to age 1 etc.). The line is the predicted regression line between growth increments and $\log_{10}$(Age).

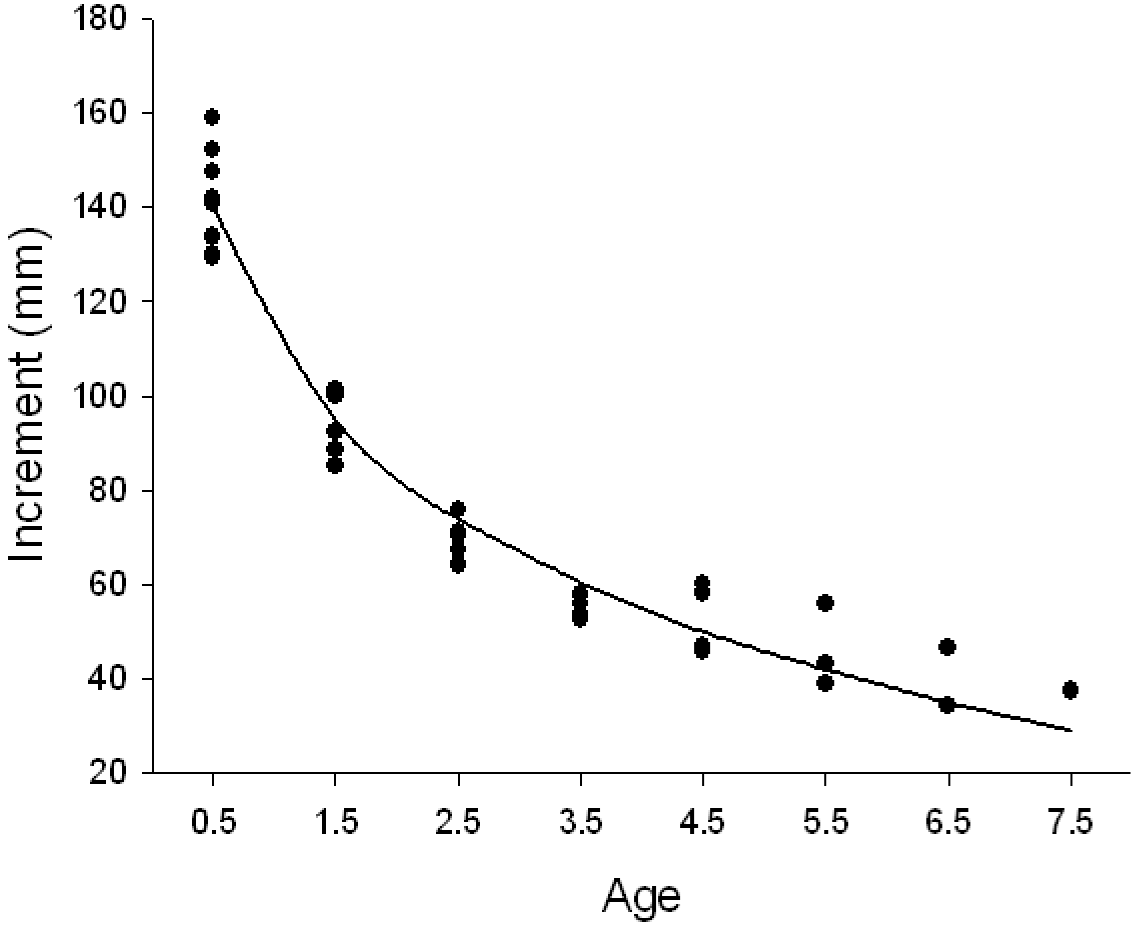

Figure 10. Mean annual growth increments of channel catfish plotted against age. Ages represent mid points between ages from 0 to 8 (i.e. 0.5 represents age 0 to 1 etc.). The line is the predicted regression line between growth increments and $\log_{10}$(Age).

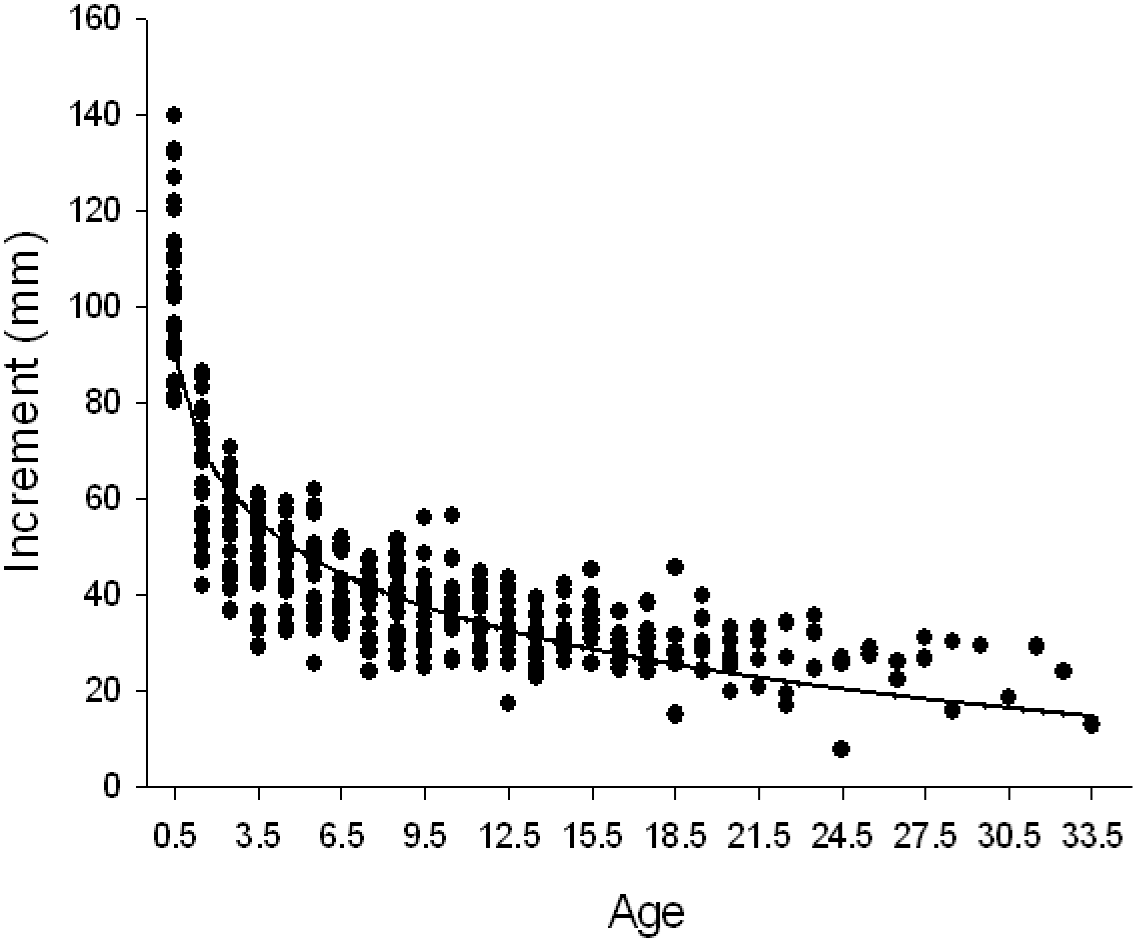

Figure 11. Mean annual growth increments for flathead catfish plotted against age. Ages represent mid points between ages from 0 to 34 (i.e. 0.5 represents age 0 to 1 fish for age 1 fish etc.). The line is the predicted regression line between growth increments and $\log_{10}$(Age).

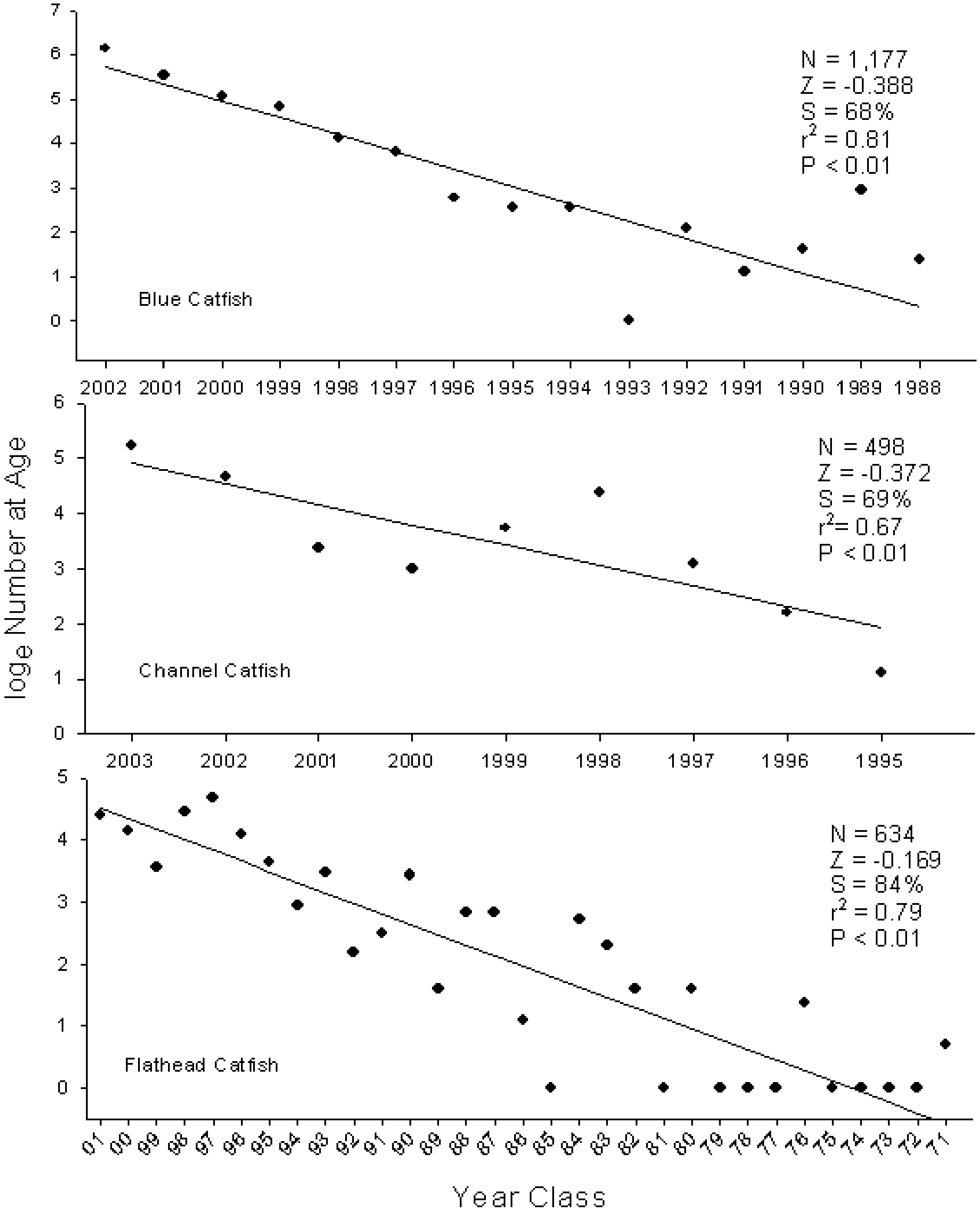

Figure 12. Weighted catch-curve regressions and associated statistics for blue catfish (top), channel catfish (middle) and flathead catfish (bottom).

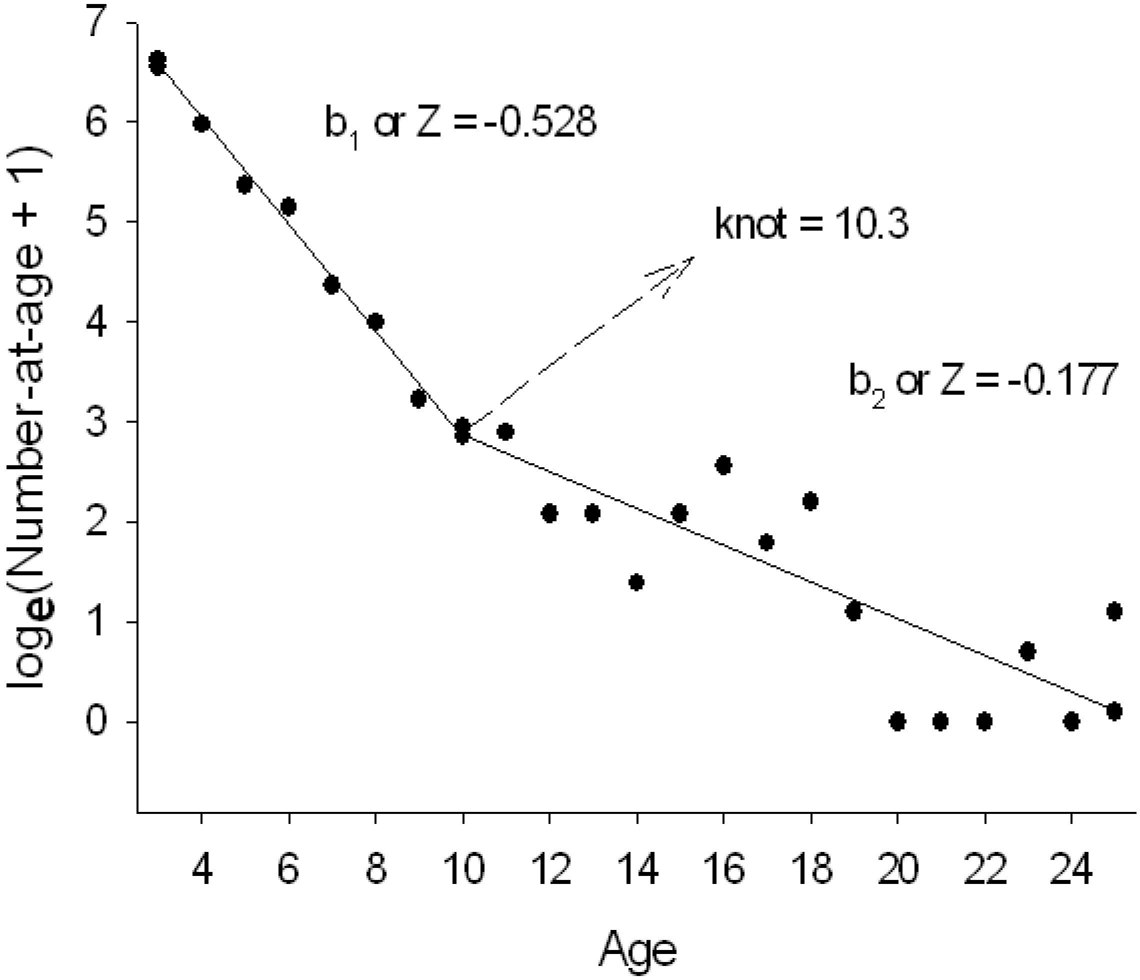

Figure 13. Differential mortality among small (< 10.3 years old) blue catfish and large (> 10.3 years old) blue catfish computed from piecewise non-linear regression which identified the knot (10.3 years old) where mortality changed.

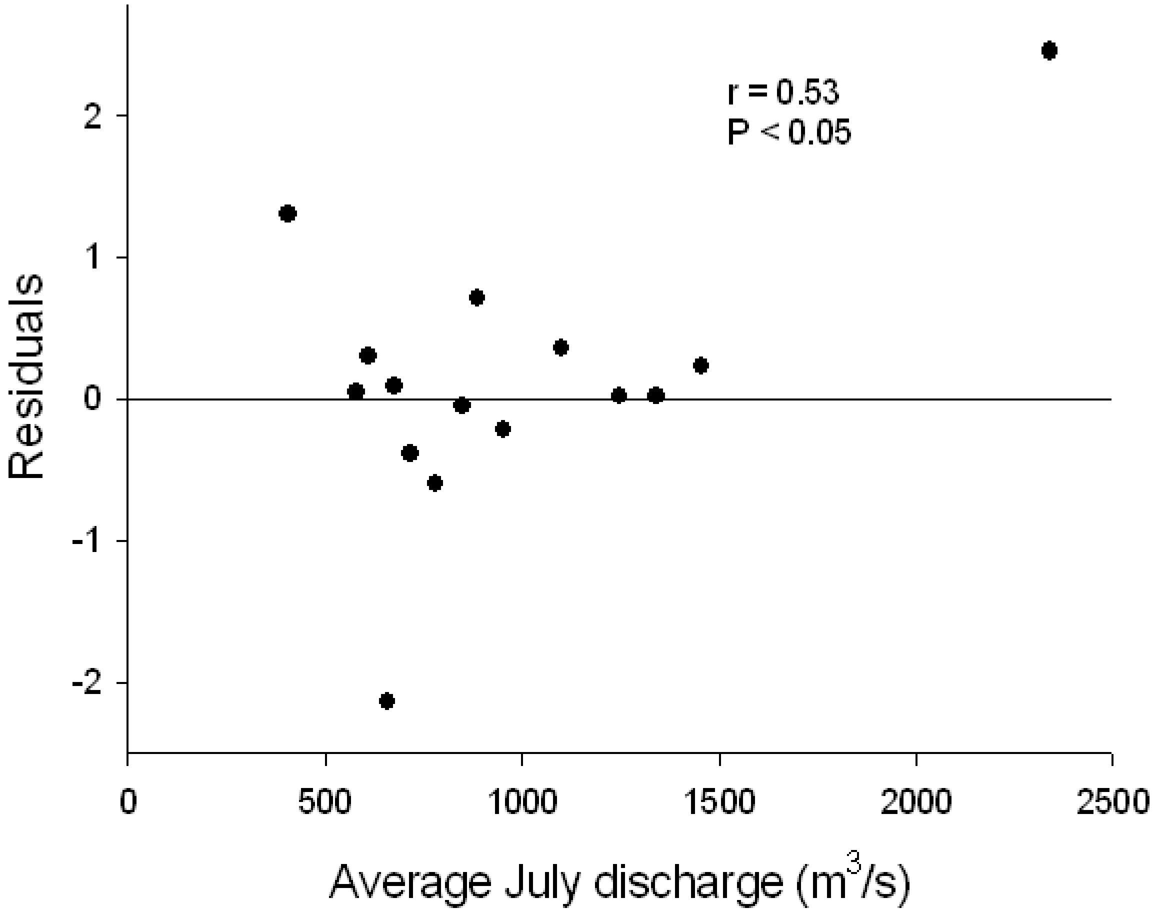

Figure 14. Weighted catch-curve residuals for blue catfish plotted against average July discharge (m^3/s).

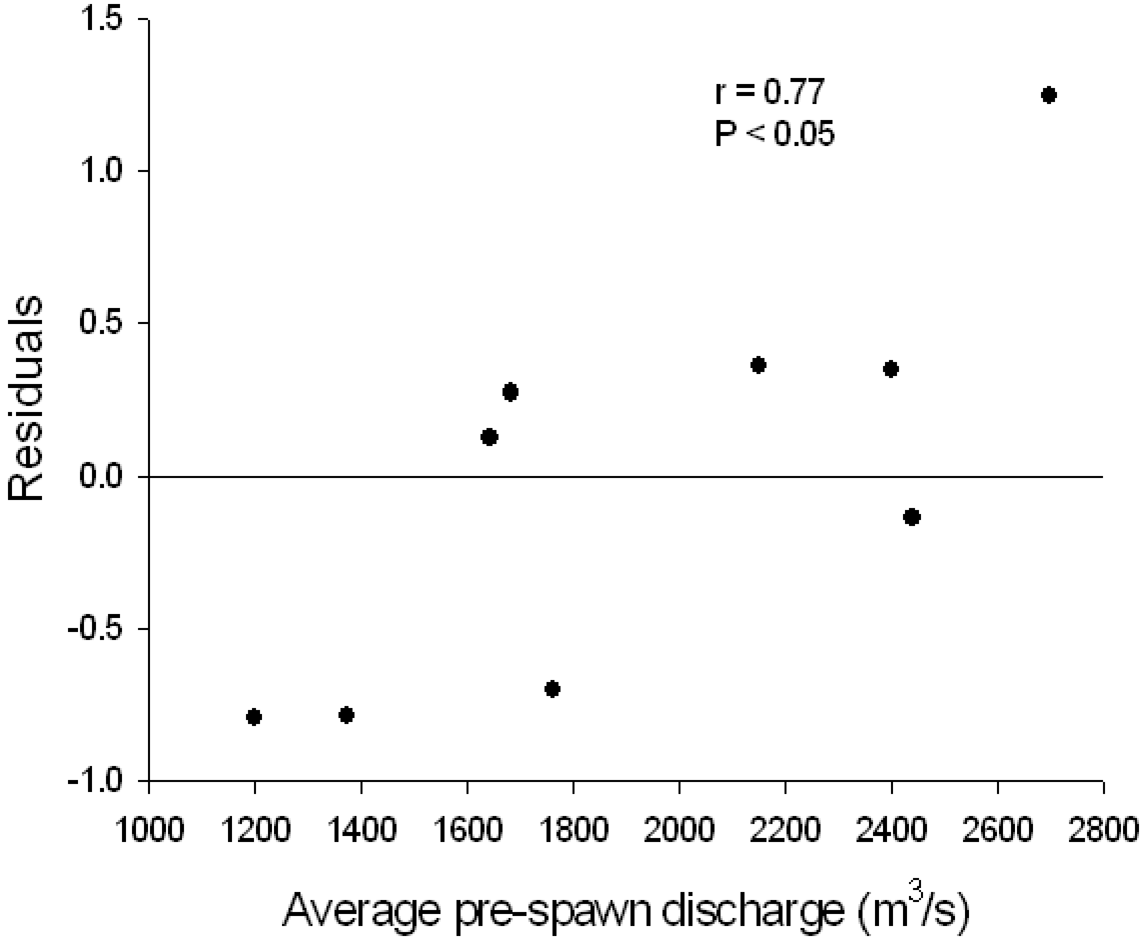

Figure 15. Weighted catch-curve residuals for channel catfish plotted against average pre-spawn (January-April) dischage (m^3/s).

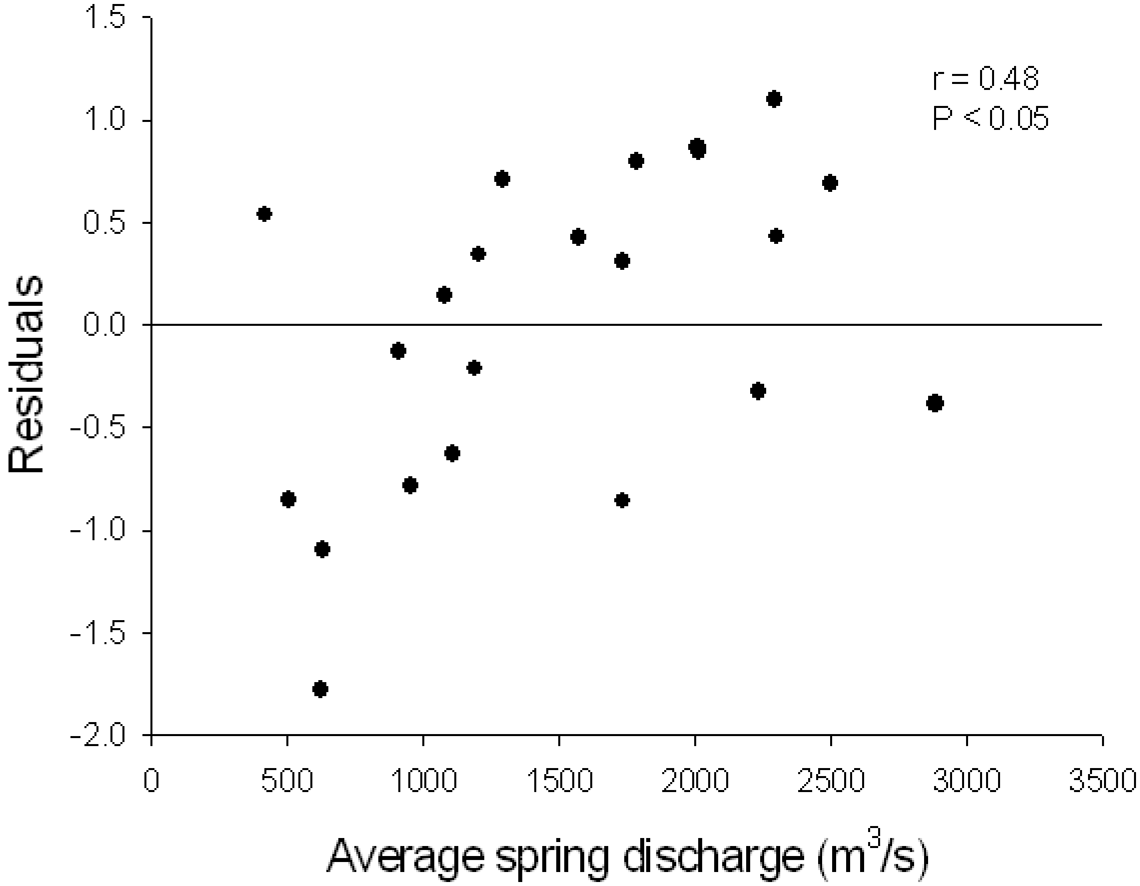

Figure 16. Weighted catch-curve residuals for flathead catfish plotted against average spring (March-May) discharge (m^3/s).

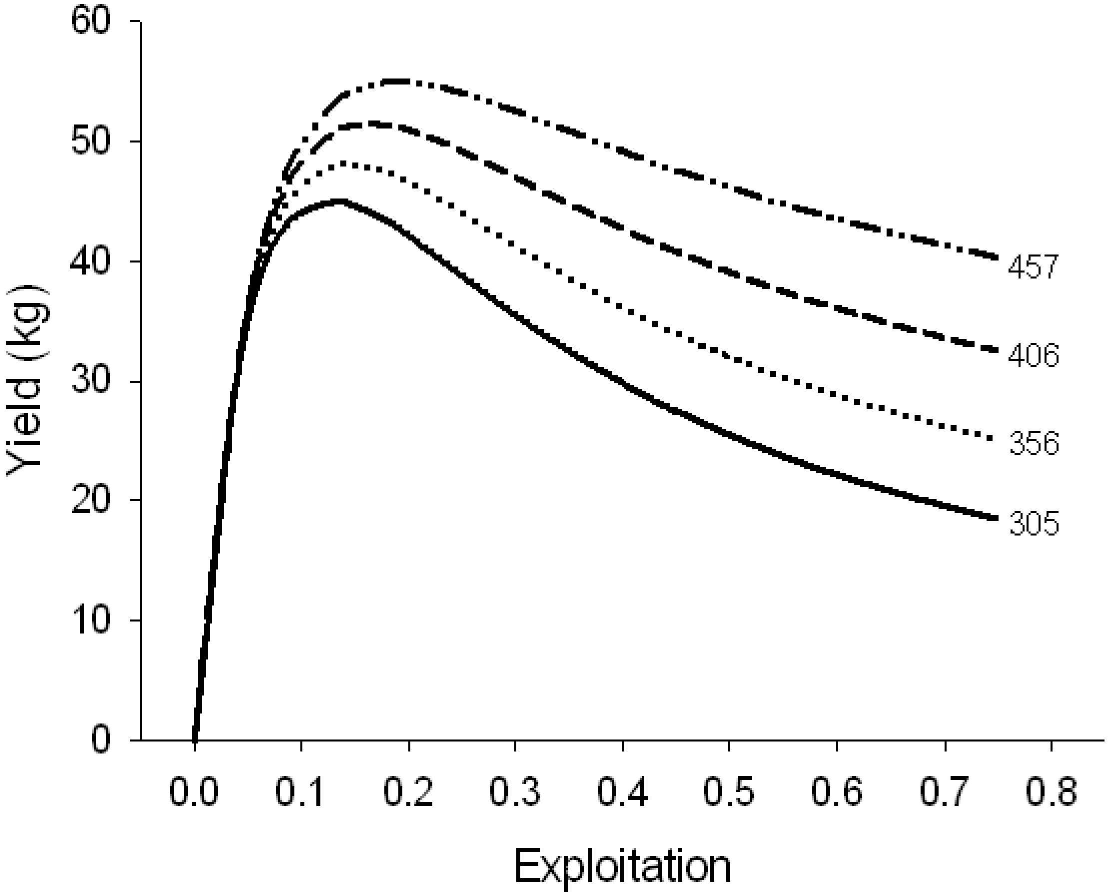

Figure 17. The predicted yield for blue catfish over a range of exploitation and minimum length limits in Lake Wilson, Alabama.

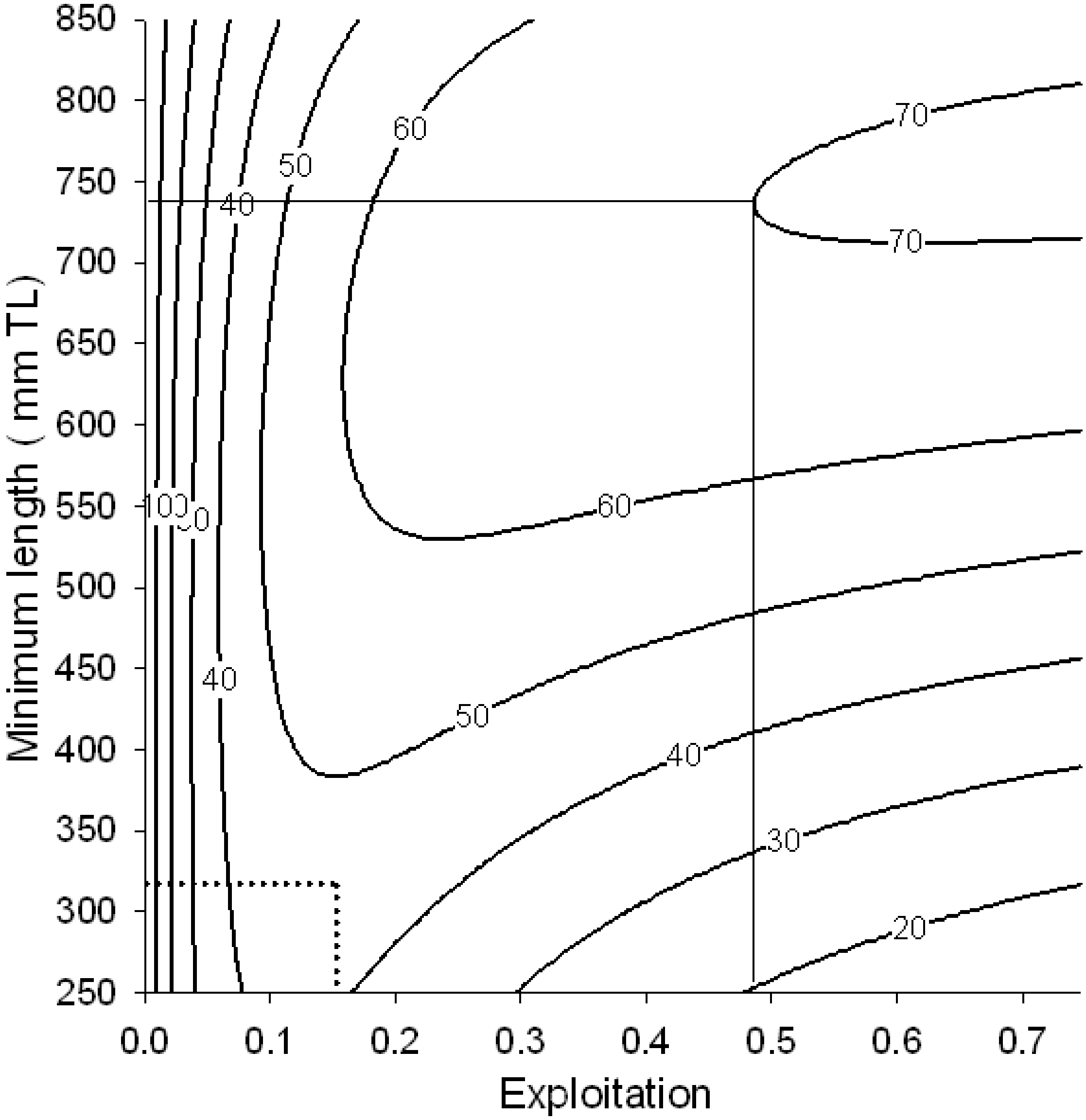

Figure 18. Yield contour plot for blue catfish, Lake Wilson. The solid lines represent the maximum yield, and the dotted lines are the approximate location of the current fishery.

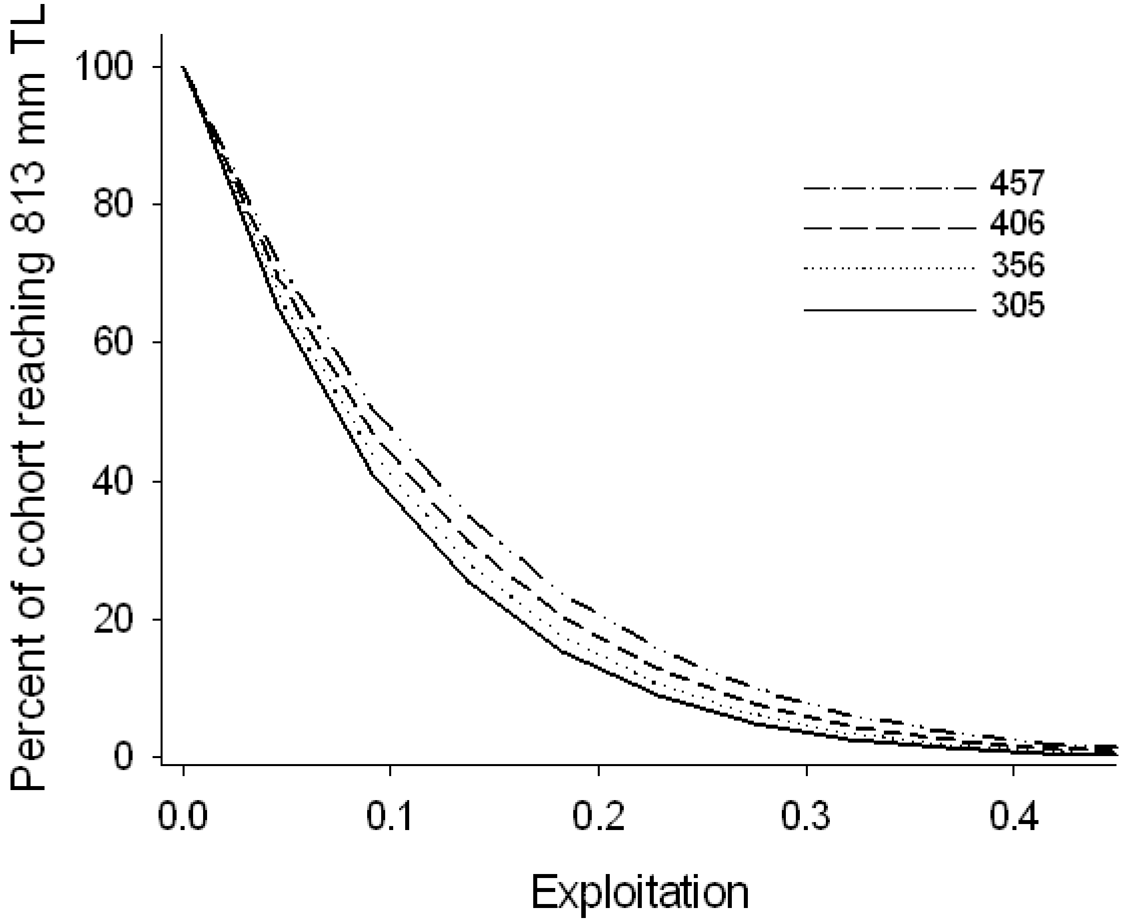

Figure 19. The predicted percent of a cohort of blue catfish reaching angler-memorable size over a range of exploitation. The simulation was ran with an initial population of 100 recruits.

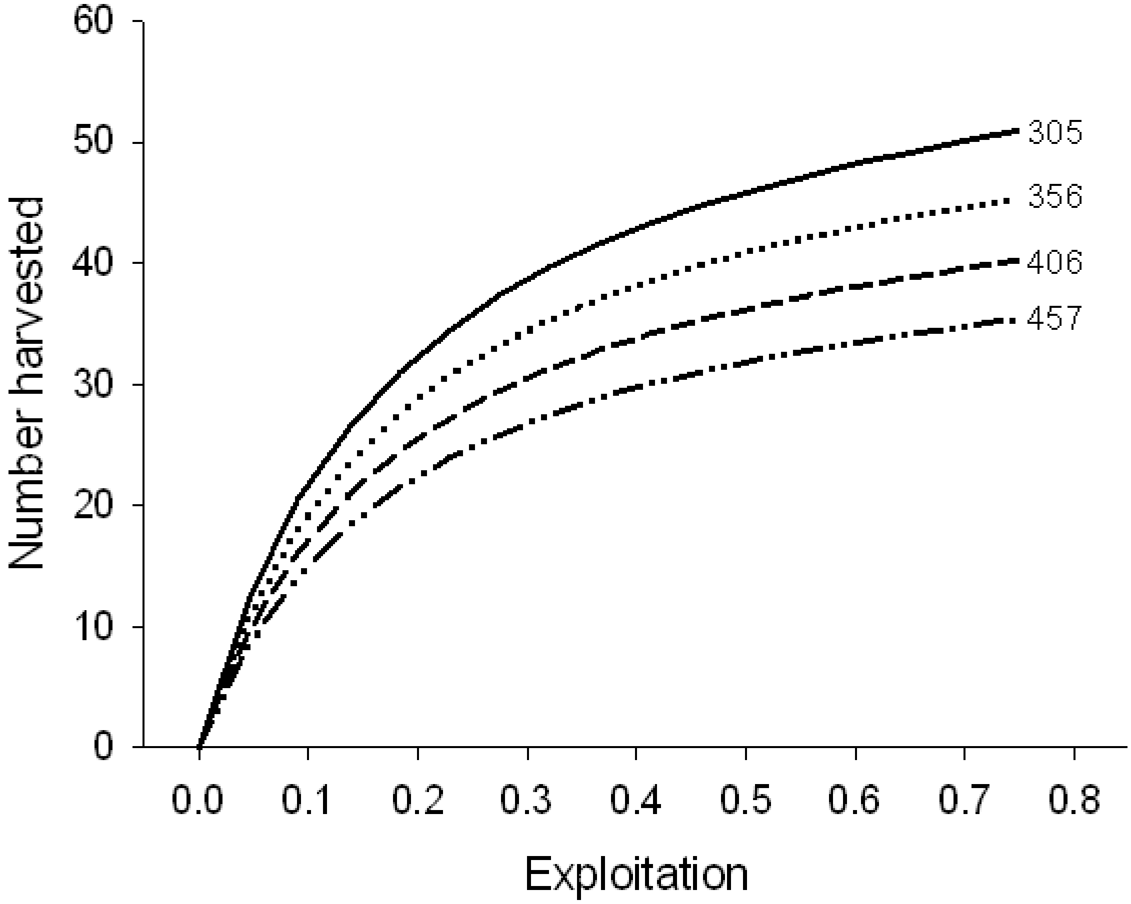

Figure 20. The predicted number of blue catfish available to anglers over a range of exploitation and minimum length limits.

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