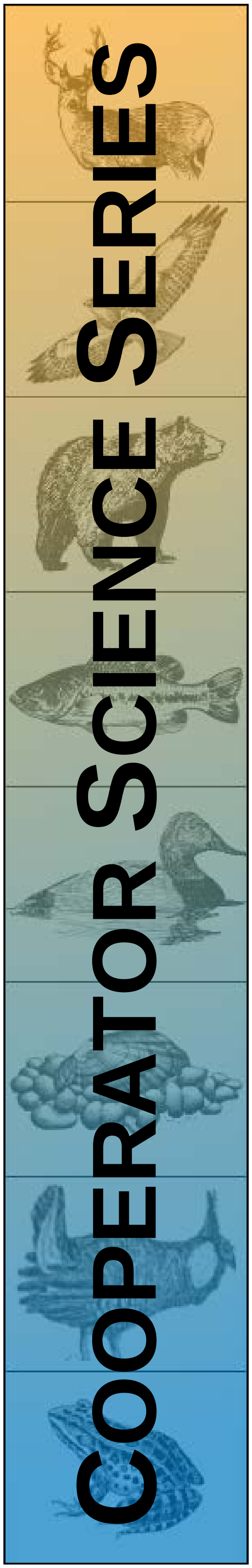

Experimental stocking of sport fish in the regulated Tallapoosa River to determine critical periods for recruitment

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ABSTRACT - The stocking of fish in riverine systems to re-establish stocks for conservation and management appears limited to a few species and often occurs in reaches impacted by impoundments. Stocking of sport fish species such as centrarchids and ictalurids is often restricted to lentic environments, although stocking in lotic environments is feasible with variable success. R. L. Harris Dam on the Tallapoosa River, Alabama is the newest and uppermost dam facility on the river (operating since 1983); flows from the dam have been managed adaptively for multiple stakeholder objectives since 2005. One of the stakeholders' primary objectives is to provide quality sport fisheries in the Tallapoosa River in the managed area below the dam. Historically, ictalurids and cyprinids dominated the river above Lake Martin. However, investigations after Harris Dam closed have detected a shift in community structure to domination by centrarchids. Flow management (termed the Green Plan) has been occurring since March 2005; however, sport fish populations as measured by recruitment of age-1 sport fishes below the dam has not responded adequately to flow management. The objectives of this research were to: (1) determine if stocking Channel Catfish *Ictalurus punctatus* and Redbreast Sunfish *Lepomis auritus* influences year-class strength; (2) estimate vital rates (i.e. growth, mortality, and recruitment) for Channel Catfish populations for use in an age-based population model; and (3) identify age-specific survivorship and fecundity rates contributing to Channel Catfish population stability. No marked Redbreast Sunfish were recaptured due to poor marking efficacy and therefore no further analysis was conducted with this species. Stocked Channel Catfish, similarly, were not recaptured, leaving reasons for non-recapture unknown. Matrix models exploring vital rates illustrated survival to age-1 for Channel Catfish to be less than 0.03% and that survival through ages 2 – 4 had equal contribution to overall population growth, indicating recruitment limitation may impact population size and stability. Results from this study indicate stock enhancement of sport fish populations below Harris Dam may not be an effective management technique at this time.

INTRODUCTION

Specific information regarding stocking of fish in riverine systems appears limited to a few species, namely, salmonids (Gephard and McMenemy 2004), Striped Bass *Morone saxatilis* (Long et al. 2013), Paddlefish *Polydon spatula* (Grady and Elkington 2009), sturgeons (Collins and Smith 1996), and American Shad *Alosa sapidissima* (and other river herring; Gephard and McMenemy 2004). For these species, stocking programs have been designed to re-establish stocks for conservation and management of fisheries. In most cases, tens of thousands or even millions of small fish (or larvae) are stocked and these are usually marked with either tetracycline or coded-wire tags. Stocking programs for centrarchids and ictalurids appear to be limited to reservoirs and small impoundments (e.g.; Copeland and Noble 1994; Isermann et al. 2002; Santucci et al. 1994); however, South Carolina Department of Natural Resources (SCDNR) has been stocking Redbreast Sunfish *Lepomis auritus* in multiple rivers (Bonvechio et al. 2016).

Success of stock enhancement of black basses, catfishes and sunfishes is variable. Copeland and Noble (1994) stocked small numbers of age-0 Largemouth Bass *Micropterus salmoides* in a North Carolina reservoir and reported return rates of 4.3-7.6%; however, Hoffman and Bettoli (2005) stocked over 125,000 fingerling Largemouth Bass into Chickamauga Reservoir, Tennessee, and reported a return rate of less than 1%. Stocking Redbreast Sunfish into various South Carolina rivers resulted in an average rate of return at age 1 of 14% (C. Thomason, SCDNR personal communication). Patton and Hubert (1996) reported recruitment to age-1 of stocked Channel Catfish *Ictalurus punctatus* in a regulated Wyoming river, but provided little information regarding details of the number marked or recaptured. They attributed the stocking of Channel Catfish a success because natural recruitment was not evident in their study system due to depressed, regulated water temperatures. No other recapture data for these riverine species were uncovered in the primary literature.

The Tallapoosa River, Alabama, is regulated by four dams owned by the Alabama Power Company. R. L. Harris Dam is the newest and uppermost facility on the river (operating since 1983) and flows from the dam have been managed adaptively for multiple stakeholder objectives since 2005 (Irwin and Kennedy 2009). One of the stakeholders' primary objectives is to provide quality sport fisheries in the Tallapoosa River in the managed area below the dam. Flow management (termed the Green Plan) has been occurring since March 2005 (Irwin 2014); however, sport fish populations as measured by recruitment to age-1 sport fishes (centrarchids and ictalurids), relative to recruitment at unregulated sites, have not responded adequately to specific flows at the dam. Two main types of flow manipulation have occurred; 1) provision of higher volumes in the mainstem (during non-generation periods) by pulsing flows through the dam and 2) provision of spawning windows of opportunity below the dam in the spring and summer months. Spawning windows (minimum of 7 days without 2-unit generation flows or < 8,000 cfs) have been provided in most years since adaptive management began, but based on the depressed recruitment in the mainstem in non-drought years (drought in 2007, 2008), these management periods may not be adequate for early growth and survival, and ultimately recruitment to the fisheries. Another factor regulating both growth and recruitment of fishes is the temperature regime, which is influenced by Harris Dam management and has been shown to influence early life history processes of fishes (Andress 2002; Long and Martin 2008; Rogers and Allen 2009; Porta and Long 2015) as well as growth of fish (Patton and Hubert 1996). In an effort to further identify potential recruitment bottlenecks and favorable conditions for growth of resident sport fish, we conducted experimental stockings of tagged juvenile sport fish below Harris Dam.

Based on the hypothesis that operations at R. L. Harris Dam (i.e., flow and temperature regimes) are affecting recruitment of sport fishes, the objectives of this research were to: 1) determine if stocking juvenile Channel Catfish and Redbreast Sunfish influences year-class strength; 2) estimate vital rates (i.e. growth, mortality, and recruitment) for Channel Catfish populations for use in an age-based population model; and 3) identify age-specific survivorship and fecundity rates contributing to Channel Catfish population stability.

Methods

This study was performed under the auspices of Auburn University IACUC protocol # 2015-2610. Juvenile Redbreast Sunfish and Channel Catfish were stocked in the regulated reaches of the Tallapoosa River below R. L. Harris Dam in 2015 and 2016 (Figure 1). Redbreast Sunfish were produced at ADCNR Eastaboga Fish Hatchery and transported to Auburn University Shell Center for marking. Redbreast Sunfish were mass marked by immersion in 650 mg/L oxytetracycline (OTC) bath, buffered to a pH of approximately 7.5 with sodium phosphate, and held for 7 h to mark calcified structures. A subsample of Redbreast Sunfish (n = 120) was held in aquaria for 30 days post-OTC marking in both years to determine marking efficacy. Channel Catfish were produced at Marion Fish Hatchery allowing for a genetically identifiable strain via single nucleotide polymorphisms (SNPs) that could be differentiated from native Tallapoosa Channel Catfish with DNA analysis (E. Peatman, unpublished data, oral communnication.).

Redbreast Sunfish (45.51 ± 0.51 mm TL; mean ± SE) marked with OTC were stocked in the Wadley (2,000) reach in 2015 and the Wadley (19,500) and Horseshoe Bend (500) reaches in 2016 totaling 22,000 stocked fish (Table 1). Channel Catfish (138.75 ± 0.93 mm TL; mean ± SE) were stocked in 3 locations of the regulated Tallapoosa River in February of 2015 and 2016. In 2015, 67,592 Channel Catfish were stocked in the Malone (23,064), Wadley (21,384) and Horseshoe Bend (23,144) reaches on the Tallapoosa River. In 2016, Channel Catfish were stocked in the same locations at Malone (7,410), Wadley (9,112) and Horseshoe Bend (23,210) on the Tallapoosa River with a total of 39,732 catfish stocked (Table 2).

Sampling to recapture marked fish began in the summer after fish were stocked in 2015 and 2016 once river water temperature reached 18 ° C. Boat-electrofishing and prepositioned area electrofishers (PAEs) were used to recapture fish with both low and high frequency pulsed-DC (15-60 pps) and AC (120 pps) currents, respectively, for the two gears. These gears were used in complement to sample multiple habitat types within the regulated section of the Tallapoosa below Harris Dam and PAEs were also sampled upstream of Harris Dam in the Heflin reach (Figure 1). In 2015, three boat-electrofishing sampling events occurred and 250 PAE samples were collected. A total of four boat-electrofishing samples and 220 PAE samples were collected in 2016. All fish captured were euthanized in a MS-222 bath (400 mg/L), put on ice and returned to Auburn University where fish were measured to the nearest 0.1 mm TL and weighed to the nearest 0.01 g.

Sagittal otoliths were extracted from fish using a dissecting microscope with forceps and stored in centrifuge tubes prior to preparation. Catfish otoliths were prepared by the methods described by Buckmeier et al. (2002). Otoliths were embedded in crystal bond resin on glass slides and were ground to the core with fine sandpaper (400 grit) until a thin transverse section was obtained. Two readers aged fish independently and any discrepancies of ages between readers were reconciled with a concert read (Buckmeier et al. 2002). Additional length and age data for Channel Catfish from 1996-1997 (n = 81) and 2009-2011 (n = 175) were obtained and combined with our data for further analysis and model development (Nash 1999; Sammons et al. 2013).

<u>*Statistical analysis*</u>

Growth - von Bertalanffy growth models ($L_t = L_\infty \{1 - e^{-k[t-t0]}\}$), where L_t is TL at time t, L_∞ is theoretical maximum TL, e is the base of natural logarithms, and k is the growth coefficient) were computed for populations of Channel Catfish before and after flow management implementation (Green Plan). A seven parameter model was tested for the von Bertalanffy function with varying parameters (L_∞; k; t_0; L_∞ and k; L_∞ and t_0; L_∞, k and t_0; k and t_0). These models were then compared to a null model (null; constructed with all catfish) to determine differences in growth parameters pre- and post-Green Plan. A corrected Akaike's Information Criterion (AIC_c) was used to determine the best fitting model.

Fertility - The equation derived from the von Bertalanffy growth model was used to predict mean length-at-age for Channel Catfish. A linear least squares regression analysis was then applied to log-transformed predicted lengths from growth models to $\log_e$-transformed fertility estimates acquired from Jearld and Brown (1971). The resulting equations allowed for estimation of fertility at age:

$$\log_e (TL) = b_1 * \log_e (\# \text{ of eggs}) + b_0 \quad (1)$$

$$f = b_0 + (b_1 * \log_e [\text{length-at-age}]) \quad (2)$$

where f is the estimated fertility, b_0 and b_1 are the intercept and slope, respectively, of the linear regression of $\log_e$ of total length verses $\log_e$ number of eggs. Fertility (f) was then back transformed (e^f) to obtain fertility at age estimates.

Mortality - Using catch-at-age data from catfish captured in 2010 (n = 101), a weighted catch curve was constructed to estimate instantaneous mortality (Z), annual mortality ($A = 1 - e^{-z}$) and survival ($S = e^{-z}$). Fish less than the maximum catch-at-age were assumed not fully vulnerable to the sampling gear (fish ≤ age-3; Smith et al. 2012). All population parameters were calculated using the FSA package in R (R Core Team 2013; Ogle 2017)

Population models - Estimates of annual survival and fertility-at-age were used to develop an age classified matrix model to determine parameters (annual survival, age at maturity, fecundity) within the Channel Catfish population that strongly affect the population growth rate, λ. Age-classified matrix models were structured following a basic design:

$$\begin{pmatrix} f_0/2 & f_1/2 & f_2/2 & f_3/2 & . \; . \; . & f_{10}/2 & f_{11}/2 \\ S_0 & 0 & 0 & 0 & . \; . \; . & 0 & 0 \\ 0 & S_1 & 0 & 0 & . \; . \; . & 0 & 0 \\ 0 & 0 & S_2 & 0 & . \; . \; . & 0 & 0 \\ 0 & 0 & 0 & S_3 & . \; . \; . & 0 & 0 \\ 0 & 0 & 0 & 0 & . \; . \; . & S_{(t-1)} & 0 \end{pmatrix} \quad (3)$$

where S_i is the probability of individuals in age class *i* surviving one year, f_i is the fertility rate of individuals in age class *i* and *t* is time or age in years. Fish populations typically exhibit indeterminate growth and size-structured matrix models normally best represent these populations, however, length-at-age was highly variable in the Channel Catfish population so we constructed age-structured models (Ganias et al. 2015). The number of age classes was set from zero to the maximum aged fish recaptured from the regulated reaches of the Tallapoosa River below R. L. Harris Dam. Based on the constructed age-length key we constructed fertility rates that were applied to fish ≥ 4 years of age, corresponding to the lengths at maturity reported for female Channel Catfish by Hubert (1999).

After fertility and survival estimates of 4+ age classes were determined, survival of age-0 Channel Catfish was estimated by assuming the population exhibited a stationary age distribution. Consequently, population growth rate was set to one (λ = 1.0001) to estimate year one survival. These models served as a baseline in order to assess environmental variables and the effects these variables have on the Channel Catfish population in the regulated reaches of the Tallapoosa River.

Elasticity analysis – Although deterministic matrix models do not include variability, proportionate contribution of annual survival and fertility was calculated with sensitivity and elasticity analysis. Changes in elements of the population model directly affecting λ can be calculated with sensitivity analysis. Sensitivity can then be extended to an index (elasticity) to measure the proportional sensitivity and quantify the degree to which population growth is determined by alternate life history transitions (De Kroon et al. 1986) Elasticity of a matrix element was calculated from the product of the sensitivity of the matrix element and the element itself, divided by λ. Elasticity was summed across various age-classes to determine contribution of multiple age-classes to overall population growth rates (Heppell et al. 1999). All matrix population modeling was conducted in PopTools (Hood 2010).

RESULTS

No OTC marks were present on sectioned otoliths of Redbreast Sunfish that were held back to estimate marking efficacy. It is presumed the fish did not uptake the OTC properly to mark calcified structures, but whether this was due to immersion duration, OTC concentration, fish size or other environmental factors is unknown (Unkenholz et al. 1997). Additionally, sectioned otoliths from a range of sizes (52-195 mm) of Redbreast Sunfish collected from the field did not appear to have laid down annuli; therefore, accurate ages could not be determined. Redbreast otoliths in general were morphologically abnormal in cross section with fracturing and apparent false annuli (i.e., check marks). Therefore, no further analyses were conducted on Redbreast Sunfish.

A total of 10.95 hours of pedal-down time of boat electrofishing was recorded for both years. Channel Catfish catch per unit effort (fish/hour) was similar for 2015 and 2016 (4.08 [±3.21] and 8.51

[±4.03], respectively; df = 5, t = -0.086, P > 0.4; Figure 2). Of the 110 Channel Catfish collected from 2015 and 2016, no fish possessed the SNPs of Marion strain Channel Catfish and therefore no stocked fish were recaptured (E. Peatman, unpublished data).

Length histograms were constructed for Channel Catfish from 2015 and 2016 (Figure 3). These histograms indicated a lack of fish in the 150-250 mm size classes which were expected to contain stocked Channel Catfish.

The Channel Catfish population was comprised of fish from age-0 to 17, ranging in size from 32 – 559 mm TL. The von Bertalanffy growth model predicted asymptotic mean length of the Channel Catfish population to be 440.9 mm TL with a growth coefficient of -0.31 and a theoretical length at t_0 equal to -0.94 (Figure 4). These estimates were based off a null model constructed with Channel Catfish data collected from 1996-1997, 2009-2011 and 2015-2016. Akaike's Information Criterion model selection indicated no difference in growth parameters of Channel Catfish populations before and after Green Plan implementation (2005; Table 3).

Utilizing the equation developed from the von Bertalanffy growth model an age-at-length key was constructed with mean length at age 0 – 11 ranging from 111.5 – 430.0 mm (Table 4). Fertility-at-age was calculated from the resulting age-at-length key for fish ≥ age 4 and ranged from 6152.23 to 12538.27 eggs (Table 4).

A weighted catch curve analysis estimated instantaneous mortality of the Channel Catfish population to be -0.385 and annual mortality of 31.9% (Figure 5). Utilizing the annual mortality calculated from the catch cure, annual survival was estimated to be 68.1%.

Applying annual survival and fertility rates into an age based population matrix model with population growth set to 1 (λ = 1.0001) survival of age-0 fish was estimated to be 0.0292% (Figure 6). Elasticity analysis revealed greater than 51% of the relative contribution to population growth was based on survival rates of fish from age 0 to age 4 (Figure 7).

Discussion

Adaptive management of natural resources focuses on reducing uncertainty related to the response of objectives (i.e., fish populations in this report) to management alternatives (Williams et al. 2009). Flows at Harris Dam have been managed to improve fish population response (e.g., sport fish recruitment) since 2005 and although positive responses in fish habitat stability and availability have been measured (Irwin et al. 2011), response of fishes to river management has been variable and direction of some responses have been negative and unexpected (Kennedy 2015). One example of this is the depressed number of juvenile sport fishes (e.g. centrarchids and ictalurids) in the regulated mainstem (Irwin and Goar 2014; Irwin unpublished data) which indicates that a recruitment bottleneck may exist (Scheimer et al. 2002). The main objective of this research was to determine if stock enhancement could help identify if and where recruitment bottlenecks exist in the regulated Tallapoosa River. The lack of uptake of OTC by Redbreast Sunfish and the lack of recapture of stocked Channel Catfish disallowed our evaluation of specific hydrologic and thermal regimes on success of stock enhancement techniques and individual fish growth rates related to those variables; however, the stocking experiment was a success in that it illustrated that environmental bottlenecks for recruitment likely exist. Active incremental hypothesis testing and risk taking in adaptive processes can help reduce uncertainty faster than reliance on monitoring data examining variation in metrics of interest on a year-to-year time step. Sitkin (1992) reported that strategic failure through experimentation can enhance adaptation by challenging the status quo—in this case, the notion that remedial stockings could solve the problem of lack of recruitment of Redbreast Sunfish and Channel Catfish in the Tallapoosa River was invalidated by the stocking experiment.

Although we were unable to quantify the survival and recruitment of stocked Redbreast Sunfish due to failure of the OTC marking process, our search for marked fish led us to observe what appears to be growth abnormalities expressed on otoliths from fish in the mainstem. Marks on the otoliths appear as fractures and checks in the otolith structure; this phenomenon has been observed in other species in the Tallapoosa River Alabama Bass and Channel Catfish (Irwin et al. 1997; Sakaris 2006). Payan et al. (2004) reported that in an experimental setting, Rainbow Trout *Oncorhynchus mykiss* exposed to stress exhibited gross abnormalities in otolith morphology and discontinuity checks in otolith growth. Earley (2012) reported chronic stress markers (blood cortisol levels) for Tallapoosa Bass in the middle Tallapoosa River related to the hydropeaking regime in the river. Developing a strategy to quantify potential stress marks that are expressed on otoliths could be a viable monitoring tool to detect stress (or relief of stress) related to management regimes.

Redbreast Sunfish spawning success has been studied in the middle Tallapoosa River and is related to specific thermal and hydrologic regimes (Andress 2002; Martin 2008). Kennedy (2015) indicated that Redbreast Sunfish was one of the species that showed negative trends in occupancy relative to distance from the dam during Green Plan management. Increased base flow through pulsing has eliminated periods of low flow with coincident warm water temperatures in the late summer that were conducive to spawning of multiple fish species including Redbreast Sunfish (Freeman et al. 2001). Modification of spawning windows and base flows to allow for mitigation of cold water pollution during spawning periods could benefit a suite of fishes (Kennedy 2015).

Mark-recapture studies on Channel Catfish have been conducted in rivers with variable re-capture results; return rates were reported between 8.6 and 15.6 % (Dames et al. 1989; Pellett et al. 1998). The reasons for non-recapture of stocked fish in the Tallapoosa River are unknown at this time; explanations range from mass out-migration to mortality to capture inefficiency, and combinations of these. With respect to capture inefficiency or gear selectivity, our electrofishing capture rates of Channel Catfish in the mainstem at the Horseshoe Bend stocking site were higher than any we recorded over multiple decades of sampling, and appeared to be related to flow conditions at the site—low water conditions were conducive to increased capture rates. In general, capture rates of Channel Catfish have been low with all gear types (trot-lines, PAEs, boat electrofishing; Irwin and Belcher 1999; Irwin et al. 2011; Sammons et al. 2013; current study), but all sizes of fish were collected, including some specimens in the size range of the stocked fish, indicating that size-selective detection may not be an issue, although size or age class related capture efficiency may present additional bias. Other potential reasons for paucity of fish in our boat electrofishing samples in the size range of the stocked fish are hypothetical; either fish emigrated from the mainstem to tributaries or to the downstream reservoir due to abiotic and/or biotic constraints (i.e., thermal/hydrologic alteration and/or forage) or were subject to high mortality from predators.

Published accounts indicate that survival and recruitment of stocked fish depends on suitable physical habitat (Jackson et al. 2002), and the thermal and hydrologic regime of the receiving water body (Coutant et al. 1974; Sakaris and Irwin 2010). The middle Tallapoosa River below Harris Dam is a complex system comprised of the mainstem river, multiple large tributaries and the downstream reservoir (Lake Martin). Channel Catfish are known to move between both tributaries and mainstem rivers (Dames et al. 1989; Butler and Wahl 2011) and between rivers and associated reservoirs (Hubert and O'Shea 1991). The tributary and reservoir influence on population structure of fish species in the Tallapoosa River Basin is hypothetical and unknown. Because of the mobile nature of Channel Catfish and Striped Bass (i.e., Tallapoosa River; Sammons 2011) in lotic systems, stocked fish of both species may have moved to tributary habitats or to Lake Martin. Although we have no data on movements of Channel Catfish in the Tallapoosa River, other published accounts indicate that the species is highly mobile between wintering habitat in lentic habitats (pools or downstream reservoirs in large rivers) and spawning habitats (cavities and coarse substrates in mainstem or tributary habitat; Butler and Wahl 2011). These authors radio tagged Channel Catfish in the Fox River, Illinois and fish that were released in the winter moved to a downstream reservoir and returned to the river in the spring. Perhaps the

Channel Catfish that were stocked during winter months in the Tallapoosa River sought overwinter refuge in lentic downstream habitat. In addition, because the fish were subadults, they have yet to recruit to the spawning stock potentially limiting upstream movements into the mainstem.

In addition, availability of food resources may influence fish survival (Walters and Juanes 1993) and some evidence exists that hatchery fish lack the ability to forage effectively in their new environment leading to increased mortality (Hubert and O'Shea 1991). Recent data on invertebrate communities in the Middle Tallapoosa River indicate a lack of insects that would be available as prey for Channel Catfish (Irwin, unpublished data). Jolley and Irwin (2011) studied Channel Catfish food habits in the Coosa River and indicated that insects were the most utilized prey type of all sizes of fish. Data regarding food habits of Tallapoosa River Channel Catfish are lacking and if available may help illustrate biological constraints. Interestingly, relative weights were variable, but on average were low for fish collected in this study (range 78.9-127.5; mean = 87.7, 1.75 SD); however, it is acknowledged that relative weight does not necessarily reflect healthy condition because fish can compensate for lipid or protein losses by taking on water weight (Shulman and Love 1999). Current research is underway to develop a non-lethal method for predicting condition of field-caught Channel Catfish based on bioelectrical impedance analysis (BIA; Irwin, unpublished data).

Predation rates of stocked fish by resident adult piscivores have been reported to range from 23-47% (Spinelli et al. 1985; Marsh and Brooks 1989; Buckmeier et al. 2005) and have been related to environmental conditions in the receiving water body at the time of stocking. For example, cold water shock increased predation rates of Channel Catfish by Largemouth Bass; whereas, temperature differentials of 7°C caused intense predation rates (Coutant et al. 1974). Although temperature differentials immediately following stocking were nil (~2°C), temperature differentials by May in 2015 and 2016 could exceed 5°C (Irwin, unpublished data). Daily temperature differentials in summer and fall months in some years exceed 8°C which could cause a number of physiological responses and biological consequences including acute mortality, increased predation rates, decreased feeding and stress responses (see Donaldson et al. 2008 for a review).

Peterson (2003) identified that both physiological (thermal, chemical and nutrition) and structural (physical habitat) ecosystem components were critical to survival of young life stages of fish. Schiemer et al. (2002) discussed sources of mortality for age-0 fish and the ecophysiological complexities of spawning—hatching—shifting to exogenous feeding—finding suitable refuge and foraging habitat. Coupled with hydropeaking that can displace Channel Catfish juveniles downstream and thermal alteration, the regulated Tallapoosa River seems to be a fairly hostile environment for the species' life history style. In addition, age-0 Channel Catfish exhibit diel shifts in habitat use where they move to shallow marginal habitats at night (Irwin et al. 1999); often these movements are coincident with hydropeaking events. Over the course of the adaptive management project, temperature data have been collected above and below the dam. Because fish require adequate thermal energy to develop oocytes and spawn (see Pawiroredjo et al. 2008 for Channel Catfish thresholds), we calculated the cumulative degree days (°D) for Channel Catfish for 12 years (2005-2016) to determine if thermal conditions for spawning were met. Below the dam, median conditions for spawning (100°D) were met in 58.3 % of years and the earliest that conditions were met was 8 July. At the unregulated site, thermal spawning conditions were met in every year and always earlier than at the regulated sites. Sakaris (2006) noted recruitment of small age-0 fish in September and hypothesized that protracted spawning of Channel Catfish below the dam was probable. Given the small sizes of late-spawned fish, overwinter mortality is likely high as reported by Patton and Hubert (1996) in a similar, thermally altered system. Responses to thermal regimes within the regulated reaches of the river will certainly be species specific and future analysis will attempt to model environmental influence on recruitment processes.

Success or failure in setting year-class strength depends on conditions for spawning and survival of juveniles. Sammons et al. (2013) evaluated catch-curve residuals for Channel Catfish in the middle

Tallapoosa River and reported that no strong year-classes were formed between 1999 and 2010. In addition, no explanatory hydrologic variables were identified in their study. Sakaris (2006) reported that hydrologic variables including mean discharge, minimum discharge, number of high pulses and rise rate to be positively related to growth of age-0 Channel Catfish in the lower Tallapoosa River (below Thurlow Dam). Age-0 fish recruitment is an issue but mortality of older classes may also contribute to low population numbers (sources of mortality—fishing and natural). Unfortunately, the sample sizes of Channel Catfish in our study were not robust enough to evaluate the impacts of hydrologic or thermal variation on year-class strength. Future sampling could focus on bolstering sample sizes to evaluate the current status of the population related to hydrologic and thermal regimes.

Effective adaptive management uses predictive models and iterative hypothesis testing to fine-tune management needed to meet stakeholder objectives (Walters 1986; McLain and Lee 1996). The stocking experiment that we conducted was an example of testing the hypothesis that recruitment of age-0 fish fails at very early life stages—if stocked fish were larger than the vulnerable life stages then a positive impact on the population might be realized. The construction of a population model was the next step in identification of uncertainties about vital rates for Channel Catfish in the Tallapoosa River. These models are valuable for projecting impacts of age-specific mortality on population growth rates (DeAngelis et al. 1977). Monitoring data may be used to update vital rates used in the models as they respond to various management actions (Irwin and Freeman 2002). If vital rates can be related to environmental variation caused by management, then preferred management portfolios can be identified. Quantification of sources of mortality (i.e., natural and fishing) of various life stages could identify the impact of management options on population sustainability.

The use of the matrix models to explore the vital rates of various life history stages that impose constraints on Channel Catfish population growth rates provide more inference for the recruitment limiting hypothesis; survival through each of the first four age classes had the largest influence on projected population growth. The hypothesis that age-0 recruitment is affecting population growth was supported with the population model, which estimated survival to age-1 to be less than 0.03%. However, the model also indicated survival to ages 2-4 had equal contribution to overall population growth. These projections corroborate the notion that recruitment limitation is impacting population size and stability.

Nash (1999) characterized the Channel Catfish population in the middle Tallapoosa River as a recruitment-overfishing limited population based on age structure of the population. Based on the low capture rates of young fish in our long-term monitoring of adaptive management and the overall lack of optimal thermal requirements for spawning, it is possible that recruitment overfishing is occurring. Exploitation rates for Channel Catfish on the Tallapoosa River are not known. A recent survey of anglers indicated that Channel Catfish were highly valued by Tallapoosa River anglers and based on anecdotal observations (many limb and trot lines), there is pressure on the fishery (Gerken 2015). Slipke et al. (2002) evaluated a heavily exploited Channel Catfish population in Iowa that was also thought to be regulated by growth-overfishing processes; however, their spawning potential ratio (SPR) models indicated that by changing the minimum-length limit regulation from 330 to 381 mm, recruitment of age-0 fish was predicted to increase four-fold. Using predictive models similar to the approach by Slipke et al. (2002) could help identify exploitation rates too high for sustained populations of Channel Catfish in a recruitment limited situation. Creel surveys are planned in conjunction with the upcoming FERC process, so some data regarding fishing pressure and harvest may be available in the future to update model parameters.

Brown et al. (2013) addressed the concept of half-way technology as related to dam management and fish stock enhancement in Atlantic coastal rivers. They contended that stock enhancement (i.e., half-way technology) cannot be successful for stock recovery without addressing fish passage and out-migration issues for American shad and other riverine clupeids. Similarly, a stocking program for sport fish enhancement below Harris Dam may not be an effective management technique at this time. Understanding or predicting the mechanisms for “failure” is crucial to learn in adaptive frameworks and often inference comes from the experience of others. An impediment to understanding potential management of Channel Catfish in the Tallapoosa River through remedial stocking is that there appears to be only two published account of stocking Channel Catfish in rivers; no stocked fish were recaptured in the Yalobusha River, MS (Cloutman 1997) and it is unclear regarding contribution of stocked fish in the Laramie River, WY (Patton and Hubert 1996). In general, States do not intensively manage Channel Catfish in rivers except through regulations (Michaletz and Dillard 1999), further limiting our reliance on existing knowledge.

Historically the Tallapoosa River fish community was dominated by catfishes and minnows (Swingle 1953) and the community is now dominated by centrarchids (Irwin and Belcher 1999). In the current adaptive management project, meeting the stated objectives of preserving and/or enhancing fish biodiversity and productive sport fisheries below Harris Dam will likely require ecosystem wide management. Given potential constraints for management at the dam, the riverine ecosystem may not return to pre-dam conditions; however, positive responses attributed to increased base flow provided through the Green Plan illustrate that some incremental improvements are possible (Kennedy 2015). The future potential for modification of the Green Plan exists given the commitment by the stakeholders over the life of the adaptive management project.

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Table 1.-Number and location of Redbreast Sunfish stocked in the regulated reaches of the Tallapoosa River below R. L. Harris Dam in 2015 and 2016.

Redbreast Sunfish		
Reach	**2015**	**2016**
Wadley	2,000	19,500
Horseshoe Bend		500
	2,000	20,000
Total		**22,000**

Table 2.-Number and location of Channel Catfish stocked in the regulated reaches of the Tallapoosa River below R. L. Harris Dam in 2015 and 2016.

Channel Catfish		
Reach	**2015**	**2016**
Malone	23,064	7,410
Wadley	21,384	9,112
Horseshoe Bend	23,144	23,210
	67,592	39,732
Total		**107,324**

Table 3.-Akaike's Information Criterion (corrected) model selection of von Bertalanffy growth functions for Channel Catfish in the regulated reaches of the Tallapoosa River, Alabama.

Model	AICc	Delta	Likelihood	Weight
Null	3409.82	0	1	0.38
L_∞	3411.19	1.37	0.51	0.19
t0	3411.64	1.82	0.4	0.15
L_∞&k	3413.19	3.36	0.19	0.07
L_∞&t0	3413.25	3.42	0.18	0.07
k&t0	3413.49	3.67	0.16	0.06
k	3413.54	3.71	0.16	0.06
L_∞&k&t0	3415.23	5.41	0.07	0.03

Table 4.-Predicted mean length and fertility for Channel Catfish in the regulated reaches of the Tallapoosa River below R. L. Harris Dam (log(TL)=3.2563(log(#eggs))-4.4773).

Age	Mean Length	Fertility
0	101.47	325.94
1	175.22	566.092
2	233.55	756.032
3	305.89	991.5923
4	361.17	1171.601
5	379.22	1230.377
6	384.53	1247.668
7	389.41	1263.558
8	394.08	1278.765
9	401.33	1302.374
10	405.5	1315.952
11	422	1369.681

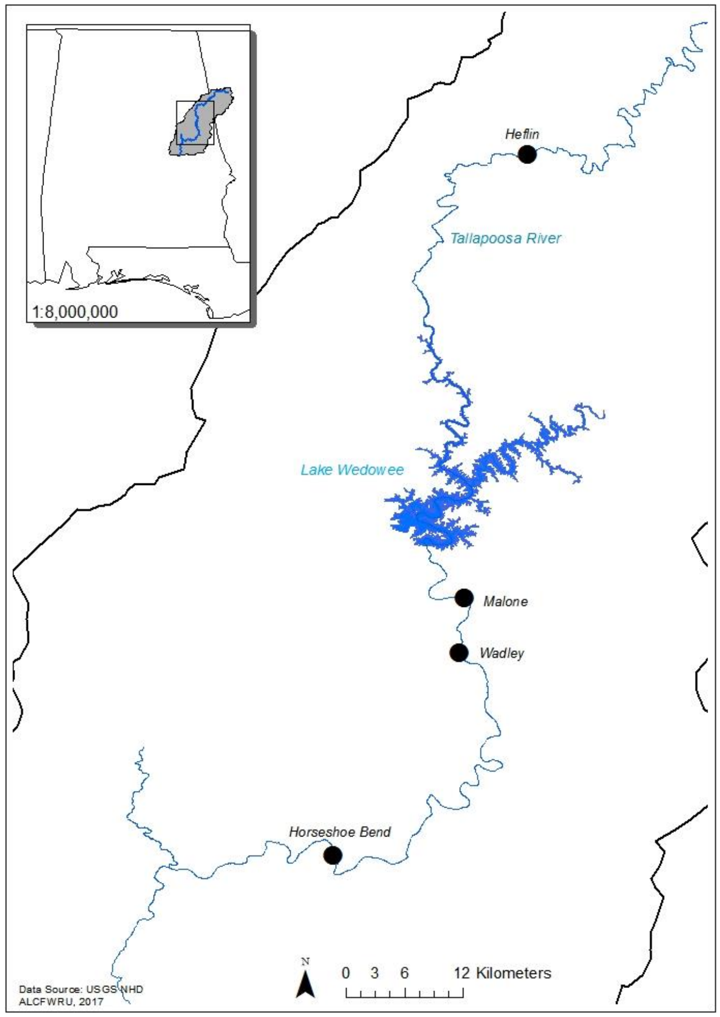


Figure 1.-Locations of stocking and sampling sites on the Tallapoosa River, Alabama. Channel Catfish were stocked and boat electrofishing and PAE sampling occurred at Wadley and Horseshoe Bend sites. PAE sampling also occurred at the Heflin and Malone sites.

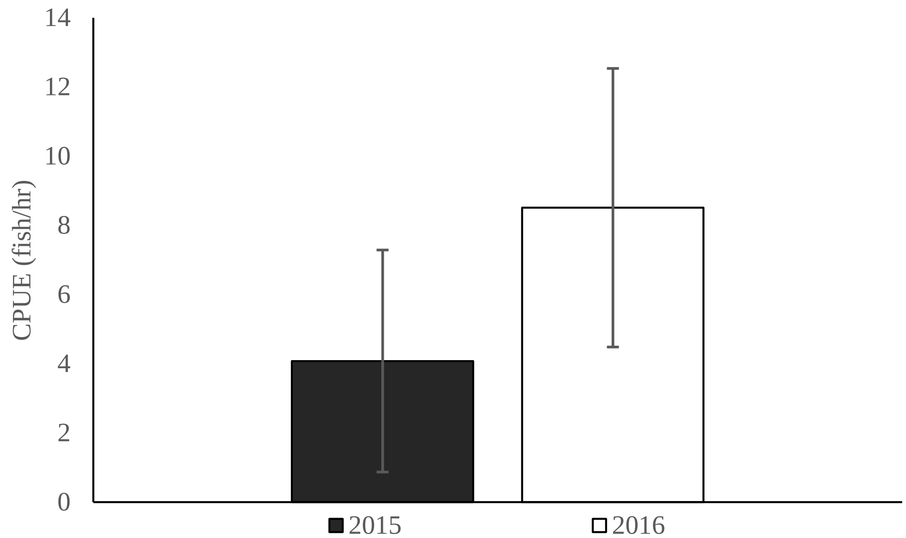


Figure 2.-Channel Catfish mean catch per unit effort (+ SE) in the regulated reaches of the Tallapoosa River below R. L. Harris Dam in 2015 and 2016.

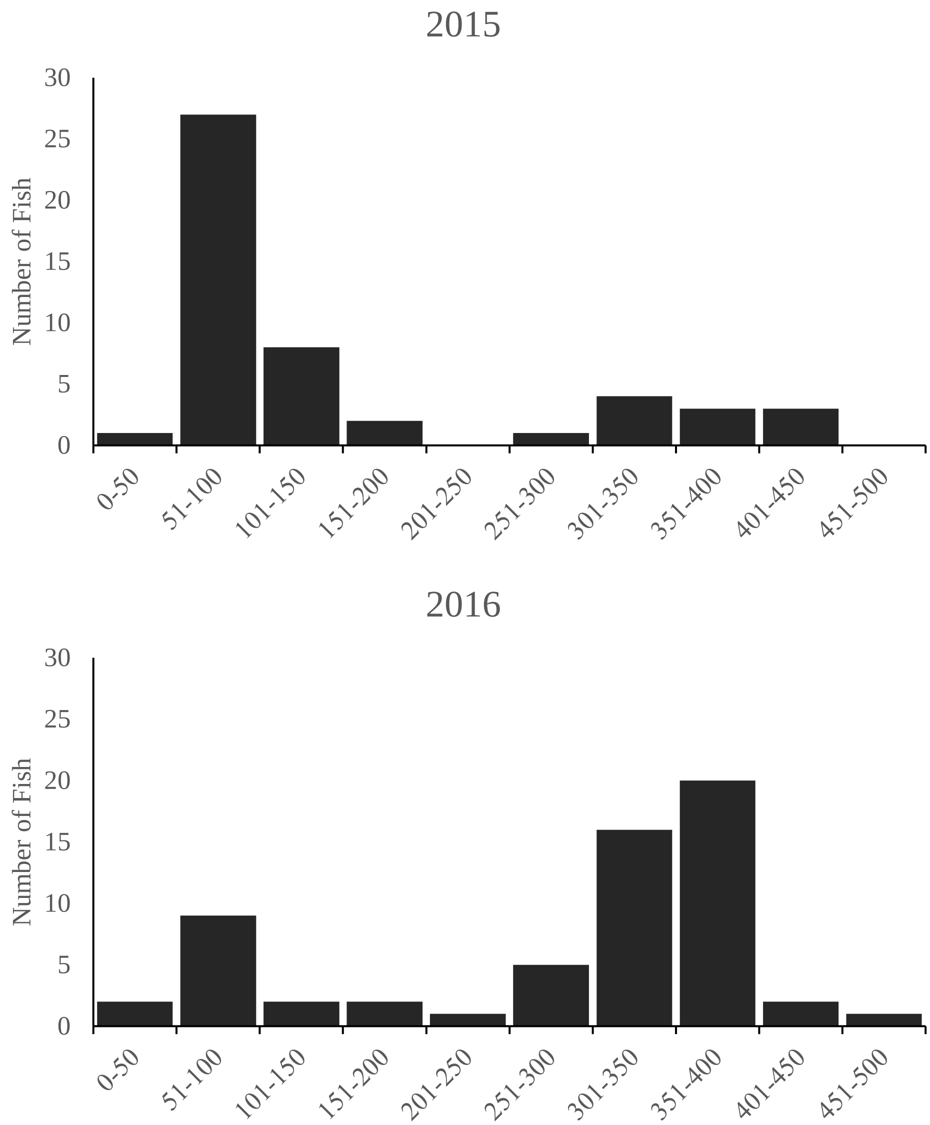


Figure 3.-Length-frequency histograms for Channel Catfish collected in the regulated reaches of the Tallapoosa River below R. L. Harris Dam in 2015 and 2016.

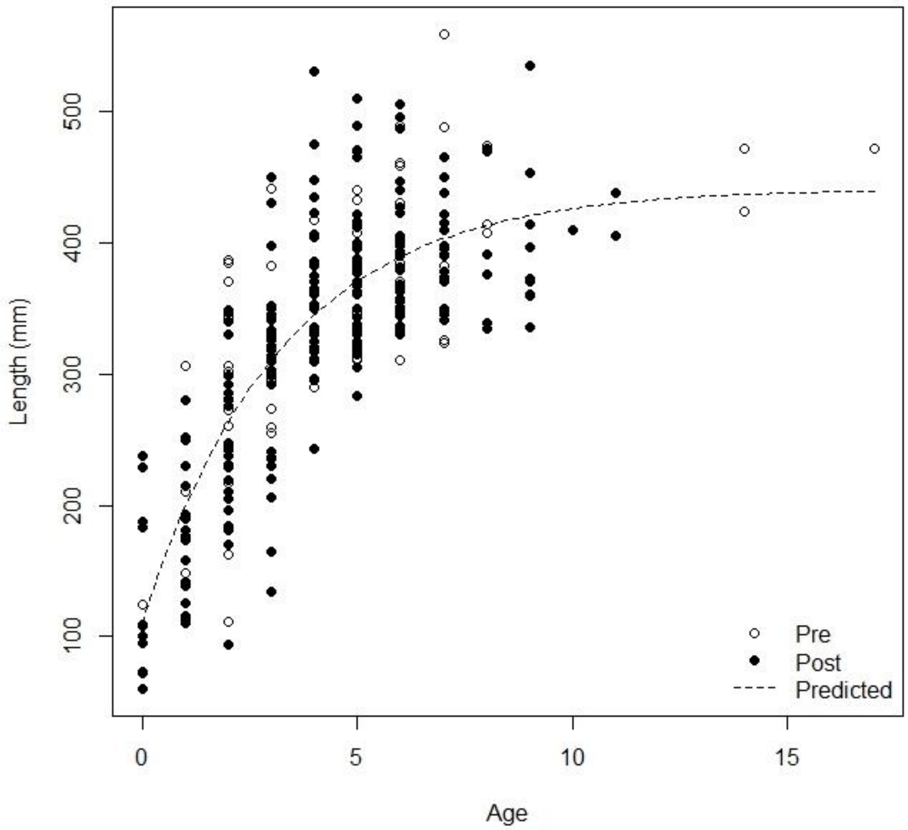


Figure 4.-Channel Catfish age and length data from before (Pre) and after (Post) implementation of “Green Plan”, below R. L. Harris Dam on the Tallapoosa River, Alabama, fitted to a von Bertalanffy growth model. The dotted line represents the null model.

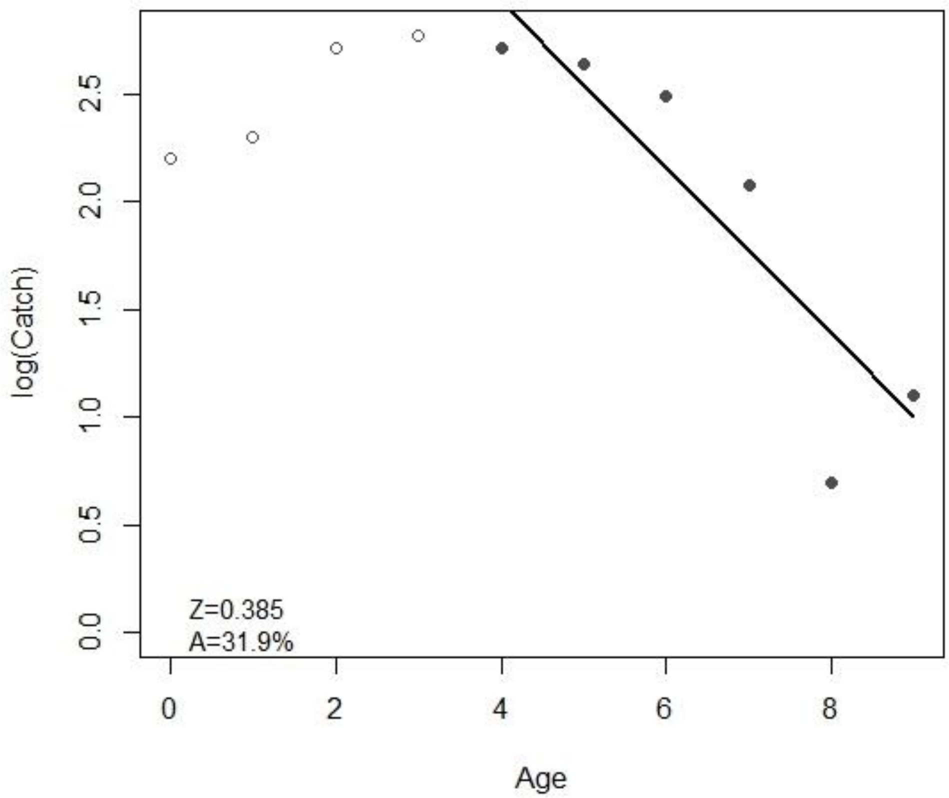
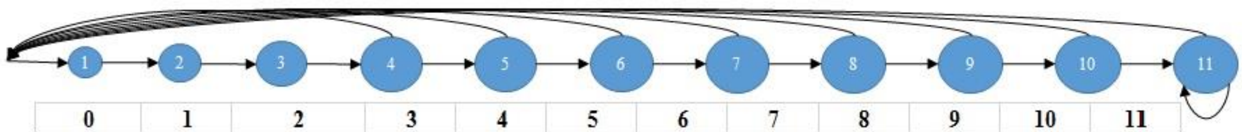


Figure 5.-Weighted catch curve analysis on Channel Catfish (n = 101) catch-at-age data from 2010 in the regulated reaches of the Tallapoosa River below R. L. Harris Dam, Alabama. Open circles indicate age classes not recruited to the gear and therefore excluded from the catch curve analysis.



0	1	2	3	4	5	6	7	8	9	10	11
0	0	0	0	2489.5	3136.637	3679.503	4116.787	4459.524	4723.127	4923.194	5073.613
0.0002920	0	0	0	0	0	0	0	0	0	0	0
0	0.681	0	0	0	0	0	0	0	0	0	0
0	0	0.681	0	0	0	0	0	0	0	0	0
0	0	0	0.681	0	0	0	0	0	0	0	0
0	0	0	0	0.681	0	0	0	0	0	0	0
0	0	0	0	0	0.681	0	0	0	0	0	0
0	0	0	0	0	0	0.681	0	0	0	0	0
0	0	0	0	0	0	0	0.681	0	0	0	0
0	0	0	0	0	0	0	0	0.681	0	0	0
0	0	0	0	0	0	0	0	0	0.681	0	0
0	0	0	0	0	0	0	0	0	0	0.681	0.681

Figure 6.-Age classified matrix model with a stable population (λ = 1.002; r = 0.0002) used to determine survival of age-0 fish Channel Catfish (S = 0.0292%) in the regulated reaches of the Tallapoosa River below R. L. Harris Dam, Alabama. Red text indicates estimated survival of age-0 fish after setting λ to 1.002.

0	1	2	3	4	5	6	7	8	9	10	11
0	0	0	0	0.029711	0.025489	0.02036	0.015511	0.011441	0.008251	0.005856	0.012878
0.129496	0	0	0	0	0	0	0	0	0	0	0
0	0.129496	0	0	0	0	0	0	0	0	0	0
0	0	0.129495974	0	0	0	0	0	0	0	0	0
0	0	0	0.129496	0	0	0	0	0	0	0	0
0	0	0	0	0.099785	0	0	0	0	0	0	0
0	0	0	0	0	0.074296	0	0	0	0	0	0
0	0	0	0	0	0	0.053936	0	0	0	0	0
0	0	0	0	0	0	0	0.038425	0	0	0	0
0	0	0	0	0	0	0	0	0.026985	0	0	0
0	0	0	0	0	0	0	0	0	0.018734	0	0
0	0	0	0	0	0	0	0	0	0	0.012878	0.027481

Figure 7.-Elasticity analysis of an age based population matrix model for Channel Catfish in the regulated reaches of the Tallapoosa River below R. L. Harris Dam, Alabama. Proportional sensitivity of age classes to total population growth is indicated by red text.