EFFECTS OF ENVIRONMENTAL VARIATION ON STOCKING SUCCESS OF AN ENDEMIC BLACK BASS SPECIES IN THE CHATTAHOOCHEE RIVER, GEORGIA

By

MICHAEL JAMES PORTA

Bachelor of Science in Wildlife and Fisheries Management

Frostburg State University

Frostburg, Maryland

2006

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
December, 2011

EFFECTS OF ENVIRONMENTAL VARIATION ON STOCKING SUCCESS OF AN ENDEMIC BLACK BASS SPECIES IN THE CHATTAHOOCHEE RIVER, GEORGIA

Thesis Approved:

Dr. James M. Long

Thesis Advisor

Dr. Daniel E. Shoup

Dr. Shannon K. Brewer

Dr. Sheryl A. Tucker

Dean of the Graduate College

TABLE OF CONTENTS

Chapter Page

LIST OF TABLES

Chapter II

Chapter III

LIST OF FIGURES

Chapter II

Chapter III

LIST OF APPENDICES

Chapter II

Chapter III

CHAPTER I

INTRODUCTION TO THE THESIS

Dams perform many positive functions for humans, which include storage and release of water for power generation, flood control, irrigation, navigation, water supply, and recreation (Peters 1986). However, dams also create significant ecological impacts for resident aquatic communities, which include interference with natural flow regimes and river continuity, alteration of water temperature and oxygen levels, disruption of sediment transport, alter floodplains, obstruction of fish passage, and transformation from lotic to lentic systems (Bednarek 2001). Habitats below dams, especially those with hypolimnetic releases, have been particularly affected. Temperature reductions from hypolimnetic reservoir release have a major influence on fish and invertebrates downstream. Reservoir releases may be too cold for extended periods of time to allow for adequate reproduction and growth of native, warmwater fish species (Ruane et al 1986; Travnichek et al. 1995; King et al. 1998; Clarkson and Childs 2000; Todd et al. 2005), creating effects so great as to largely extirpate most of the native, self-sustaining warmwater fisheries. In many instances, fisheries managers have supplementally stocked trout to mitigate for those negative effects, creating coldwater fisheries (Fry and Hanson 1968; Long and Martin 2008).

In the upper Chattahoochee River, Georgia, dams have had similar effects, but land-use change has reversed that trend (Long and Martin 2008). Below Morgan Falls Dam, urbanization of Atlanta, Georgia has caused water temperatures to warm due to increased urban runoff resulting from increased impervious surface area of the watershed(Long and Martin 2008). The increased temperature resulted in several trout kills below Morgan Falls Dam (Long and Martin 2008; Runge et al. 2008), and has created a transitional zone that currently supports populations of coldwater and warmwater fish species. Although this has complicated stocking decisions, it has given fisheries managers an opportunity to restore an endemic warmwater black bass to historic population numbers. In 2003, the Georgia Department of Natural Resources and the National Park Service initiated a five-year stocking program below Morgan Falls Dam to re-establish a shoal bass population to historic numbers and to provide further sport-fishing opportunities (Long and Martin 2008). In the following chapters, I evaluate the five-year shoal bass stocking program in the Morgan Falls Dam tailwater. To do this I will assess: 1) contribution, population characteristics, and factors affecting the recruitment of stocked juvenile shoal bass to the adult population in the Chattahoochee River below Morgan Falls Dam, and 2) short-term, post-stocking responses by juvenile shoal bass.

REFERENCES

Bednarek, A. 2001. Undamming rivers: A review of the ecological impacts of dam removal. Environmental Management 27:803-814.

Clarkson, R.W. and M.R. Childs. 2000. Temperature effects of hypolimnial-release dams on early life stages of Colorado River basin big-river fishes. Copeia 2:402-412.

Fry, J.P., and W.D. Hanson. 1968. Lake Taneycomo: a cold-water reservoir in Missouri. Transactions of the American Fisheries Society 97:138-145.

King, J., J. A. Cambray, and N.D. Impson. 1998. Linked effects of dam-released floods and water temperature on spawning of the Clanwilliam yellowfish *Barbus capensis*. *Hydrobiologia* 384:245-265.

Long, J.M. and C. Martin. 2008. The evolution of fisheries management of the upper Chattahoochee River in response to changing water management. Pages 21-36, *In* M.S. Allen, S. Sammons, and M.J. Maceina, editors. Balancing fisheries management and water uses for impounded river systems. American Fisheries Society. Symposium 62. Bethesda, Maryland. 697 pp.

Peters, J.C. 1986. Enhancing tailwater fisheries. In G. E. Hall & M. J. Van Den Avyle (eds), Reservoir Fisheries Management: Strategies for the 80's. Southern Division American Fisheries Society, Bethesda, Maryland: 278– 285.

Ruane, R. J., C. E. Bohac, W. M. Seawell & R. M. Shane, 1986. Improving the downstream environment by reservoir release modifications. In G. E. Hall & M. J. Van Den Avyle (eds), Reservoir Fisheries Management: Strategies for the 80's. Southern Division American Fisheries Society, Bethesda, Maryland: 270– 277.

Runge, J.P., J.T. Peterson, and C.R. Martin. 2008. Survival and dispersal of hatchery-raised rainbow trout in a river basin undergoing urbanization. North American Journal of Fisheries Management 28:745-757.

Todd, C.R., T. Ryan, S.J. Nicol, and A.R. Bearlin. 2005. The impact of cold water releases on the critical period of post-spawning survival and its implications for Murray cod (*Maccullochella peelii peelii*): a case study of the Mitta Mitta River, Southeastern Australia. River Research Applications 21:1035-1052.

Travnichek, V.H., M.B. Bain, and M.J. Maceina. 1995. Recovery of a warmwater fish assemblage after the initiation of a minimum-flow release downstream from a hydroelectric dam. Transactions of the American Fisheries Society 124:836-844.

CHAPTER II

CONTRIBUTION, POPULATION CHARACTERISTICS, AND VARIABLES INFLUENCING RECRUITMENT OF SHOAL BASS *MICROPTERUS CATARACTAE* STOCKED INTO THE CHATTAHOOCHEE RIVER, GEORGIA

Abstract

In 2003, the Georgia Department of Natural Resources and the National Park Service initiated a five-year shoal bass stocking program below Morgan Falls Dam in the Chattahoochee River, Georgia with a goal of rehabilitating population abundance to historic levels and to provide further sport-fishing opportunities. Shoal bass were marked with oxytetracyline (OTC) and stocked as juveniles at one of two size classes (Phase I [~25 mm, TL] and Phase II [~60 mm, TL]) in spring (April – June) each year (2003-2007). Contribution to the adult population was evaluated by collecting adult shoal bass with boat electrofishing from 2007-2011 and viewing their otoliths for the presence of an OTC mark. Stocked shoal bass dominated the total sample of adult fish collected (62%) and most of these fish (41%) were stocked at the larger size class. Based on results from multiple regression modeling, age-3 shoal bass catch-per-unit-effort was positively related to mean size at stocking and spring water temperatures. Natural mortality of shoal bass in this population was low (20%) with increased longevity (14 years) and low

growth rates. Overall, the five-year shoal bass stocking program was successful in increasing shoal bass abundance in the Chattahoochee River below Morgan Falls Dam.

Introduction

The shoal bass *Micropterus cataractae,* once considered the Apalachicola or Flint River form of redeye bass *M. coosae* (Ramsey and Smitherman1972), is a recently-described species of black bass endemic to the Apalachicola-Chattahoochee-Flint River Basin in Alabama, Florida, and Georgia (Figure 1; Williams and Burgess 1999). The shoal bass is a habitat specialist inhabiting shoals of medium to large river systems (Williams and Burgess 1999; Wheeler and Allen 2003; Stormer and Maceina 2008). Throughout their range, shoal bass have been negatively impacted by dams, resulting in local extirpations and declines in abundance (Williams and Burgess 1999; Long and Martin 2008). As a result, shoal bass have been listed as a species of special concern in Alabama, (Williams and Burgess 1999), threatened in Florida (Gilbert 1992), and vulnerable throughout their range by the American Fisheries Society Endangered Species Committee (Jelks et al. 2008).

In the upper Chattahoochee River, Georgia, the shoal bass is limited to only small reaches of river because of the many impoundments that have eliminated their habitat and impeded their movements (Williams and Burgess 1999). In particular, the creation of Lake Sidney Lanier in 1958 caused shoal bass to disappear from a 76-kilometer (km) reach of the Chattahoochee River due to impoundment flooding, and from a 77-km reach below the lake due to coldwater hypolimnetic releases from the dam (Figure 1; Long and Martin 2008). To mitigate for the loss of this and other warm-water fish species below Lake Lanier, trout (Salmonidae) were stocked in the newly-created Chattahoochee River tailwater.

Urbanization of Atlanta, Georgia, through which the Chattahoochee River tailwater flows, has caused water temperatures to warm in the river below Morgan Falls Dam, leading to occasional die-offs of the stocked trout (Long and Martin 2008; Runge et al. 2008). As a result, the water temperature regime was thought suitable for re-establishing a shoal bass population (Long and Martin 2008). Furthermore, this 19-km reach contains some of the best remaining shoal habitat in the river (Nestler et al. 1986; Georgia Power 2006). Thus, the Georgia Department of Natural Resources (GADNR) and the National Park Service (NPS) initiated a five-year shoal bass stocking program in 2003 below Morgan Falls Dam to re-establish a population to historic population abundance levels and to provide further sport-fishing opportunities (Long and Martin 2008).

In 2003, thirty pairs of shoal bass brood stock were collected from North Highlands reservoir on the lower Chattahoochee River, and stocked into a 0.4-ha earthen pond at the Steve Cocke Fish Hatchery for spawning. Fry were produced annually for 5 years from this initial brood of shoal bass and stocked into two to three sites at the Chattahoochee River below Morgan Falls Dam. Each year, stocked fish were marked in-transit as 30-day old fingerlings (Phase I size; ~25 mm, TL) with 500 mg/L buffered oxytetracycline (OTC; Hoffman and Bettoli 2005) and stocked in April- May. In 2004 and 2005, approximately 10,000 fingerlings were held over following marking, grown for an additional 30 days to Phase II fingerling size (~ 60 mm TL), marked again with OTC, and stocked in early June. In 2006, unusual weather conditions allowed juvenile fish to grow faster and these were stocked at Phase II size, but at Phase I time (i.e., April). Prior to stocking, shoal bass were acclimated to the temperature of the river. In 2003, fish were stocked below Morgan Falls Dam and at Johnson Ferry (~ 8 km downstream). In 2004-2007, fish were stocked below Morgan Falls Dam, Cochran Shoals (~ 10 km downstream), and Paces Mills (~ 14 km downstream).

It has yet to be determined if stocking these fish has accomplished the goals of this program. Due to their recent description and restricted distribution, few studies have investigated supplemental stocking of shoal bass. In the Flint River, Georgia below Warwick Dam, shoal bass stocked as Phase-I fingerlings resulted in high contributions to year class strength (T. Ingram, GADNR, personal communication). However, reintroductions of larger shoal bass (178-241 mm TL) into several Alabama tributaries were mostly unsuccessful (Sammons and Maceina 2009).

Size at stocking can affect the success of fish reintroduction efforts. Stocking larger juveniles mimics an early spawning event, possibly conferring a competitive advantage over smaller individuals. In theory, larger juveniles have a substantial length advantage over smaller juveniles, making them less vulnerable to predators, and allowing them to transition to piscivory earlier, ultimately leading to higher survival to adulthood (Goodgame and Miranda 1993; Ludsin and DeVries 1997). Therefore, contribution to the year class may be higher when larger juvenile fish are stocked (Loska 1982). However, rearing larger fish is expensive because it requires more hatchery space, longer periods spent in hatchery ponds, increased hatchery personnel effort, and higher mortality due to cannibalism (Colvin et al. 2008). Smaller fish, though, can be raised in greater numbers at less expense, so that if few survive, the resultant addition to the adult populations may be equal to stocking fewer, more expensive, larger fish.

Environmental factors may also influence stocking success. Temperature is an important environmental variable affecting fish reproduction, incubation, metabolism, swimming, feeding, and growth (Coutant 1975; Venables et al. 1978). Water temperatures in the upper Chattahoochee River remain unnaturally cold due to hypolimnetic release from Buford Dam, resulting in a marginal thermal habitat for warmwater fish species (Georgia Power 2006). Furthermore, variable river flows due to peaking operations from upstream Buford dam (Georgia Power 2006) are also common in the upper Chattahoochee River and can affect fish growth (Paragamian and Wiley 1987) and year class strength (Crecco and Savoy 1984; Lukas and Orth 1995; Bonvechio and Allen 2005).

The goal of this study was to evaluate the relative success of the shoal bass stocking program in the upper Chattahoochee River. My objectives to meet this goal were to determine the proportion of adult fish that were marked with OTC and summarize various aspects of their population characteristics (e.g. relative abundance, growth, and mortality). Furthermore, I determined how size at stocking, water temperature and river discharge affected the recruitment of stocked juvenile shoal bass to the adult population.

Study Site

The study area was located in the NPS Chattahoochee River National Recreation Area (CRNRA). The CRNRA manages several land units bordering the Chattahoochee River downstream of Morgan Falls Dam, including Cochran Shoals and Paces Mill (Figure 1). The Chattahoochee River below Morgan Falls Dam is unnaturally cold due to the release of hypolimnetic water from upstream Buford Dam, but exhibits a longitudinal gradient in water temperature, being colder immediately downstream of Morgan Falls Dam and warming through the downstream reaches (Figure 2). Despite this warming trend in the river, the water temperature regime in this reach of river remains marginal for warmwater black basses.

Methods

To determine the contribution of stocked fish to the adult population, adult shoal bass were collected from the river using boat-mounted DC electrofishing gear during GADNR standardized black bass sampling (30-minutes of effort) during 2007-2011 at three locations (Morgan Falls Dam, Cochran Shoals, and Paces Mill; Figure 1). Fish were measured (mm total length, TL). Otoliths (sagittae) were removed (except in 2009), embedded in epoxy, sectioned with a Buehler® low-speed Isomet saw, and sanded with 600-grit sandpaper. Shoal bass ages were estimated from otoliths, chosen and viewed at random three different times, by a single reader. The median age among the three estimates was considered the age of the fish. These ages, combined with OTC mark presence, were used to evaluate year-class strength of stocked fish. The presence of an OTC mark on the otoliths (0 marks [wild fish], 1 mark [Phase-I stocking; Figure 3], or 2 marks [Phase-II stocking; Figure 4]) was determined using an epifluorescent compound microscope (Motic BA400T-FL, Motic Incorporation LTD, Hong Kong) equipped with a 100-W ultraviolet (Hg arc) light source and fluorescent filter (495 dichroic mirror, 470 excitation filter, and 515-nm IF barrier filter).

Percent contribution of each stocked year class (2003-2007) and size-at-stocking (Phase-I and Phase-II) was calculated as the ratio of stocked to wild fish. An examination of 20 known marked and 20 unmarked shoal bass otoliths found OTC detection rate was 95%, which was used to adjust calculations of stocked fish contribution. Total mortality for each cohort of stocked shoal bass (2003-2008 including Phase-I and Phase-II stockings) was estimated by regressing $\log_{10}$-abundance on year where more than five fish per cohort over at least three sampling years existed. Length-at-age of shoal bass collected during GADNR standardized sampling was calculated separately for stocked and wild fish. I pooled fish of similar age among sampling years; $\log_{10}$ transformed age and length and tested for differences in regression slopes (i.e., growth) between stocked and wild fish with analysis of covariance (ANCOVA). I included only age groups that were represented in both wild and stocked fish.

Recruitment of shoal bass to the adult population in relation to stocking size and environmental variation was modeled using multiple stepwise regression. Shoal bass abundance at age-3 from GADNR standardized sampling conducted during 2007-2011 was the dependent variable in the model and was pooled among sampling sites each year. Age-3 fish were considered the minimum age fully susceptible to capture with boat electrofishing during GADNR sampling and had the potential to have resulted from stocking (e.g., juveniles stocked in 2004 would be three years old in 2007 and those stocked in 2007 would be three years old in 2010). In order to include abundance of age-3 fish captured in 2009, when otoliths were not taken for age estimation, I compared mean lengths of age-3 fish among sampling years with ANOVA, which was not significant ($F_{1,26}=0.35$, $P=0.56$), and then used an age-length key to assign ages to these fish based on length. Age-3 fish stocked as Phase I and Phase II size in 2004 and 2005 were considered independent cohorts. Abundance of age-3 fish was $\log_{10}$ transformed to normalize the data for inclusion in the model. Size at stocking and environmental variables of water temperature and river discharge during spring, summer, fall, and winter were considered for inclusion in the stepwise regression model as independent variables. Daily mean water temperature was obtained from GADNR and the United States Geological Survey (USGS) stream gage below Morgan Falls Dam. Mean daily river discharge (m^3/s) was obtained from the USGS stream gage below Morgan Falls Dam. Mean water temperature and discharge were summarized for each of the following time periods: spring (date of stocking – 21 June), summer (22 June – 21 September), fall (22 September – 21 December), and winter (22 December – 21 March). Multicolinearity was assessed using correlation analysis to ensure no variables with correlation coefficients > 0.80 were included in the model. The final regression model was considered significant at $P < 0.10$ due to low power associated with small sample size (n = 6 stocking events), and I wanted to discover potential relationships.

Results

During the five-year shoal bass stocking project, a total of 210,474 fingerlings were stocked into the Chattahoochee River below Morgan Falls Dam (Table 1). The number of fish stocked varied annually, from > 70,000 in 2005 to > 6,000 in 2006. In 2006, rapid growth combined with high rates of cannibalism in hatchery ponds resulted in a drastic reduction in the number of fish raised, and an increase in mean size. As a result, these fish were stocked at Phase-II size, but at Phase-I time. Otherwise, the size of fingerlings ranged from 23-30 mm TL for Phase-I fish and from 55-68 mm TL for Phase-II fish.

A total of 155 adult shoal bass were collected during GADNR standardized sampling in spring from 2007 to 2011, and comprised 12 year classes. Of these fish, 62 were wild (40%) and 93 were stocked (60%) (Figure 5). Shoal bass from the 2002 year class dominated (16.8%) the wild fish portion of the total sample, followed by 2001 (12.3%) and 2008 (5.2%). All other wild cohorts combined made up <6% of the total adult shoal bass sample. Stocked fish were dominated by the 2004 year class (37.4%), followed by 2006 (11.6%), 2005 (5.8), 2007 (4.5%) and 2003 (0.7%).

In 2004 and 2005, when shoal bass were stocked at two sizes (Phase-I and Phase-II fingerlings), those stocked at the larger size dominated the stocked sample of the total adult population (63%). Additionally, the 2006 stocked cohort, which quickly grew to Phase-II fingerling size because of cannibalism in the hatchery, contributed 19% to the stocked adult shoal bass sample. In total, shoal bass stocked as Phase-II fingerlings comprised 83% of the stocked shoal bass in the adult population (Figure 6).

Estimated ages of shoal bass ranged from 0 – 14 years. Analysis of covariance revealed no significant difference in log10 (mean TL) at log10 (age) regression slopes between wild and stocked shoal bass in the Chattahoochee River below Morgan Falls Dam ($F_{1,121}=1.84$, $P>0.05$; Figure 7). Only the 2004 cohort of shoal bass contained sufficient number of fish to calculate total mortality, which was estimated at 20% (Figure 8).

Mean flow was highly correlated with mean river temperature for all seasons ($r > 0.80$; $P < 0.05$). In the upper Chattahoochee River, river discharge is largely controlled by Buford Dam, whose hypolimnetic releases decrease water temperature. As a result, only seasonal water temperatures were included in the model. The multiple regression model for shoal bass indicated that age-3 abundance was positively related to mean length at stocking and mean spring water temperature ($F_{2,3}$= 20.78, $r^2 = 0.93$, $P < 0.10$; Figure 10). Mean length at stocking explained most of the variation in the model ($F_{1,4}$= 9.24, $r^2 = 0.70$).

Discussion

Unlike previous supplemental black bass stocking events, which often contributed very little to year class strength of wild populations (Funk and Fleener 1974; Boxrucker 1986; Buynak and Mitchell 1999; Hoffman and Bettoli 2005; Heitman et al. 2006; Diana and Wahl 2009; Sammons and Maceina 2009), contribution of stocked shoal bass to the adult population in the Chattahoochee River, Georgia below Morgan Falls Dam was high; stocked fish comprised 100% of their year class for each year during stocking. These stocking contributions are considerably higher than those found in other shoal bass stocking programs. In the Flint River, Georgia, annual stocking contribution from 1999-2009 ranged from 3-50% (GADNR unpublished data). In four tributaries to the Chattahoochee River in Alabama, 6.7% of stocked shoal bass comprised the adult black bass population (Sammons and Maceina 2009). Based on my results, it appears that the low mortality of the shoal bass population in the upper Chattahoochee River coupled with the larger juvenile size at stocking contributed the most to the success of this program.

Results based on multiple-regression modeling suggest that shoal bass recruitment to age-3 was related more to size-at-stocking than exogenous factors such as water temperature, although the causal mechanism is unknown. Stocking larger fish has led to increased recruitment in other freshwater fish species including largemouth bass *Micropterus salmoides* (Loska 1982; Buynak and Mitchell 1999; Mesing et al. 2008), muskellunge *Esox masquinongy* (Szendrey and Wahl 1996), and walleye *Sander vitreus* (Santucci and Wahl 1993; Brooks et al. 2002). Larger stocked fish have a larger gape size that allows them to transition immediately to piscivory or target a wider range of prey sizes, whereas smaller fish may continue to feed on aquatic invertebrates instead of transitioning to larger prey items (Mesing et al. 2008). Juvenile bass that transition to piscivory earlier tend to experience higher survival to adulthood (Goodgame and Miranda 1993; Ludsin and DeVries 1997). Furthermore, larger fish may avoid predation and consequently have higher survivorship rates because they exceed predator gape limits (Santucci and Wahl 1993; Szendrey and Wahl 1996).

The role of water temperature also probably affected juvenile shoal bass recruitment. Temperature-mediated growth during the first year is an important factor determining recruitment of age-0 fish to the adult population for many species (Horning and Pearson 1973; Venables et al. 1978; Coutant and DeAngelis 1983; Sabo and Orth 1995; Tidwell et al. 2003). Although no one has studied the temperature required for optimizing growth of shoal bass, related largemouth bass and smallmouth bass *Micropterus dolomieu* achieve optimal growth between 25 and 27 ˚C (Horning and Pearson 1973; Coutant and DeAngelis 1983). Average water temperature in the Chattahoochee River below Morgan Falls Dam during spring rarely exceeded 20˚C during the five-year stocking period. The smaller fish (~25 mm TL) that were stocked in these colder habitats were less successful at recruiting to adulthood than the larger fish

(~60 mm TL), but the mechanism responsible is unclear because the larger fish were also stocked later in the spring when water conditions were relatively warmer.

Stocking fish later in the spring not only affects the available water temperature, but also the availability of prey resources. The match-mismatch theory indicates successful recruitment is a function of the timing and duration of prey abundance and availability to juvenile fish (Kristiansen et al. 2011). Because the Chattahoochee River has a depressed thermal regime, the timing of prey availability may be later compared to other warmwater rivers of the area and stocking fish later in the spring could provide greater resources than those available to early-stocked fish, increasing their survival (Neal et al. 2002; Mesing et al 2008). During May stockings, water temperature was approximately 15^oC whereas June temperatures had warmed to 21^oC, which is closer to temperatures associated with spawning of warmwater fish species (Carlander 1977), presumably producing available prey resources for stocked juvenile shoal bass.

Alternatively, difference in temperature of rearing ponds and stocking locations may have played a role apart from actual temperature, causing additional stress and higher mortality (Diana and Wahl 2009). Fish stocked into the Chattahoochee River were raised in warm hatchery ponds and stocked into an unnaturally cold river environment. On the day of the first stocking in early May, the difference in water temperature between the hatchery pond temperature and river temperature was ~8^oC (23^oC and 15^oC, for the hatchery pond and river, respectively). Conversely, on the day of the second stocking in June, the disparity in water temperature between hatchery pond and river were less extreme, differing by ~3^oC (24^oC and 21^oC, for the hatchery pond and river, respectively). How temperature-mediated stress might affect stocking success should be further studied.

The depressed water temperature regime below Morgan Falls Dam also likely led to increased longevity, but slow growth of shoal bass in the upper Chattahoochee River. Natural mortality estimates of the shoal bass population below Morgan Falls Dam were low (20%) with high longevity (14 years), which resemble estimates of northern bass populations that experience colder water temperatures (Beamesderfer and North 1995). I am aware of no other study that has estimated shoal bass mortality for comparison, but the longevity of shoal bass in this reach of the Chattahoochee River (14 years) far exceeded the previous maximum age of eight years found in a lower Chattahoochee River tributary in Alabama (Wright 1967; Williams and Burgess 1999). Moreover, the growth rate of fish in the upper Chattahoochee River below Morgan Falls Dam was much lower than has been observed for other shoal bass populations. Sammons and Maceina (Auburn University, unpublished data) found that age-2 shoal bass in the Ocmulgee and Flint rivers, Georgia, averaged 259 and 284 mm TL, respectively. In the Chattahoochee River, age-2 shoal bass averaged 151 and 187 mm TL for wild and stocked fish, respectively. In the Chipola River, Florida, age-5 shoal bass were 384 mm (Parsons and Crittenden 1959), which is considerably larger than 5-year old shoal bass in the Chattahoochee River below Morgan Falls Dam at 262 and 264 mm TL for wild and stocked fish, respectively.

The impetus for stocking shoal bass was to re-establish this native species in an area where they were largely extirpated and this program achieved that goal. However, I found that wild fish were sometimes abundant in the samples collected by GADNR from

2007-2011, confirming the results of previous shoal bass surveys conducted in this reach (Georgia Power 2006; Dakin et al. 2007). Shoal bass surveys during the 1970's and 1980's indicated a very low abundance of shoal bass in the Chattahoochee River below Morgan Falls Dam (Long and Martin 2008). It is unknown whether these wild fish were spawned in the river, or immigrated from downstream areas where conditions were more conducive to spawning. Interestingly, no wild shoal bass cohorts were produced during the years when shoal bass were stocked (2003-2007), although wild cohorts were represented prior to (1999-2002) and following (2008-2009) the stocking program. How artificial reproduction of shoal bass (i.e., stocking) might affect natural reproduction in the Chattahoochee River below Morgan Falls Dam is unknown and in need of study.

Overall, stocking efforts were successful in increasing shoal bass abundance below Morgan Falls Dam. These results suggest that future shoal bass stocking efforts in the upper Chattahoochee River, Georgia would be most effective when larger fish could be stocked in areas or times when water temperatures are warmer. However, because wild cohorts had been observed, research related to factors affecting wild cohort formation would be useful.

REFERENCES

Beamesderfer, R. C. P., and J.A. North. 1995. Growth, natural mortality, and predicted response to fishing for largemouth bass and smallmouth bass populations in North America. North American Journal of Fisheries Management 15:688-704.

Bonvechio, T. F., and M.S. Allen. 2005. Relations between hydrological variables and year-class strength of sportfish in eight Florida waterbodies. Hydrobiologia 532:193-207.

Boxrucker, J. 1986. Evaluation of supplemental stocking of largemouth bass as a management tool in small impoundments. North American Journal of Fisheries Management 6:391-396.

Brooks, R. C., R. C. Heidinger, R. J. H. Hoxmeier, and D. H. Wahl. 2002. Relative survival of three sizes of walleyes stocked into Illinois lakes. North American Journal of Fisheries Management 22: 995-1006.

Buynak, G.L., and B. Mitchell. 1999. Contribution of stocked advanced-fingerling largemouth bass to the population and fishery at Taylorsville Lake, Kentucky. North American Journal of Fisheries Management 19:494-503.

Carlander, K.D. 1977. Handbook of freshwater fishery biology. Volume 2. Iowa State University Press, Ames. 431 pp.

Colvin, N.E., C.L. Racey, and S.E. Lochman. 2008. Stocking contribution and growth of largemouth bass stocked at 50 and 100 mm into backwaters of the Arkansas River. North American Journal of Fisheries Management 28:434-441.

Coutant, C. C. 1975. Responses of bass to natural and artificial temperature regimes. Pages 272–285 in H. Clepper, editor. Black bass biology and management. Sportfishing Institute, Washington, D.C.

Coutant, C.C. and D.L. DeAngelis. 1983. Comparative temperature-dependent growth rates of largemouth and smallmouth bass fry. Transactions of the American Fisheries Society 112:416-423.

Crecco, V. A. and T. F. Savoy. 1984. Effects of fluctuations in hydrographic conditions on year-class strength of American shad (Alosa sapidissima) in the Connecticut River. Canadian Journal of Fisheries and Aquatic Science 41: 1216-1223.

Dakin, E.E., B.A. Porter, B.J. Freeman, and J.M. Long. 2007. Genetic integrity of an isolated population of shoal bass (Micropterus cataractate) in the Upper Chattahoochee River basin. National Park Service, Natural Resource Report NPS/NRWRD/NRTR-2007/366, Ft. Collins, Colorado.

Diana, M.J., and D.H. Wahl. 2009. Growth and survival of four sizes of stocked largemouth bass. North American Journal of Fisheries Management 29:1653-1663.

Funk, J.L. and G.C. Fleener. 1974. The fishery of a Missouri Ozark stream, Big Piney River, and the effects of stocking fingerling smallmouth bass. Transactions of the American Fisheries Society 103:757-771.

Georgia Power and GeoSyntec Consultants. 2006. Morgan Falls Hydro, FERC Project No. 2237. Fisheries and aquatic resources. Resource Study Report to Federal Energy Regulatory Commission, Washington, D.C.

Gilbert, C. R. 1992. Rare and endangered biota of Florida. Vol. 11**:** Fishes. University Press of Florida, Gainesville.

Goodgame, L.S. and L.E. Miranda. 1993. Early growth and survival of age-0 largemouth bass in relation to parental size and swim-up time. Transactions of the American Fisheries Society 122:131-138.

Heitman, N.E., C.L. Racey, and S.E. Lochman. 2006. Stocking contribution and growth of largemouth bass in pools of the Arkansas River. North American Journal of Fisheries Management 26:175-179.

Hoffman, K.J. and P.W. Bettoli. 2005. Growth, dispersal, mortality, and contribution of largemouth bass stocked into Chickimauga Lake, Tennessee. North American Journal of Fisheries Management 25:1518-1527.

Horning, W. B., II, and R. E. Pearson. 1973. Growth temperature requirements and lower lethal temperatures for juvenile smallmouth bass (*Micropterus dolomieui*). Journal of the Fisheries Research Board of Canada 30:1226-1230.

Hurst, H.N. 1969. Comparative life history of the redeye bass, *Micropterus coosae* Hubbs and Bailey, and the spotted bass *Micropterus p. punctulatus* (Rafinesque), in Halawakee Creek, Alabama. Master's thesis. Auburn University, Auburn, Alabama. 56 pp.

Jelks, H.L., S.J. Walsh, N.M. Burkhead, S.Contreras-Balderas, E. Díaz-Pardo, D.A. Hendrickson, J.Lyons, N.E. Mandrak, F. McCormick, J.S. Nelson, S.P. Platania, B.A. Porter, C.B. Renaud, J. J. Schmitter-Soto, E.B. Taylor, and M.L. Warren, Jr. 2008. Conservation status of imperiled North American freshwater and diadromous fishes. Fisheries 33(8):372-407.

Kristiansen, T., K.F. Drinkwater, R.G. Lough, and S. Sundby. 2011. Recruitment variability in north Atlantic cod and match-mismatch dynamics. PLos ONE 6(3):e17456. doi:10.1371/journal.pone.0017456.

Long, J.M. and C. Martin. 2008. The evolution of fisheries management of the upper Chattahoochee River in response to changing water management. Pages 21-36, *In* M.S. Allen, S. Sammons, and M.J. Maceina, editors. Balancing fisheries management and water uses for impounded river systems. American Fisheries Society. Symposium 62. Bethesda, Maryland. 697 pp.

Loska, P. M. 1982. A literature review on the stocking of black basses (*Micropterus* spp.) in reservoirs and streams. Georgia Department of Natural Resources, Game and Fish Division, Atlanta.

Lukas, J.A. and D.J. Orth. 1995. Factors affecting nesting success of smallmouth bass in a regulated Virginia stream. Transactions of the American Fisheries Society 124:726-735.

Ludsin, S. A., and D. R. DeVries. 1997. First-year recruitment of largemouth bass: the inter-dependency of early life stages. Ecological Applications 7:1024–1038.

Mesing, C. L., R. L. Cailteux, P. A. Strickland, E. A. Long, and M. W. Rogers. 2008. Stocking of advanced fingerling largemouth bass to supplement year-classes in Lake Talquin, Florida. North American Journal of Fisheries Management 28:1762–1774.

Neal, J. W., R. L. Noble, and T. N. Churchill. 2002. Timing of largemouth bass supplemental stocking in a tropical reservoir: impacts on growth and survival. Pages 691–701 *in* D.P. Phillip and M. S. Ridgway, editors. Black bass: ecology, conservation, and management. American Fisheries Society, Symposium 31, Bethesda, Maryland.

Nestler, J.M., J. Fritschen, R.T. Milhous, and J. Troxel. 1986. Effects of flow alterations on trout angling and recreation in the Chattahoochee River between Ruford Dam and Peachtree Creek. Final report to the Department of the Army, United State Army Corps of Engineers, Washington D.C.

Paragamian, V.L., and M.J. Wiley. 1987. Effects of Variable Streamflows on Growth of Smallmouth Bass in the Maquoketa River, Iowa. North American Journal of Fisheries Management 7:357-362.

Parsons, J.W., and E. Crittenden. 1959. Growth of the redeye bass in the Chipola River, Florida. Transactions of the American Fisheries Society 88:191-192.

Ramsey, J.S. and R.O. Smitherman. 1972. Development of color pattern in pond-reared young of five *Micropterus* species of southeastern U.S. Proceedings of the Annual Conference of the Southeastern Association of Game and Fish Commissioners 24:348-356.

Runge, J.P., J.T. Peterson, and C.R. Martin. 2008. Survival and dispersal of hatchery-raised rainbow trout in a river basin undergoing urbanization. North American Journal of Fisheries Management 28:745-757.

Sammons, S.M., and M.J. Maceina. 2009. Conservation status of shoal bass in Alabama: distribution, abundance, stocking efficacy, and possible effects of sympatric congeneric black bass in selected tributaries of the Chattahoochee River, Alabama. Final Report submitted to Alabama Division of Wildlife and Freshwater Fisheries. 93 pp.

Santucci, V. J. and D. H. Wahl. 1993. Factors influencing survival and growth of stocked walleye (*Stizostedion vitreum*) in a centrarchid-dominated impoundment. Canadian Journal of Fisheries and Aquatic Sciences 50: 1548-1558.

Stormer, D.G., and M.J. Maceina. 2009. Habitat use, home range, and movement of shoal bass in Alabama. North American Journal of Fisheries Management 29:604-613.

Szendrey, T. A., and D. H. Wahl. 1996. Size-specific survival and growth of stocked muskellunge: effects of predation and prey availability. North American Journal of Fisheries Management 16:395–402.

Tidwell, J. H., S. D. Coyle, L. A. Bright, A. VanArnum, and D. Yasharian. 2003. Effect of water temperature on growth, survival, and biochemical composition of largemouth bass *Micropterus salmoides*. Journal of the World Aquaculture Society 34:175–183.

Venables, B. J., W. D. Pearson, and L. C. Fitzpatrick. 1977. Thermal and metabolic relations of largemouth bass, Micropterus salmoides, from a heated reservoir and a hatchery in north central Texas. Comparative Biochemical Physiology 57A:93-98.

Wheeler, A.P. and M.S. Allen. 2003. Habitat and diet partitioning between shoal bass and largemouth bass in the Chipola River, Florida. Transactions of the American Fisheries Society 132:438-449.

Williams, J. D., and G. H. Burgess. 1999. A new species of bass, *Micropterus cataractae* (Teleostei: Centrarchidae), from the Apalachicola River basin in Alabama, Florida, and Georgia. Bulletin of the Florida Museum of Natural History 42(2):80–114.

Wright, S.E., IV. 1967. Life history and taxonomy of the Flint River redeye bass (*Micropterus coosae*, Hubbs and Bailey). M.S. thesis, University of Georgia, Athens. 51 pp.

Table 1: Number of shoal bass stocked, stocking date, and mean total length of fish stocked below Morgan Falls Dam in the Chattahoochee River, Georgia during the five year GADNR/NPS shoal bass stocking program (2003-2007).

Cohort	Date of stocking	Number stocked	Mean total length at stocking (mm)
2003	April 29	57,632	25.0
2004a	May 4	30,834	30.3
2004b	June 9	10,122	68.2
2005a	May 9	61,166	28.9
2005b	June 14	9,460	63.2
2006	May 8	6,723	55.6
2007	April 26	34,237	23.7
Total		210,747	

Table 2: Dependent and independent variables used in the multiple stepwise regression model relating age-3 shoal bass abundance to several environmental variables. Lstock=mean length of fish stocked (mm), SpTemp=mean spring temperature following stocking in each year, SuTemp=mean summer temperature, FaTemp=mean fall temperature, WiTemp=mean winter temperature. Letters following cohort year represent size at stocking (a= Phase I fingerlings [~25 mm TL], b=Phase II fingerlings [~60 mm TL]). Age-3 abundance was Log_{10} transformed prior to inclusion in the model.

	Dependent Variable	Independent Variables				
Cohort	Log_{10}(age-3 abundance)	Lstock (mm)	SpTemp	SuTemp	FaTemp	WiTemp
2003	0	25	15.7	17.3	14.1	9.0
2004a	2.8	30	19.2	17.9	13.4	9.7
2004b	32.0	68	20.4	17.9	13.4	9.7
2005a	0	28.9	16.5	17.8	14.3	9.8
2005b	6.0	63.2	15.5	17.8	14.3	9.8
2006	4.5	55.6	16.5	19.6	13.3	9.5
2007	1.5	23.7	17.7	18.3	13.6	9.5

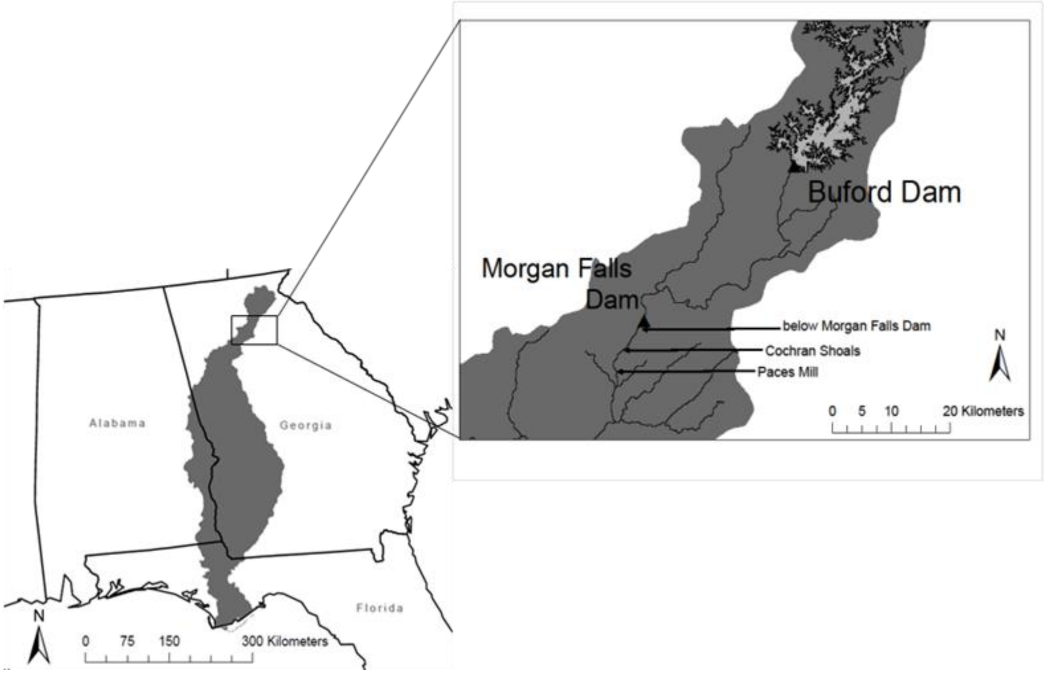

Figure 1: Map of Apalachicola River basin and the upper Chattahoochee River noting the three locations where juvenile shoal bass were stocked as part of a restoration program that occurred from 2003 to 2007.

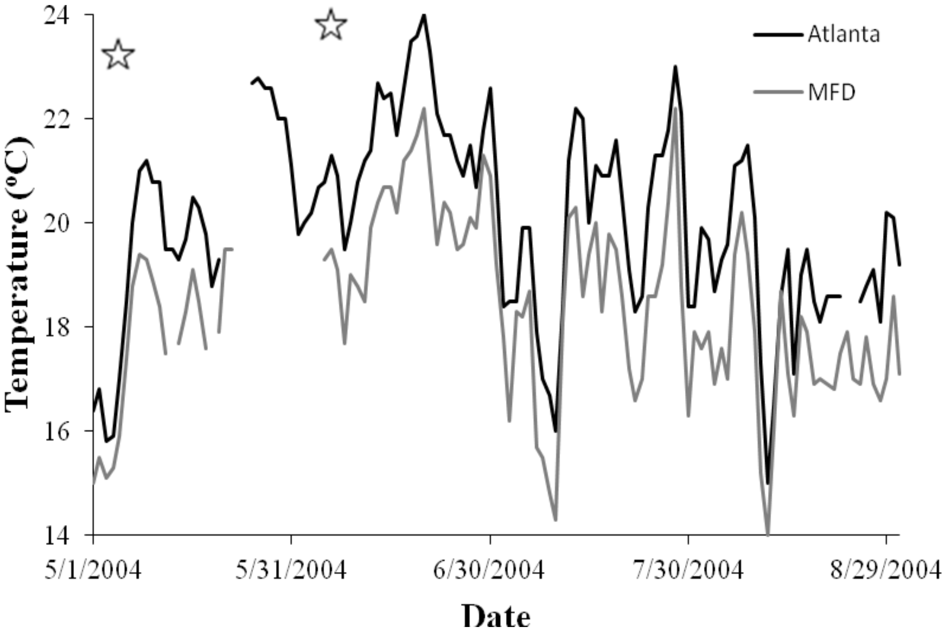

Figure 2: Longitudinal gradients in temperature present in the Chattahoochee River, Georgia downstream of Morgan Falls Dam (MFD). The Atlanta stream gage is located approximately 1.6 km downstream of MFD. Stars indicate the hatchery water temperature on the day of stocking.

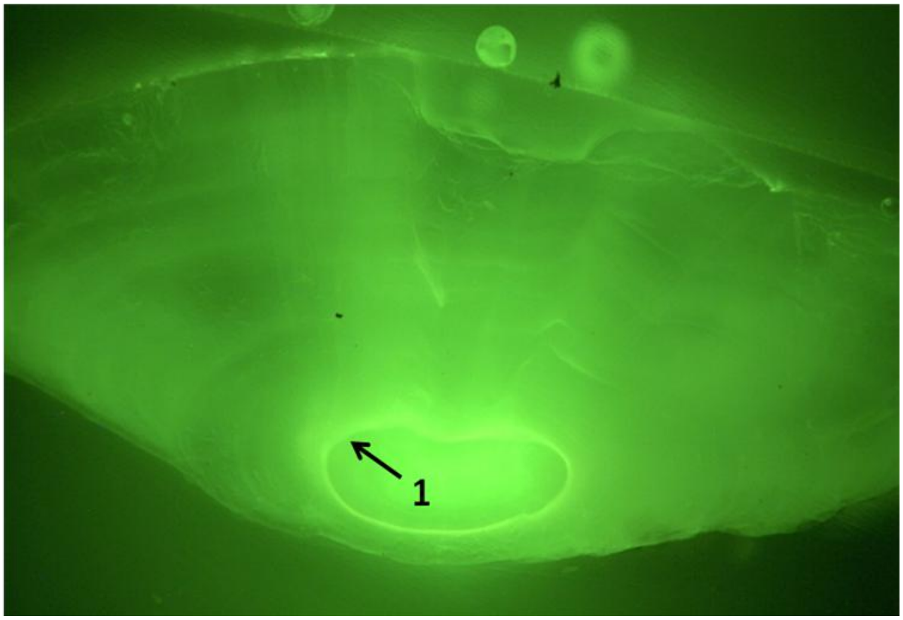

Figure 3. A shoal bass otolith under fluorescent light showing one oxytetracycline (OTC) mark, which represents a fish stocked in the Chattahoochee River, Georgia during early spring at Phase I fingerling size (~25 mm TL).

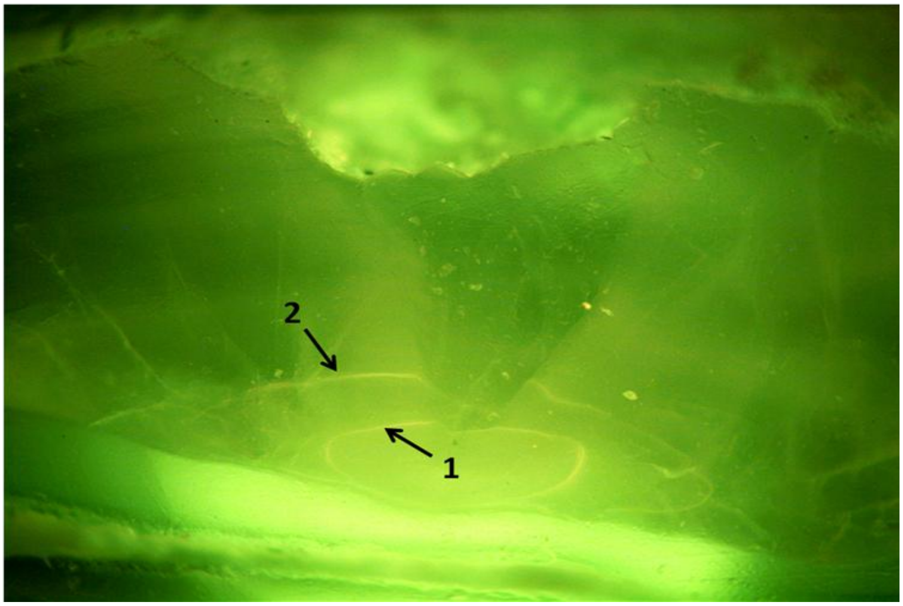

Figure 4: A shoal bass otolith under fluorescent light showing two oxytetracycline (OTC) marks, which represent a fish stocked in the Chattahoochee River, Georgia during late spring at Phase II fingerling size (~60 mm TL).

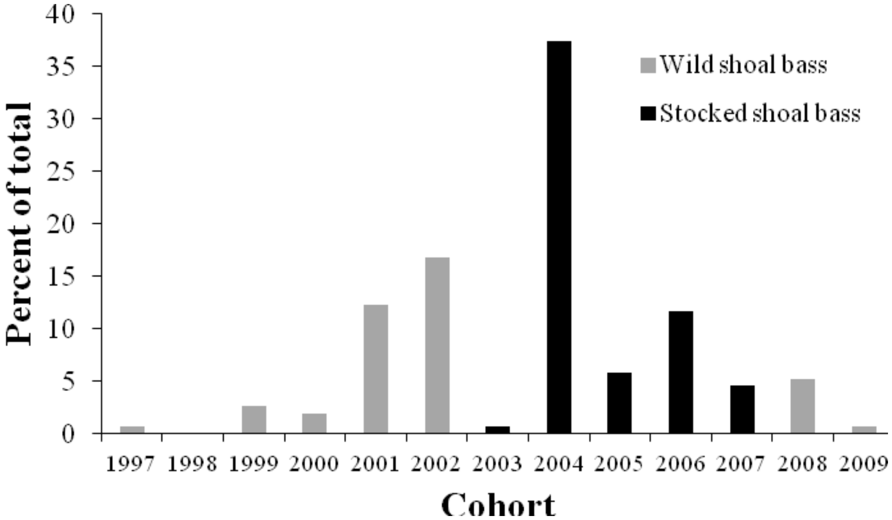

Figure 5: Percent contribution of 12 shoal bass cohorts collected from the Chattahoochee River, Georgia (2007-2011) during Georgia Department of Natural Resources standardized sampling.

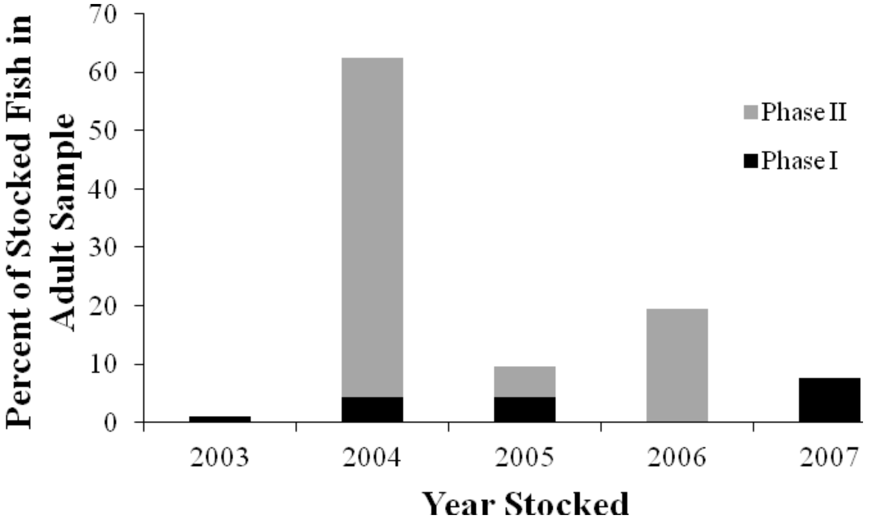

Figure 6: Percent contribution for the stocked portion of the adult sample during the five year stocking program (2003-2007) that were collected from the Chattahoochee River, Georgia during spring Georgia Department of Natural Resources standardized sampling.

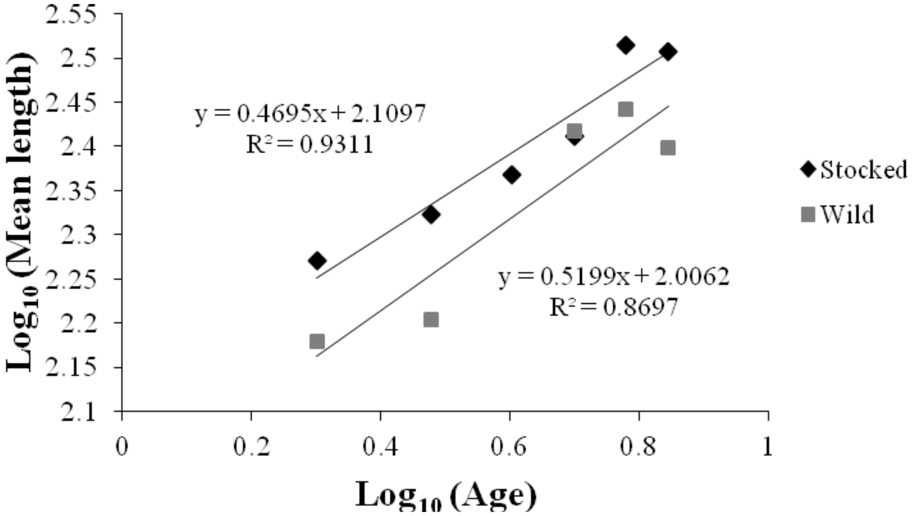

Figure 7: Comparison of mean total lengths of stocked and wild adult shoal bass collected from the Chattahoochee River, Georgia, in 2007, 2008, 2010, and 2011 during spring Georgia Department of Natural Resources standardized sampling.

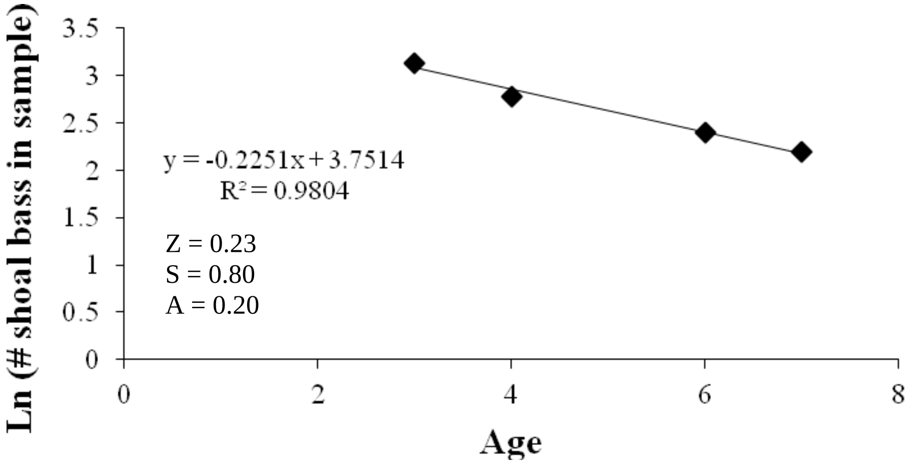

Figure 8. Catch curve for the 2004 stocked cohort from the Chattahoochee River, Georgia, in 2007, 2008, 2010, and 2011 during spring Georgia Department of Natural Resources standardized sampling.

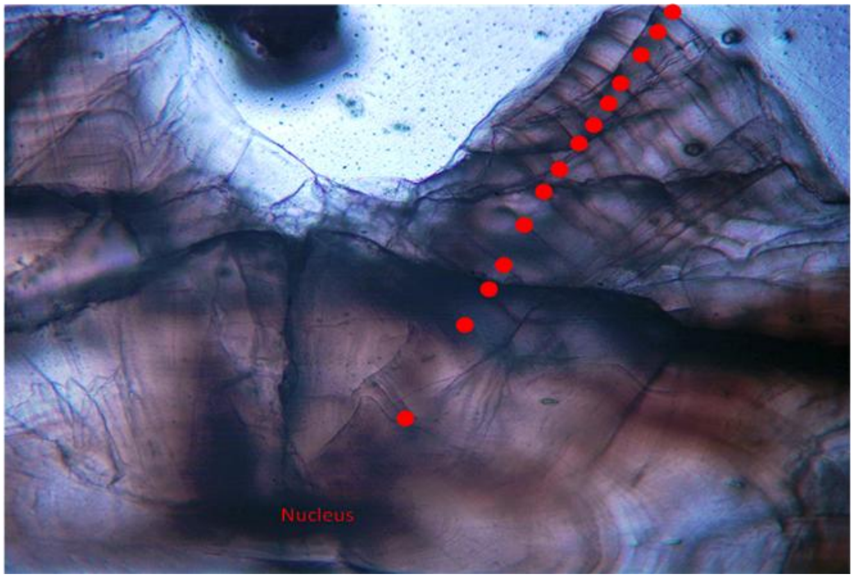

Figure 9: Sectioned shoal bass otolith estimated at 14 years old collected from the Chattahoochee River, Georgia, in 2011 during spring Georgia Department of Natural Resources standardized black bass sampling. Solid circles mark each annuli.

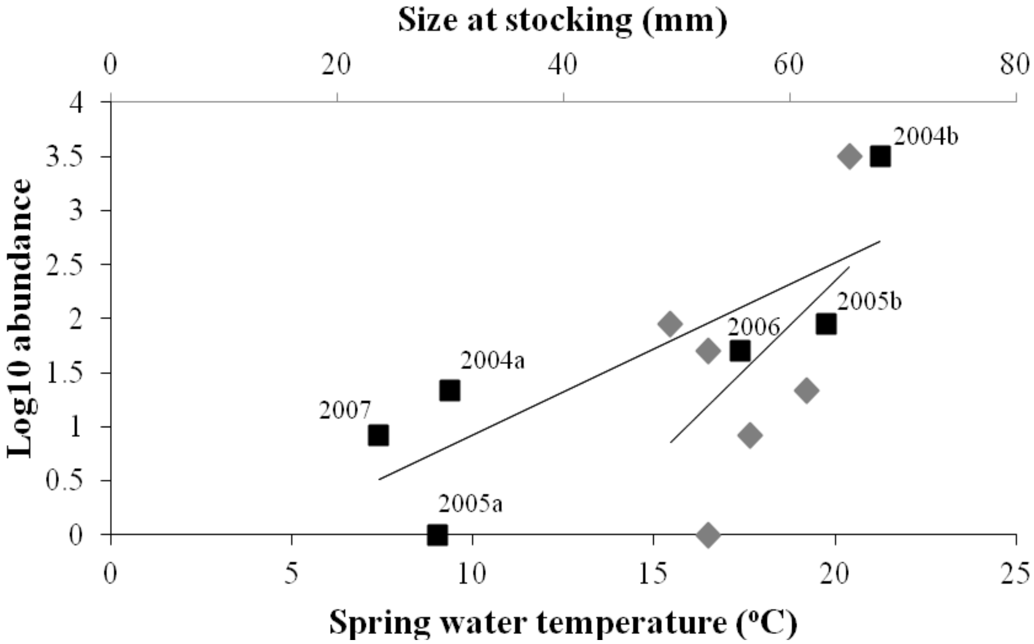

Figure 10: Shoal bass age-3 abundance related to both spring water temperature (r^2=0.23; gray diamonds) and size at stocking (r^2=0.70; black squares). Estimates predicted from a stepwise multiple regression model ($\log_{10}$age-3 abundance = -6.262 + 0.055_{Lstock} + 0.306_{SpTemp}).

Appendix 1. Size, age, and stocking cohort (based on number of OTC marks) for shoal bass captured during standardized electrofishing by the Georgia Department of Natural Resources on the Chattahoochee River, Georgia.

Year	Fish ID	Total length (mm)	Age	Number of OTC marks
2007	2	260	5	0
2007	3	260	5	0
2007	7	250	5	0
2007	8	270	3	2
2007	11	265	5	0
2007	12	240	3	2
2007	14	280	5	0
2007	15	220	3	2
2007	16	200	3	2
2007	17	195	3	2
2007	18	225	3	2
2007	19	220	3	2
2007	20	210	3	2
2007	21	270	5	0
2007	22	210	3	2
2007	23	210	3	2
2007	25	180	2	1
2007	26	230	3	2
2007	27	400	8	0
2007	28	350	6	0
2007	29	330	8	0
2007	30	215	3	2
2007	31	240	5	0
2007	32	200	3	2
2007	33	230	3	2
2007	34	130	1	1
2007	35	170	3	1
2007	36	280	5	0
2007	37	295	6	0
2007	38	160	1	1
2007	40	295	5	0
2007	41	300	5	0
2007	42	205	3	2
2007	43	240	7	0
2007	44	175	3	1
2007	45	230	5	0
2007	46	290	6	0
2007	47	250	5	0

2007	48	235	3	2
2007	49	240	5	0
2007	50	120	1	1
2007	51	190	3	2
2007	52	190	2	1
2007	53	175	3	2
2007	54	230	3	2
2007	55	195	3	2
2007	57	250	5	0
2007	58	255	5	0
2007	59	200	3	2
2008	3	242	4	2
2008	4	274	6	0
2008	5	244	4	2
2008	6	197	2	1
2008	8	207	3	2
2008	10	229	4	2
2008	11	206	3	2
2008	12	247	4	2
2008	13	243	6	0
2008	14	268	4	2
2008	15	221	3	2
2008	17	185	2	1
2008	18	292	9	0
2008	19	115	1	1
2008	20	240	4	2
2008	21	232	6	0
2008	24	260	7	0
2008	25	252	7	0
2008	26	234	4	2
2008	27	221	4	2
2008	28	226	8	0
2008	29	251	4	2
2008	30	195	4	1
2008	31	229	3	2
2008	32	237	4	2
2008	33	232	4	2
2008	34	161	2	1
2008	35	213	4	2
2008	36	253	6	0
2008	37	221	4	2
2008	38	226	4	2
2008	39	222	4	2

2008	40	156	2	1
2008	41	101	1	1
2008	43	68	0	0
2009	20	201	2	1
2009	21	191	2	1
2009	22	191	2	1
2009	23	149	1	0
2009	24	126	1	0
2009	25	202	3	1
2009	26	213	2	1
2009	27	209	3	1
2009	28	208	3	1
2009	29	138	1	0
2010	C-1	341	6	1
2010	C-2	360	9	0
2010	C-3	194	3	1
2010	C-4	312	6	2
2010	C-5	381	8	0
2010	C-6	304	6	2
2010	C-7	342	6	2
2010	C-8	309	6	2
2010	C-9	330	8	0
2010	C-10	305	6	2
2010	C-11	152	2	0
2010	C2-1	312	6	2
2010	C2-2	105	1	0
2010	C2-3	316	6	2
2010	C2-4	353	8	0
2010	C2-5	384	9	0
2010	C2-6	298	6	2
2010	C2-7	320	6	2
2010	C2-8	364	9	0
2010	C2-9	352	6	2
2010	C2-10	154	2	0
2010	J-1	362	11	0
2010	J-2	179	5	1
2010	J-3	148	2	0
2010	M-1	295	9	0
2010	M-2	336	9	0
2010	M-3	249	4	1
2011	C-1	342	7	2
2011	C-2	342	10	0
2011	C-3	336	9	0

2011	C-4	295	7	1
2011	C-5	355	7	2
2011	C-6	327	7	2
2011	C-7	276	5	1
2011	C-8	275	5	1
2011	C-9	306	7	2
2011	C-10	370	10	0
2011	C-11	282	5	1
2011	C-12	322	10	0
2011	C-13	310	7	2
2011	C-14	398	10	0
2011	C-15	372	9	0
2011	C-16	379	10	0
2011	C-17	381	10	0
2011	C-18	475	6	2
2011	C-19	263	5	1
2011	C-20	366	11	0
2011	C-21	422	14	0
2011	C-22	326	7	2
2011	C-23	333	7	2
2011	C-24	385	9	0
2011	J-1	270	6	1
2011	J-2	404	10	0
2011	M-1	264	5	1
2011	M-2	394	9	0
2011	M-3	381	9	0
2011	M-4	296	7	2
2011	M-5	306	5	1
2011	M-6	368	10	0
2011	M-7	221	5	1
2011	P-1	160	3	0

CHAPTER III

POST-STOCKING RESPONSES OF JUVENILE SHOAL BASS *MICROPTERUS CATARACTAE* IN A MARGINAL TAILWATER ENVIRONMENT

Abstract

Juvenile shoal bass *Micropterus cataractae* stocked in the Morgan Falls Dam tailwater in Upper Chattahoochee River, Georgia were studied and compared to a naturally-occurring congener, largemouth bass *M. salmoides*, to assess the effects of a marginal tailwater environment on juvenile black bass age, growth and prey use. In spring 2004, Shoal bass were marked with oxytetracycline (OTC) and stocked twice (early and late) at three locations: below Morgan Falls Dam, Cochran Shoals, and Paces Mill. Juvenile bass were then sampled with backpack electrofishing twice in summer 2004 at the three stocking sites. Captured fish were measured for total length and otoliths were removed for OTC mark detection and age estimation; daily growth was then calculated. Both species of bass were longer at downstream, warmer sites (Cochran Shoals and Paces Mill) than at the upstream, coldest site (Morgan Falls Dam). Shoal bass growth in the hatchery prior to stocking was slightly less than largemouth bass growth in the river during the same time period. After stocking, shoal bass growth was reduced approximately 60%, which was visible on the otolith as a constricted daily growth increment (i.e., natural mark). Daily rings subsequent to the natural mark were constricted and difficult to discern

resulting in underestimated ages from 3 to 9 days depending on stocking location (greater underestimates occurred at colder stocking sites in the river). Both species tended to be older and grow faster at warmer, more downstream sites. In both months, diets of shoal bass and largemouth bass consisted mainly of ephemeroptera nymphs and simuliidae larvae, however, shoal bass diets were more diverse than largemouth bass, containing 22 different prey categories whereas largemouth bass only consumed 11. In August, phase-I shoal bass diets were diverse (17 items) containing mostly aquatic inverterbrates and had a lower percentage (31%) of empty stomachs, whereas phase-II shoal bass had low diversity (9 diet items), containing fewer aquatic invertebrates, and a high percentage of empty stomachs (45%). Our results demonstrate how artificially cold tailwaters could affect early life stages of some of the native warmwater species that live in those environments.

Introduction

Shoal bass *Micropterus cataractae* are fluvial specialists, preferring rocky and shoal habitat (Williams and Burgess 1999). Throughout most of their range, they have been impacted by impoundments, which have eliminated habitat, impeded movements, and altered water chemistry (Williams and Burgess 1999). Information on the early life history of shoal bass is scarce, and little information exists on the effects of environmental variation on age-0 shoal bass. Due to the release of hypolimnetic water through Buford Dam, the Chattahoochee River in the vicinity of Morgan Falls Dam impoundment and tailwater is unnaturally cold (Long and Martin 2008). However, Below Morgan Falls Dam, urbanization of Atlanta, Georgia has caused water temperatures to warm, creating a transition zone capable of supporting coldwater and warmwater species (Georgia Power 2006). In 2003, Georgia Department of Natural Resources and the National Park Service initiated a five year shoal bass stocking program at three locations below Morgan Falls Dam (Long and Martin 2008) to restore this extirpated warm water species.

Growth, and associated length, obtained during the first year is an important factor affecting recruitment of age-0 fish to the adult population (Goodgame and Miranda 1993; Ludsin and DeVries 1997). Fish able to obtain an initial size advantage during their first year often have a competitive advantage over smaller fish of the same cohort (Goodgame and Miranda 1993; Ludsin and DeVries 1997). Larger juvenile fish have a larger gape size, which allows these fish to transition immediately to piscivory or target a wider range of prey sizes, whereas smaller fish may continue to feed on aquatic invertebrates instead of transitioning to larger prey items (Mesing et al. 2008).

Furthermore, larger juveniles may avoid predation and consequently experience lower mortality rates because they exceed predator gape limits (Santucci and Wahl 1993; Szendrey and Wahl 1996). While assessing the conditions affecting recruitment of stocked shoal bass to the adult population in the Chattahoochee River (Chapter 2), I found that those fish stocked at larger sizes later in the season were more successful at recruiting to adulthood than fish stocked smaller and earlier. However, data on the dynamics of juvenile shoal bass that might explain these results are limited.

Few studies have investigated the diets of juvenile shoal bass and none have occurred in the Chattahoochee River. In the Chipola River, Florida, juvenile shoal bass consumed predominantly mayflies (Ephemeroptera; Wheeler and Allan 2003). In comparison, related largemouth bass *Micropterus salmoides* have been studied extensively and often occur in sympatry with shoal bass. Juvenile largemouth bass typically start with an invertebrate feeding stage where they eat mostly zooplankton and aquatic insects (Phillips et al. 1995; Long and Fisher 2000; Olson and Young 2003). For both of these black bass species, as body size increases, the accompanying increase in gape size allows a diet switch from invertebrates to crayfish and fish (Scalet 1977; Schramm and Maceina 1986; Phillips et al. 1995; Long and Fisher 2000; Olson and Young 2003; Wheeler and Allen 2003). This diet switch causes increased in growth rates, which can lead to higher survivorship rates (Goodgame and Miranda 1993; Sabo and Orth 1995; Ludsin and DeVries 1997).

Daily rings in fish otoliths can not only be used for calculating growth rates, which is useful for interpreting results from diet analyses, but also for estimating hatching date, which can affect juvenile fish mortality (Miller and Storck 1984; Graham and Orth

1987; Goodgame and Miranda 1993; Dicenzo and Bettoli 1995; Phillips et al. 1995). Although the timing of first-ring formation not been validated for shoal bass otoliths, Long et al. (2004) estimated spawning dates that closely corresponded to hatchery personnel's estimated spawning date, which suggests that otolith growth rings are formed daily for this species. Daily growth rings, including the timing of first-ring formation, have been validated in otoliths for other species of black bass including largemouth bass (Miller and Storck 1982; Isley and Noble 1987), smallmouth bass *M. dolomieu* (Graham and Orth 1987), and spotted bass *M. punctulatus* (DiCenzo and Bettoli 1995).

This study was undertaken using available electrofishing data on juvenile bass collected after stocking in the Chattahoochee River in 2004 to examine how introduced juvenile fish might have adapted to their environment; especially one that is marginal for warmwater fish due to coldwater releases from an upstream dam. Coincidentally, the 2004 year-class of shoal bass was most successful year class at recruiting to adulthood from the five-year stocking program (Chapter 2) and consisted of two stocking events that allow me to better understand the role of size and size-at-stocking on recruitment dynamics in this species. Moreover, juvenile largemouth bass were collected at the same time and sites, and used for comparison with age, growth rates, and diet of juvenile shoal bass because a great deal of early-life history information exists for this species. Therefore, my objectives were to: 1) estimate age and growth of a stocked cohort of juvenile shoal bass and compare with native juvenile largemouth bass, 2) determine daily growth rates of hatchery-reared shoal bass following introduction into a cold tailwater, and 3) determine shoal bass diet in its stocked environment.

Study Site

The study area is located in the NPS Chattahoochee River National Recreation Area (CRNRA) in the Atlanta, Georgia metropolitan area. The CRNRA manages several land units bordering the Chattahoochee River downstream of Morgan Falls Dam, including Cochran Shoals and Paces Mill (Figure 1). The Chattahoochee River below Morgan Falls Dam is unnaturally cold due to the release of hypolimnetic water from upstream Buford Dam, but exhibits a longitudinal gradient in water temperature, being colder immediately downstream of Morgan Falls Dam and warming through the downstream reaches at Cochran Shoals and Paces Mill (Figure 2). Despite this warming trend in the river, the water temperature regime in this reach of river remains marginal for warmwater black basses.

Methods

I followed the 2004 cohort of juvenile shoal bass and largemouth bass at three sites in the Chattahoochee River (below Morgan Falls Dam, Cochran Shoals, and Paces Mill; Figure 1). Approximately 40,000 shoal bass larvae were reared to phase-I fingerling size (~ 25 mm)in 0.4 ha earthen hatchery ponds at the Steve Cocke Fish Hatchery in Dawson, Georgia (approximately 240 km due south of Atlanta). On May 4, 2004 shoal bass were marked with oxytetracycline (OTC) and 30,000 fish were equitably divided and stocked in the river at each of three study sites. The remaining 10,000 fish were reared for another 30 days at the hatchery to phase-II fingerling size (~60 mm), marked again with OTC, and equitably divided and stocked on June 9 at each of the three sites.

Juvenile (<150 mm) shoal bass and largemouth bass were sampled from the river with backpack electrofishing on 7 June 2004 (~30-d post first stocking and 2 days pre-second stocking) and 2 August 2004 (~30-d post second stocking) from the three stocking sites. Captured fish were measured (mm, TL) and stored in 70% ethanol. Otoliths (sagittae) were removed from each fish, mounted concave side up with thermoplastic cement on individually numbered glass slides (Miller and Storck 1982), and polished with 600-grit wet/dry sandpaper until a flat plane from the center to the edge was obtained and the inner-most rings were clearly discernable. Otoliths were viewed under oil with a compound microscope (40-100x) and rings counted in the area with maximum clarity from the nucleus to the posterior edge. Each otolith was read independently in random order three times by a single individual and the average of these three counts was used for the age estimate.

Stomach contents from fish were removed, identified to the lowest taxonomic level possible (order or family for invertebrates, family or species for fish), and enumerated. Percent occurrence (the percentage of stomachs in the sample containing a particular diet item) and percent composition (number of individuals of a given prey type divided by the total number of prey items counted from a given predator stomach) of prey items were calculated for each species on each sampling date (Bowen 1996).

Daily growth for shoal bass and largemouth bass was estimated based on total length at capture, daily age estimates from otoliths, and adjusted to a size of zero length at hatch. Although daily ring formation for shoal bass is known (Long et al. 2004), the age at first ring formation is unknown, which is necessary to accurately estimate growth. Substituting this information from the closely related spotted bass (DiCenzo and Bettoli

1995), which forms its first ring at swim-up (4 days post-hatch), daily ring counts were adjusted by adding 4 days to estimate days since hatch. Based on the total length at swim-up for shoal bass at 4.4 mm (Smitherman and Ramsey 1972), daily growth for shoal bass was calculated using the following equation (Phelps et al. 2008):

$$\textbf{Daily Growth} = \frac{TL\ at\ capture - \mathbf{4.4}\ mm}{Average\ daily\ ring\ count}$$

Unlike the daily growth equation for shoal bass, the first daily ring for largemouth bass occurs at hatching and not at swim-up (Miller and Storck 1982; Isely and Noble 1987). However, similar to shoal bass, the total length was adjusted by the size at swim-up of largemouth bass at 5.0 mm (Miller and Storck 1982). Therefore, daily growth of largemouth bass was calculated using the following formula:

$$Daily\ growth\ post - hatch = \frac{TL\ at\ capture - 5.0\ mm}{Age\ estimate}$$

Otoliths were inspected for the presence and location of OTC marks: 0 marks for wild fish, 1 for Phase I fingerlings, or 2 marks for Phase II fingerlings. To determine the effect of stocking on shoal bass growth, the distance associated with ten daily increments before and after the OTC mark was measured and compared between stocking events. To assess the effects of water temperature on growth of shoal bass following stocking, data was obtained from the two United States Geological Survey (USGS) stream monitoring gages in the study reach: upstream station 02335810 at Morgan Falls Dam and downstream station 02336000 at Atlanta, Georgia (~1.6 km from Paces Mill). Differences in mean length and mean daily growth were calculated between species, among sites, and between stocking dates using analysis of variance (ANOVA) followed by a Tukey multiple comparison test. To evaluate differences in shoal bass growth rates pre- and post-stocking, mean otolith increment length during a 10-day period before and after the OTC mark (i.e., day of stocking) was tested using ANOVA followed by a Tukey multiple comparison test.

Results

In 2004, a total of 256 juvenile shoal bass were collected at three sites on the Chattahoochee River, Georgia. In June, 154 juvenile shoal bass were collected, and in August, 102 were collected. In June, shoal bass abundance was highest at Morgan Falls Dam (154 shoal bass/hour), followed by Paces Mill and Cochran Shoals (124 and 50 shoal bass/hour, respectively; Figure 3). However, during August sampling, shoal bass abundance was highest at Paces Mills (94 shoal bass/hour), followed by Cochran Shoal and Morgan Falls Dam (62 and 48 shoal bass/hour, respectively; Figure 3). Of the 256 fish collected in June and August, otoliths were removed from 177 shoal bass for age, growth, and OTC analysis. Inspection of shoal bass otoliths for OTC marks revealed that 100% of the fish collected in June and August were stocked.

Largemouth bass were much less abundant than shoal bass (Figure 3 and 4). A total of 32 largemouth bass were collected in 2004 from the same dates and sites that juvenile shoal bass were collected. Largemouth bass abundance in June was highest at Paces Mill (16 largemouth bass/hour) followed by Cochran Shoals (8 largemouth bass/hour; Figure 4). No largemouth bass were captured at Morgan Falls Dam on 7 June. In August, largemouth bass abundance was highest at Paces Mill (22 largemouth bass/hour) followed by Morgan Falls Dam and Cochran Shoals (10 and 8 largemouth bass/hour, respectively; Figure 4).

Age estimates were larger for fish captured further from Morgan Falls Dam. Based on evidence from OTC marks made on a known date, age estimates from fish captured at sites closer to the dam were underestimated. For fish stocked on 4 May and sampled 7 June, shoal bass were at-liberty for 35 days, but average daily ring counts post-OTC mark were 28, 29, and 33 days at Morgan Falls Dam, Cochran Shoals, and Paces Mill, respectively (Table 1). This translates to underestimates of 6, 5, and 1 days, on average, from the known daily age of 35. For shoal bass stocked on 9 June, which had two OTC marks, and sampled 2 August, mean daily age estimates post-second OTC mark were 37, 27, and 41 at Morgan Falls Dam, Cochran Shoals, and Paces Mill, respectively after 54 days of liberty (Table 1). These estimates were biased by 17, 27, and 13 days, on average, from the known age of 54.

Similar to shoal bass, largemouth bass age estimates increased with distance from Morgan Falls Dam. Largemouth bass daily ring count averages from the June sample were 47 (Cochran Shoals) and 49 (Paces Mill) days, and 84, 88, and 87 days (Morgan Falls Dam, Cochran Shoals, and Paces Mill, respectively) from the August sample (Table 1).

Shoal bass collected in June consisted solely of phase-I fish and differences in size among sites were apparent. Shoal bass collected below Morgan Falls Dam averaged 44 mm TL, which was shorter than fish at Cochran Shoals (mean = 52 mm TL), and at

Paces Mill (mean = 53 mm TL; $F_{2,10}$= 9.33, P<0.01; Figure 5). In August, phase-I shoal bass averaged 56, 73, and 76 mm TL and phase-II fish averaged 86, 83, and 93 mm TL at Morgan Falls Dam, Cochran Shoals, and Paces Mill, respectively ($F_{5,69}$= 10.81, P<0.01).

Largemouth bass exhibited a pattern in mean length among sites and month similar to shoal bass, but differences in mean length among sampling sites were not significant (Figure 6). No largemouth bass were collected below Morgan Falls Dam in June.

Similar to length, mean daily growth rates for shoal bass was location-specific. Mean daily growth rates of shoal bass in the hatchery averaged 0.81 mm/day before stocking in May and 0.91mm/day before stocking in June (Figure 7). Because age estimates of fish in the river were biased, shoal bass growth rates in the river were calculated based on the number of days at-liberty in the river (35 days from first stocking to capture and 54 days from second stocking to capture) instead of estimated daily age from otoliths. Mean daily growth rates for phase-I shoal bass during the first 35 days and 98 days in the river were least below Morgan Falls Dam (0.59 mm/day and 0.41 mm/day) compared to Cochran Shoals (0.73 mm/day and 0.55 mm/day) and Paces Mill (0.75 mm/day and 0.58 mm/day; $F_{5,173}$= 48.01, P<0.01). Phase-II shoal bass collected 54 days following the second stocking followed a similar trend as phase-I shoal bass where growth was slowest at Morgan Falls Dam (0.66 mm/day) followed by Cochran Shoals (0.67 mm/day) and Paces Mill (0.73 mm/day), however growth differences were not significant ($F_{2,14}$= 0.93, P>0.05) between Morgan Falls Dam and the downstream sites at Cochran Shoals and Paces Mill. Comparable to shoal bass, largemouth bass mean daily growth estimates increased with distance from Morgan Falls Dam. Unlike shoal bass though, daily growth rates for largemouth bass in the river, which were wild and not marked with OTC, were based on raw age estimates. Mean daily growth rates for largemouth bass collected on 7 June were 0.76 (Cochran Shoals) and 0.82 (Paces Mill) mm/day, and on 2 August were 0.59, 0.65, and 0.68 mm/day (Morgan Falls Dam, Cochran Shoals, and Paces Mill, respectively; Figure 8).

A noticeable constriction in daily rings on stocked shoal bass otoliths occurred at 32 and 66 days of age on average for phase-I and phase-II fish, respectively, corresponding to reduced growth in the days following stocking (Figure 9). Mean daily ring increment width for the 10 days prior to stocking were 0.33 mm, which was approximately 40% greater than the mean daily ring increment width post-stocking of 0.19 mm ($F_{4,105}$=317.4, P<0.01; Table 2).

In June and August, phase-I stocked shoal bass had a high diversity of prey items in the guts (17 in each month) (Table 3). Phase-I stocked shoal bass consumed mostly invertebrate prey items, however, in August, phase-I shoal bass consumed more fish (19% frequency of occurrence, compared to 2% in June). Most shoal bass in June had diet items in the gut (92%), however in August 31% of phase-I shoal bass guts were empty. In June, percent composition of phase-I shoal bass diets were dominated by Simuliidae larvae (53%), followed by Ephemeroptera nymphs (27%) and Chironomidae larvae (15%); all other diet items contributed <5%. In August, phase-I shoal bass diets often contained Ephemeroptera nymphs (81% frequency of occurrence) and, they dominated the composition (63%). Simuliidae larvae also contributed greatly to shoal bass diets, occurring in 13% of the diets and making up 26% of the composition. All other diet items contributed <11% by percent composition.

Differences in diet between the two cohorts of stocked shoal bass were also evident. From sampling conducted in August, when the two cohorts were similar in age but varied in size, the cohort that was stocked in May consumed more insects than the cohort that was stocked in June. Of the phase-II shoal bass collected in August, only 20% (4 of 20) contained more than one individual insect prey item, whereas 30% (6 of 20) had only 1 insect prey item in their guts. Also, phase-I shoal bass had a high diversity of prey items in the guts (17), whereas phase-II fish had only 9 different diet items in the guts. Although phase-I shoal bass consumed a higher frequency of fish (19%) in August, phase-II shoal bass had a much higher incidence of empty stomachs (9 of 20; 45%).

In June and August, largemouth bass had a low diversity of prey items in the guts (7 taxa found in June and 8 in August; Table 3). Largemouth bass consumed primarily invertebrate prey items, feeding on mostly aquatic invertebrates in June and switching to terrestrial invertebrates in August. Most fish contained prey items in the gut; only 2 out of 13 in June and 3 out of 20 in August were empty. In June 2004, percent composition of largemouth bass diets were dominated by Ephemeroptera nymphs (87%), followed by Chironomidae larvae (4%), amphipods (2.5%) and fish (2.5%; Table 5). All other diet items contributed <4% by percent composition. Interestingly, *Collembola* occurred in only 12% of largemouth bass diets, but were heavily used by the fish that ate them and made up 87% of composition (Table 3). Other diets items that contributed greatly to diet composition were Ephemeroptera nymphs (7%) and Hemiptera (3%). All other diet items contributed <3% by percent composition. The most commonly encountered diet items among largemouth bass individuals were Ephemeroptera nymphs, most often found in largemouth bass stomachs in August (47%), followed by Hemiptera (29%), fish (18%) and unidentified insects (18%).

Discussion

Differences in juvenile black bass age, growth, and prey use varied according to stocking date and location in the river, concomitant with temperature differences. Although the optimal temperature for shoal bass growth is unknown, a range of 25-30°C has been shown to be maximal for juvenile largemouth bass and smallmouth bass (Coutant and DeAngelis 1983) and this seems a logical values for a southern fish species like shoal bass. Taking fish from a 23°C warm-water hatchery in May and stocking them in the 15°C cold-water tailrace of the Chattahoochee River in June apparently caused rapid decreased growth rates, which only became exacerbated over time. However, fish stocked later in the year had similar growth rates at all three stocking sites, suggesting that these larger fish were better able to acclimate to the temperature difference. Whether fish size or differences in water temperature played the most important role is unknown because in June, when larger fish were stocked, water temperatures between hatchery ponds and the river were more similar (~3°C difference, from 24°C to 21°C).

The temperature-mediated effects on shoal bass life history also affected my ability to accurately estimate some parameters. In particular, daily-age estimates of shoal bass collected from the Chattahoochee River below Morgan Falls Dam underestimated the actual age of fish post-stocking. Daily otolith increments in this study became constricted and difficult to discern, causing the underestimation of daily-age estimates. The rate of underestimation was most severe near Morgan Falls Dam fish and followed a longitudinal trend with water temperature. The artificially cold water temperatures in the Chattahoochee River below Morgan Falls Dam appeared to shorten the growing season, causing decreased otolith growth and constriction of daily otolith increments. Otolith growth slows or ceases in colder water temperatures (Taubert and Coble 1977). When otolith growth slows, typically at the end of the growing season (Taubert and Tranquilli 1982), daily increments become compressed, making age estimation impossible because daily rings cannot be counted accurately (Isely and Noble 1987; DiCenzo and Bettoli 1995). Because of this growth pattern, age estimates for juvenile fish that could be accurately determined from otoliths varied depending on location. Miller and Storck (1982) were able to accurately age largemouth bass to 100 days in a laboratory setting, however, largemouth bass in Texas were accurately aged to 152, which was affected by growth rates (Isley and Noble 1987). In a small Tennessee pond, reduced growth rates caused compression of daily growth rings in otoliths of spotted bass, leading to underestimation of ages beyond 94 days. Without the presence of an OTC mark, which was used to correct underestimated shoal bass ages in this study, the age estimates would have been unreliable. Because largemouth bass were native to the river, and had no OTC mark to verify age, their ages may also be underestimated and should be interpreted with caution.

Differences in fish growth as a function of temperature differences between the hatchery ponds and the Chattahoochee River influenced the daily increment width and the contrast between opaque and translucent zones in juvenile shoal bass otoliths following stocking, creating a natural mark. Natural marks corresponded to OTC marks and stocking dates. Previous studies have demonstrated the creation of natural marks in hard parts of fish. Humphreys et al. (1990) recognized a growth check on scales of hatchery reared striped bass *Morone saxatilis*, which showed widely spaced daily rings corresponding to rapid growth in the hatchery and narrowly spaced increments after handling, tagging, and stocking into a new environment. Similarly, Paragamian et al. (1992) documented distinct stress check formation on otoliths of hatchery reared age-0 kokanee *Onchorynchus nerka* when fish were stocked from a warm, productive hatchery environment into a cold, food-limited natural environment. Hayes (1995) used otolith daily-growth patterns to differentiate between stream- and lake-spawned rainbow trout *Onchorynchus mykiss*. In this Great Lakes system, fish born in cold tributary streams exhibited narrow growth increments, followed by wide increments after emigration to the warmer lake. Fish born in the lake had wide increments across the entire otolith.

The effect of water temperature on growth of young-of-year shoal bass in the Chattahoochee River below MFD was obvious. Growth rates were greatest in the hatchery when water temperatures ranged from 24.4-27.8 ˚C.   These growth rates were similar to those calculated by Long et al. (2004) (0.85 mm/day) for shoal bass in the same hatchery in 2003. Although depressed following stocking into the Chattahoochee River, shoal bass growth rates were comparable to rates estimated for shoal bass in hatchery ponds in Alabama (0.63 and 0.77 mm/day, calculated using data from Smitherman and Ramsey 1972). Conversely, shoal bass growth rates from the Chattahoochee River were considerably lower than those estimated for shoal bass collected from the Flint River, Georgia (range 0.89-1.07 mm/day; Goclowski 2010). Comparatively, largemouth bass, which were resident to the Chattahoochee River and not stocked, exhibited growth rates between 0.59 and 0.82 mm/day, which is consistent with growth rates measured for this species and temperature range (Coutant and DeAngelis 1983) but less than growth rates (0.82-0.95 mm/day) estimated for largemouth bass in the Flint River, Georgia (Goclowski 2010). However, because age estimates (upon which growth rates are dependent) were likely biased, these estimates for largemouth bass growth rates were also likely biased in an upward manner.

Because shoal bass stocked at phase-II size grew faster in the hatchery than phase-I size fish in the river during the same time period, they were larger overall and this difference in size may have improved survival of phase-II fish, which dominated future adult cohorts (see Chapter 2). Previous studies have found that body size attained during the first year is an important factor in determining survival and recruitment of age-0 fish to the adult population (Horning and Pearson 1973; Venables et al. 1978; Coutant and DeAngelis 1983; Sabo and Orth 1995; Tidwell et al. 2003). Larger shoal bass might have been at a competitive advantage over the smaller phase-I individuals of the same age, and transitioning to piscivory sooner and allowing a wider range of prey sizes to be ingested, ultimately increasing foraging success. Larger phase-II shoal bass fed on very few aquatic insects, and had a high number of empty stomachs, which is indicative of fish that have transitioned to piscivory (Chapman et al. 1989; Beaudoin et al. 1999; Arrington et al. 2002; Paradis et al. 2008). Smaller phase-I fish continued to feed on higher numbers of aquatic invertebrates over a prolonged period, which may have resulted in slower growth that hampered their ability to transition to larger prey items (Mesing et al. 2008). Larger juveniles likely had better foraging opportunities and may also have been better able to avoid predation and experience lower mortality rates because they exceeded predator gape limits (Santucci and Wahl 1993; Szendrey and Wahl 1996).

The diet data used in this study was limited because it only represents prey items consumed on two days during summer 2004. However, these results are unique in that they document how a reintroduced species acclimated to feeding in sub-optimal surroundings (i.e., cold water releases), and it is the first description of diet for juvenile shoal bass in the Chattahoochee River, Georgia. These results also highlight the diversity of prey items used by juvenile shoal bass, something that has not been reported previously in the literature.

These results demonstrate how stocking fish in marginal environments could affect their growth. Moreover, it demonstrates problems associated with age estimations from these environments, which could bias calculations that require age estimates such as growth and mortality. Because our fish were marked with OTC, I could directly measure the effect of reduced growth on age estimates. However, in natural environments, further research is needed to ensure that age estimates are accurate.

The cohort of stocked shoal bass studied in this research, particularly those stocked at phase-II size, dominated the adult sample of fish collected from 2007-2011 (chapter 2). Some aspect of early life history or set of environmental variables was optimal in 2004, however, it is unclear exactly what mechanisms led to the success of this year class. Additional research on juvenile shoal bass foraging, predator avoidance, and linkages between environmental variation and recruitment are needed to understand recruitment success of shoal bass in the Chattahoochee River, below Morgan Falls Dam.

REFERENCES

Arrington, D.A., K.O. Winemiller, W.F. Loftus, and S. Akin. 2002. How often do fishes "run on empty"? Ecology 83:2145-2151.

Beaudoin, C.P, W.M. Tonn, E.E. Prepas, and L.I. Wassenaar. 1999. Individual specialization and trophic adaptability of northern pike (*Esox lucius*): an isotope and dietary analysis. Oecologia 120:386-396.

Bowen, S.H. 1996. Quantitative description of the diet. Pp. 513-529, *In* B.R. Murphy and D.W. Willis, (Eds.). Fisheries techniques. 2nd edition. American Fisheries Society, Bethesda, Maryland. 732 pp.

Chapman, L.J., W.C. Mackay, and C.W. Wilkinson. 1989. Feeding flexibility in northern pike (*Esox lucius*): fish versus invertebrate prey. Canadian Journal of Fisheries and Aquatic Science 46:666-669.

Coutant, C.C. and D.L. DeAngelis. 1983. Comparative temperature-dependent growth rates of largemouth and smallmouth bass fry. Transactions of the American Fisheries Society 112:416-423.

DiCenzo, V.J., and P.W. Bettoli. 1995. Verification of daily ring deposition in the otoliths of age-0 spotted bass. Transactions of the American Fisheries Society 124:633-636.

Georgia Power and GeoSyntec Consultants. 2006. Morgan Falls Hydro, FERC Project No. 2237. Fisheries and aquatic resources. Resource Study Report to Federal Energy Regulatory Commission, Washington, D.C.

Goclowski, M.R. 2010. Relations between shoal bass and sympatric congeneric basses in the Flint River, Georgia. Master's thesis, Auburn University, 93 pp.

Goodgame, L.S. and L.E. Miranda. 1993. Early growth and survival of age-0 largemouth bass in relation to parental size and swim-up time. Transactions of the American Fisheries Society 122:131-138.

Graham, R.J. and D.J. Orth. 1987. Otolith aging of young-of-year smallmouth bass. Pages 483-491 *in* R.C. Summerfelt and G.E. Hall, editors. Age and growth of fish. Iowa State University Press, Ames.

Hayes, J.W. 1995. Importance of stream versus early lake rearing for rainbow trout fry in Lake Alexandria, South Island, New Zealand, determined from otolith daily growth patterns. New Zealand Journal of Marine and Freshwater Research 29:409-420.

Horning, W. B., II, and R. E. Pearson. 1973. Growth temperature requirements and lower lethal temperatures for juvenile smallmouth bass (*Micropterus dolomieui*). Journal of the Fisheries Research Board of Canada 30:1226-1230.

Humphreys, M., R. E. Park, J.J. Reichle, M.T. Mattson, D.J. Dunning, and Q.E. Ross. 1990. Stocking checks on scales as marks for identifying hatchery striped bass in the Hudson River. American Fisheries Society Symposium 7:78-83.

Isley, J.J. and R.L. Noble. 1987. Use of daily otoliths rings to interpret development of length distributions of young largemouth bass. Pages 475-481 *in* R.C. Summerfelt and G.E. Hall, editors. Age and growth of fish. Iowa State University Press, Ames.

Long, J.M. and W.L. Fisher. 2000. Inter-annual and size-related differences in the diets of sympatric black bass in an Oklahoma reservoir. Journal of Freshwater Ecology 15:465-474.

Long, J.M., L.A. Klein, and A.C. Mauldin III. 2004. Length, weight, age, and growth of young-of-year shoal bass raised in a southwest Georgia hatchery pond. Proceedings of the Annual Conference of the Southeastern Association of Game and Fish Commissioners 58:40-46.

Long, J.M. and C. Martin. 2008. The evolution of fisheries management of the upper Chattahoochee River in response to changing water management. Pages 21-36, *In* M.S. Allen, S. Sammons, and M.J. Maceina, editors. Balancing fisheries management and water uses for impounded river systems. American Fisheries Society. Symposium 62. Bethesda, Maryland. 697 pp.

Ludsin, S. A., and D. R. DeVries. 1997. First-year recruitment of largemouth bass: the inter-dependency of early life stages. Ecological Applications 7:1024–1038.

Mesing, C. L., R. L. Cailteux, P. A. Strickland, E. A. Long, and M. W. Rogers. 2008. Stocking of advanced fingerling largemouth bass to supplement year-classes in Lake Talquin, Florida. North American Journal of Fisheries Management 28:1762–1774.

Miller, S.J. and T. Storck. 1982. Daily growth rings in otoliths of young-of-the-year largemouth bass. Transactions of the American Fisheries Society 111:527-530.

Olson, M.H. and B.P. Young. 2003. Patterns of diet and growth in co-occurring populations of Largemouth Bass and Smallmouth Bass. Transactions of the American Fisheries Society 132:1207-1213.

Paradis, Y., A. Bertolo, and P. Magnan. 2008. What do empty stomachs of northern pike (*Esox lucius*) reveal? Insights from carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) stable isotopes. Environmental Biology of Fishes 83:441-448.

Paragamian, V.L., E.C. Bowles, and B. Hoelscher. 1992. Use of daily growth increments on otoliths to assess stocking of hatchery-reared kokanees. Transactions of the American Fisheries Society 121:785-791.

Phelps, Q.E., D.A. Isermann, and D.W. Willis. 2008. Influence of hatch duration and individual daily growth rates on size structure of age-0 smallmouth bass cohorts in two glacial lakes. Ecology of Freshwater Fish 17:363-373.

Phillips, J.M., J.R. Jackson, and R.L. Noble. 1995. Hatching date influence on age-specific diet and growth of age-0 Largemouth Bass. Transactions of the American Fisheries Society 124:370-379.

Sabo, M.J. and D.J. Orth. 1995. Growth of age-0 smallmouth bass (*Micropterus dolomieu* Lacepède): interactive effect of temperature, spawning date, and growth autocorrelation. Ecology of Freshwater Fish 4:28-36.

Santucci, V. J. and D. H. Wahl. 1993. Factors influencing survival and growth of stocked walleye (*Stizostedion vitreum*) in a centrarchid-dominated impoundment. Canadian Journal of Fisheries and Aquatic Sciences 50: 1548-1558.

Scalet, C.G. 1977. Summer food habits of sympatric stream populations of spotted bass, *Micropterus punctulatus*, and Largemouth Bass *Micropterus salmoides*, (Osteichthyes: Centrarchidae). Southwestern Naturalist 21:493-501.

Schramm, H.J., and M.J. Maceina. 1986. Distribution and diet of Suwannee bass and largemouth bass in the lower Sante Fe River, Florida. Environmental Biology of Fishes 15:221-228.

Smitherman, P.O. and J.S. Ramsey. 1972. Observations on spawning and growth of four species of basses (*Micropterus*) in ponds. Proceedings of the Annual Conference of the Southeastern Association of Game and Fish Commissioners 24:357-365

Szendrey, T. A., and D. H. Wahl. 1996. Size-specific survival and growth of stocked muskellunge: effects of predation and prey availability. North American Journal of Fisheries Management 16:395–402.

Taubert, B.D., and D.W. Coble. 1977. Daily rings in otoliths of three species of *Lepomis* and *Tilapia mosambica.* Journal of the Fisheries Research Board of Canada 34:322-340.

Taubert, B.D., and J.A. Tranquilli. 1982. Verification of the formation of annuli in otoliths of largemouth bass. Transactions of the American Fisheries Society 111:531-534.

Tidwell, J. H., S. D. Coyle, L. A. Bright, A. VanArnum, and D. Yasharian. 2003. Effect of water temperature on growth, survival, and biochemical composition of largemouth bass *Micropterus salmoides*. Journal of the World Aquaculture Society 34:175–183.

Venables, B. J., W. D. Pearson, and L. C. Fitzpatrick. 1977. Thermal and metabolic relations of largemouth bass, Micropterus salmoides, from a heated reservoir and a hatchery in north central Texas. Comparative Biochemical Physiology 57A:93-98.

Wheeler, A.P. and M.S. Allen. 2003. Habitat and diet partitioning between shoal bass and largemouth bass in the Chipola River, Florida. Transactions of the American Fisheries Society 132:438-449.

Williams, J. D., and G. H. Burgess. 1999. A new species of bass, *Micropterus cataractae* (Teleostei: Centrarchidae), from the Apalachicola River basin in Alabama, Florida, and Georgia. Bulletin of the Florida Museum of Natural History 42(2):80–114.

Table 1: Mean age estimates of shoal bass and largemouth bass collected from the Chattahoochee River, Georgia during June and August 2004.

Cohort	Morgan Falls Dam			Cochran Shoals			Paces Mill		
	N (effort)	Mean age (CV)	Mean post-stocking age	N (effort)	Mean age (CV)	Mean post-stocking age	N (effort)	Mean age (CV)	Mean post-stocking age
Phase-I June	21	62(6.1)	28	21	60(10.2)	29	60	64(7.5)	33
Phase-I August	8	97(3.7)	64	21	92(3.6)	58	29	98(4.3)	65
Phase-II August	3	103(3.4)	37	6	93(6.4)	27	8	107(1.6)	41
LMB June	0	NA	NA	4	47(3.6)	NA	8	49(3.1)	NA
LMB August	5	84(4.1)	NA	4	88(4.6)	NA	11	87(3.1)	NA

Table 2: Mean otolith increment measurements of shoal bass collected from the Chattahoochee River, Georgia during June and August 2004.

Cohort	Morgan Falls Dam			Cochran Shoals			Paces Mill		
	N (effort)	Mean pre-stocking increment (SD)	Mean post-stocking age (SD)	N (effort)	Mean pre-stocking increment (SD)	Mean post-stocking age (SD)	N (effort)	Mean pre-stocking increment (SD)	Mean post-stocking age (SD)
Phase-I June	21	0.26 (0.03)	0.15 (0.02)	20	0.32 (0.09)	0.17 (0.06)	60	0.26 (0.04)	0.17 (0.03)
Phase-II August	3	0.37 (0.20)	0.19 (0.09)	6	0.41 (0.13)	0.20 (0.06)	8	0.26 (0.09)	0.17 (0.04)

Table 3: Mean percent composition by number and frequency of occurrence of prey items in the stomachs of age-0 shoal bass and largemouth bass in June and August 2004, from the Chattahoochee River, Georgia. Number before parentheses represents the number of stomach an item occurred. Number within the parentheses represents the mean frequency of occurrence.

	Shoal Bass						Largemouth Bass			
	June 2004 Phase I (n=139)		August 2004 Phase I (n=48)		August 2004 Phase II (n=20)		June 2004 (n=11)		August 2004 (n=17)	
Prey Item	Percent occurrence	Percent composition	Percent occurrence	Percent composition	Percent occurrence	Percent composition	Percent occurrence	Percent composition	Percent occurrence	Percent composition
Amphipoda	4(2.88)	0.30	2(4.17)	0.68	NA	NA	1(9.09)	2.52	NA	NA
Arachnida	1(0.72)	0.04	NA	NA	NA	NA	NA	NA	2(11.76)	0.67
Chironomidae	50(35.97)	14.84	2(4.17)	0.68	NA	NA	2(18.18)	4.42	2(11.76)	0.67
Chydorida	1(0.72)	0.09	NA	NA	NA	NA	NA	NA	NA	NA
Coleoptera	NA	NA	1(2.08)	0.23	NA	NA	NA	NA	NA	NA
Collembola	NA	NA	NA	NA	NA	NA	NA	NA	2(11.76)	86.92
Crayfish	2(1.44)	0.09	NA	NA	NA	NA	NA	NA	NA	NA
Diaphanosoma	3(2.16)	0.48	NA	NA	NA	NA	NA	NA	NA	NA
Ephemeroptera	84(60.43)	27.15	39(81.25)	63.47	7(35.00)	53.13	8(72.73)	87.39	8(47.06)	7.10
Fish	3(2.16)	0.13	9(18.75)	2.05	1(5.00)	3.13	2(18.18)	2.52	3(17.65)	0.89
Gastropoda	NA	NA	1(2.08)	0.23	NA	NA	NA	NA	NA	NA
Hemiptera	2(1.44)	0.09	NA	NA	NA	NA	NA	NA	5(29.41)	2.88
Hydracarina	2(1.44)	0.09	NA	NA	NA	NA	NA	NA	NA	NA
Isopoda	11(7.91)	0.74	3(6.25)	0.68	1(5.00)	3.13	NA	NA	NA	NA
Odonata	3(2.16)	0.13	1(2.08)	0.23	NA	NA	NA	NA	NA	NA
Oligochaeta	NA	NA	1(2.08)	0.23	NA	NA	NA	NA	NA	NA
Orthoptera	NA	NA	1(2.08)	0.23	NA	NA	NA	NA	NA	NA
Palaemonidae	NA	NA	2(4.17)	0.46	1(5.00)	3.13	NA	NA	NA	NA
Plecoptera	5(3.60)	0.22	2(4.17)	0.46	1(5.00)	3.13	NA	NA	1(5.88)	0.22
Simuliidae	67(48.20)	53.09	9(13.24)	25.57	1(5.00)	15.63	1(9.09)	0.84	NA	NA
Tipulidae	NA	NA	1(2.08)	2.51	NA	NA	NA	NA	NA	NA
Trichoptera	15(10.97)	1.09	4(8.33)	0.91	3(15.00)	12.50	1(9.09)	0.84	NA	NA
UID dipteran	19(6.47)	0.78	2(4.17)	0.46	1(5.00)	3.13	NA	NA	NA	NA
UID insect	15(10.79)	0.65	4(8.33)	0.91	1(5.00)	3.13	1(9.09)	1.68	3(17.65)	0.67
Total		100		100		100		100		100
N		17		17		9		7		8

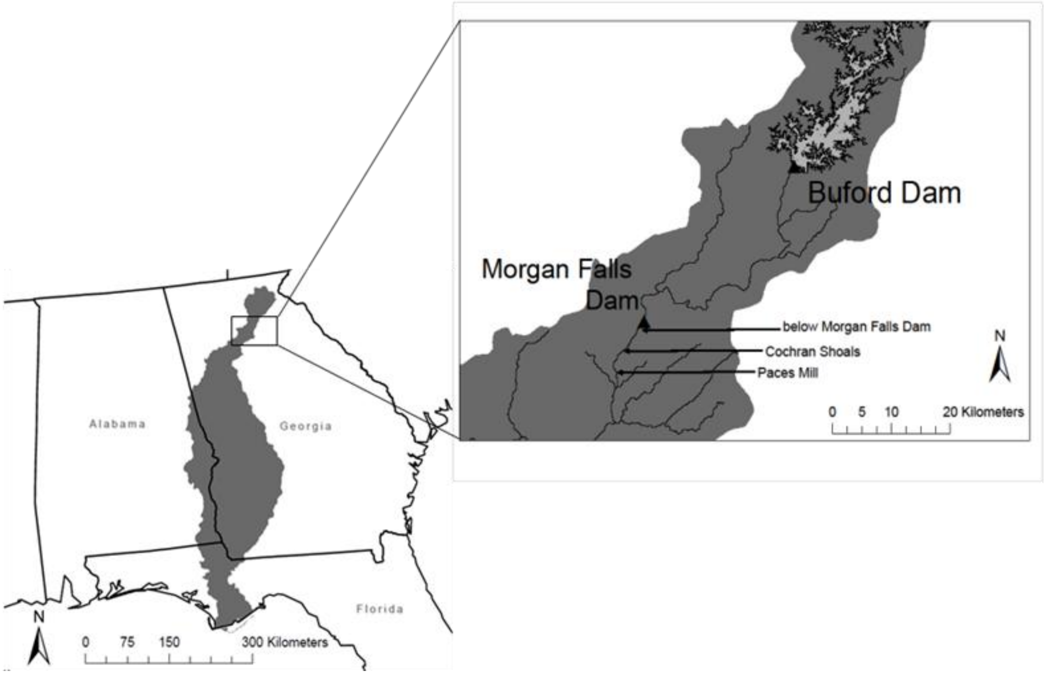

Figure 1: Map of Apalachicola River basin and the upper Chattahoochee River noting the three locations where juvenile shoal bass were stocked as part of a restoration program that occurred from 2003 to 2007.

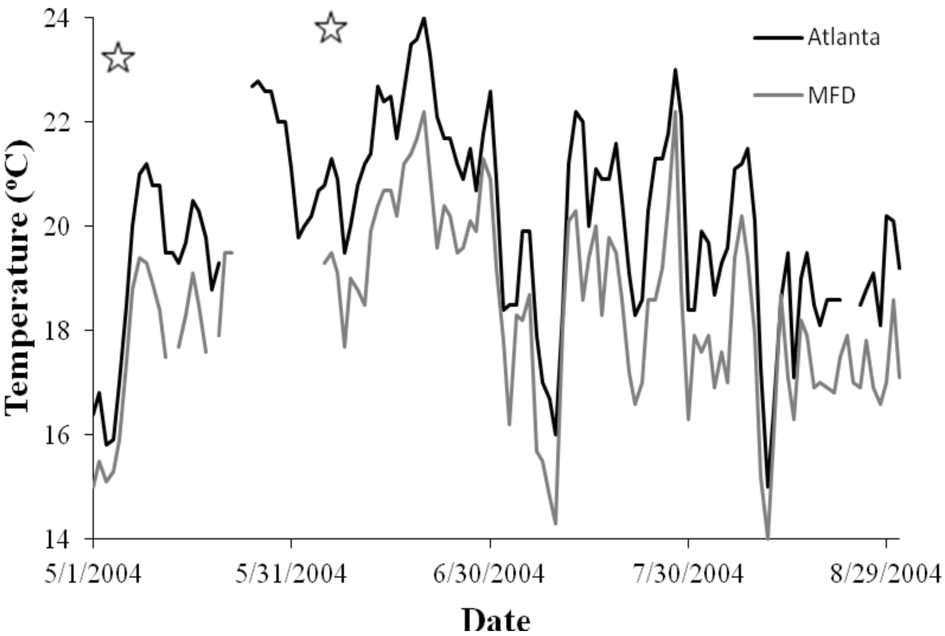

Figure 2: Longitudinal gradients in temperature present in the Chattahoochee River, Georgia downstream of Morgan Falls Dam (MFD). The Atlanta stream gage is located approximately 1.6 km downstream of MFD. Stars indicate the hatchery water temperature on the day of stocking.

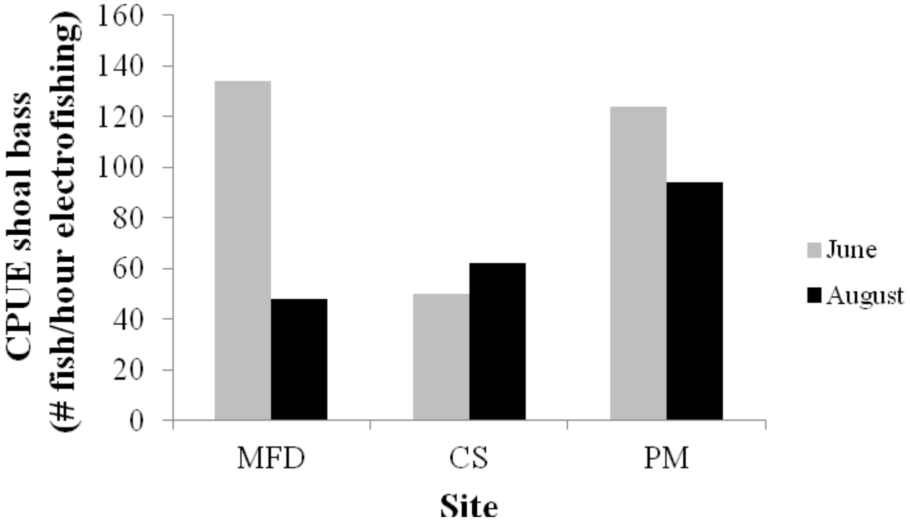

Figure 3: Relative abundance (number of fish/hour electrofishing) of shoal bass collected in June and August 2004 from three sites below Morgan Falls Dam on the Chattahoochee River, Georgia.

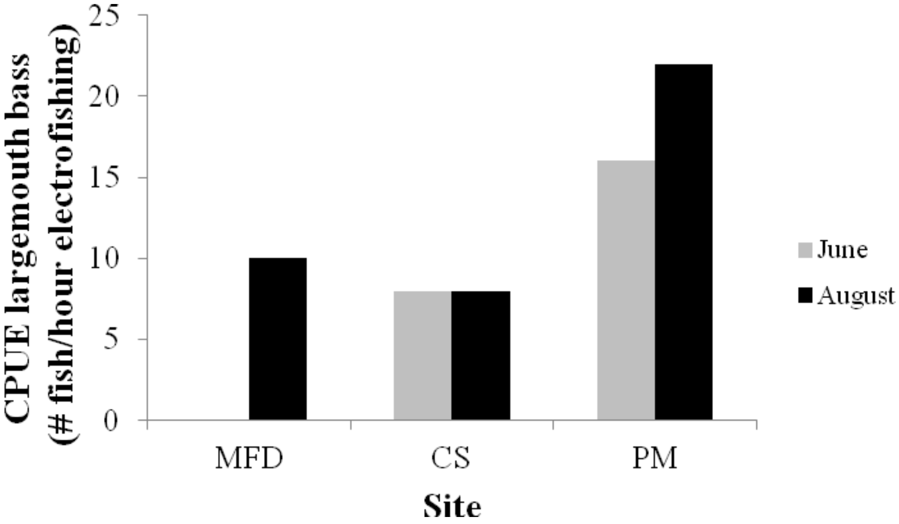

Figure 4: Relative abundance (number of fish/hour electrofishing) of largemouth bass collected in June and August 2004 from three sites below Morgan Falls Dam on the Chattahoochee River, Georgia.

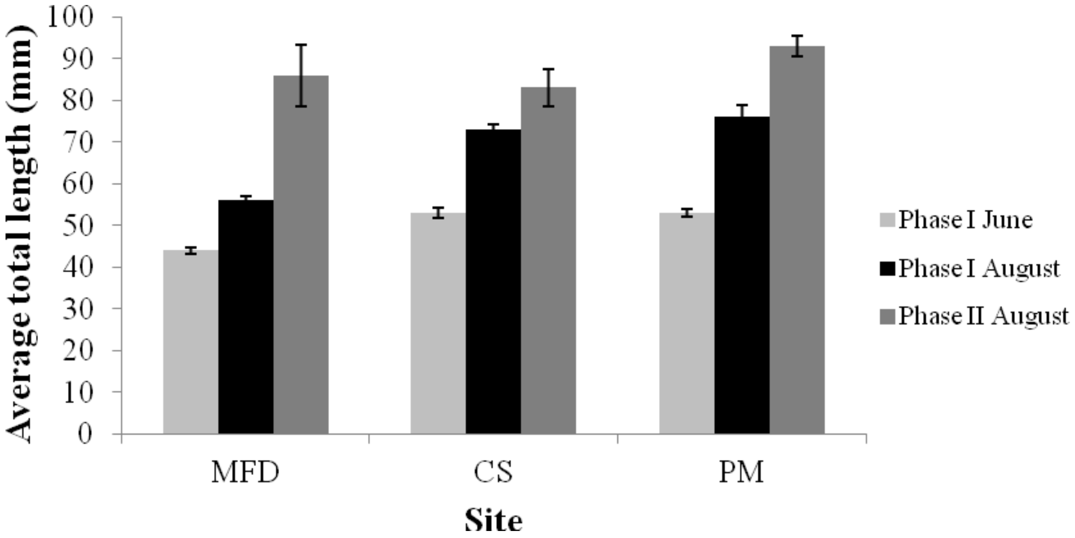

Figure 5: Mean total lengths of shoal bass collected in June and August 2004 from three sites below Morgan Falls Dam on the Chattahoochee River, Georgia. Error bars represent standard error about the mean.

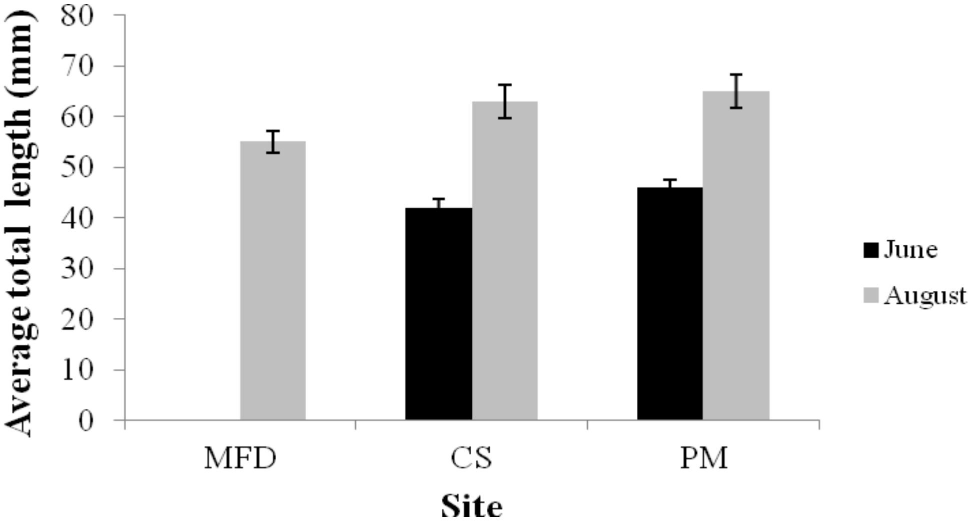

Figure 6: Mean total lengths of largemouth bass collected in June and August 2004 from three sites below Morgan Falls Dam on the Chattahoochee River, Georgia. Error bars represent standard error about the mean.

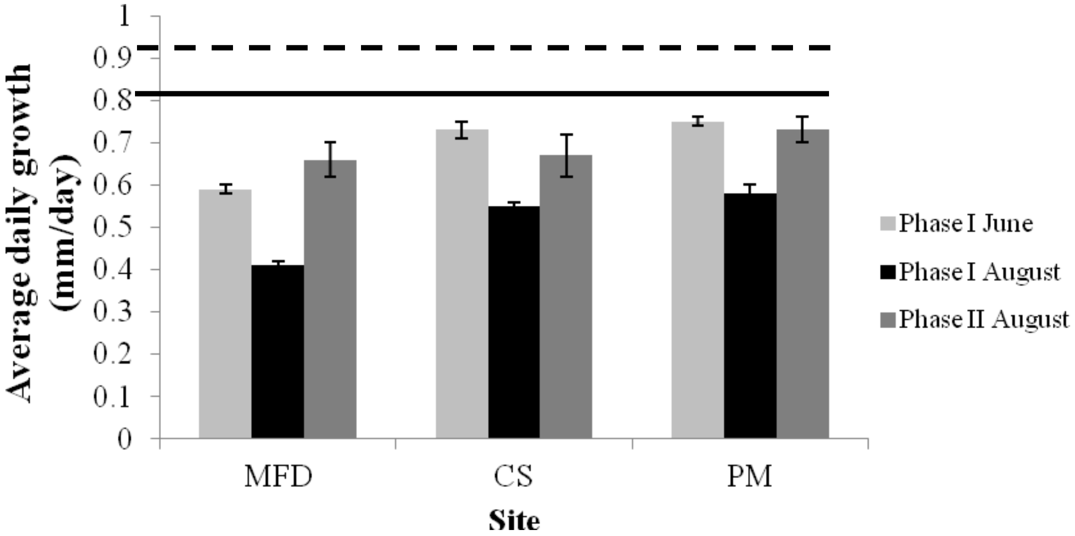

Figure 7: Growth rates estimated for shoal bass (corrected for age estimation bias), collected from three sites on the Chattahoochee River, Georgia below Morgan Falls Dam during June and August 2004. The solid line represents hatchery growth pre-first stocking, and the dashed line represents hatchery growth pre-second stocking. Phase I fish were stocked in May and Phase II fish were stocked in June. Error bars represent standard error about the mean.

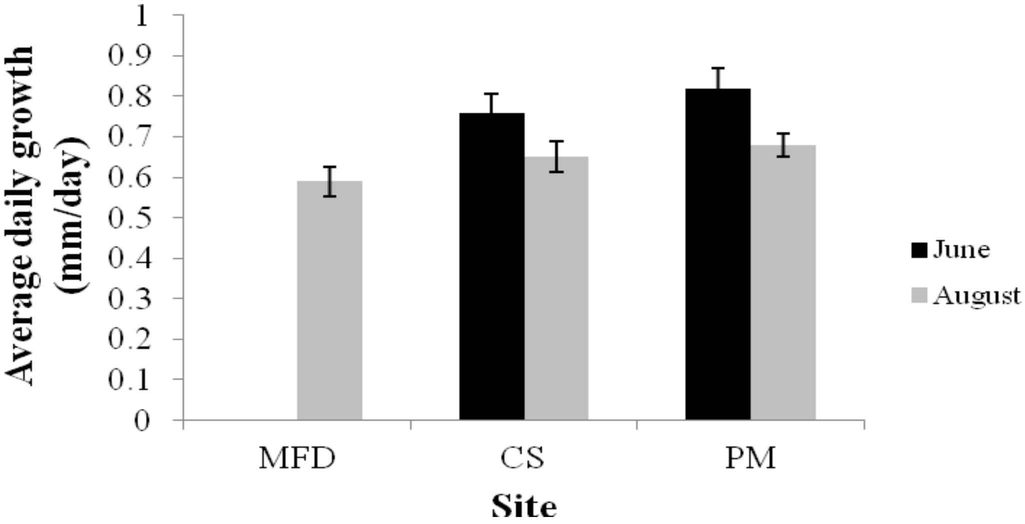

Figure 8: Growth rates estimated from juvenile largemouth bass collected from three sites on the Chattahoochee River, Georgia below Morgan Falls Dam during June and August 2004. Error bars represent standard error about the mean.

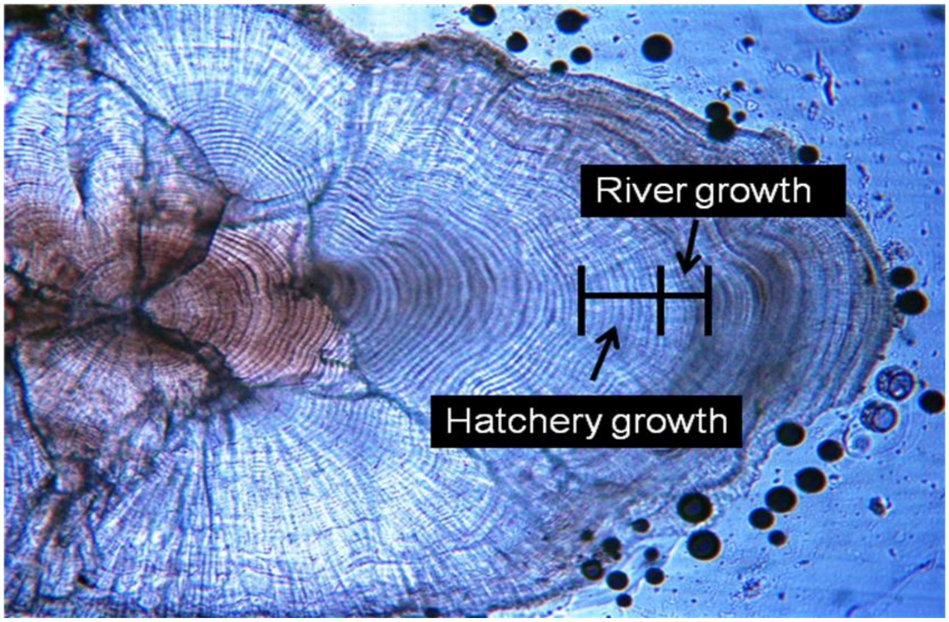

Figure 9: Juvenile shoal bass otolith depicting 10 growth increments before (hatchery growth) and after (river growth) the oxytetracyline mark collected from the Chattahoochee River, Georgia in June 2004.

Appendix 2. Size, age, growth, and stocking cohort (based on number of OTC marks) for juvenile shoal bass captured during June and August 2004 with backpack electrofishing from the Chattahoochee River, Georgia.

Date	Site	Fish ID	OTC	TL (mm)	Age Pre-mark	Age Post-mark	Final Age	Days in River	Corrected Age	Corrected Growth
6/7/04	MFD	3	1	48	35	26	61	34	69	0.63
6/7/04	MFD	4	1	41	33	26	59	34	67	0.55
6/7/04	MFD	5	1	42	33	28	61	34	67	0.56
6/7/04	MFD	6	1	43	35	26	61	34	69	0.56
6/7/04	MFD	7	1	48	34	28	62	34	68	0.64
6/7/04	MFD	8	1	47	34	29	63	34	68	0.63
6/7/04	MFD	9	1	45	34	27	62	34	68	0.59
6/7/04	MFD	10	1	40	30	29	59	34	64	0.55
6/7/04	MFD	12	1	47	33	29	62	34	67	0.63
6/7/04	MFD	13	1	42	33	28	62	34	67	0.56
6/7/04	MFD	14	1	46	34	29	63	34	68	0.61
6/7/04	MFD	15	1	50	33	28	62	34	67	0.68
6/7/04	MFD	16	1	43	35	28	62	34	69	0.56
6/7/04	MFD	17	1	40	30	30	59	34	64	0.56
6/7/04	MFD	18	1	45	35	29	64	34	69	0.59
6/7/04	MFD	19	1	51	34	31	64	34	68	0.69
6/7/04	MFD	20	1	39	34	29	63	34	68	0.51
6/7/04	MFD	21	1	43	36	29	65	34	70	0.55
6/7/04	MFD	23	1	38	33	30	64	34	67	0.50
6/7/04	MFD	24	1	45	34	29	63	34	68	0.60
6/7/04	MFD	25	1	45	32	27	60	34	66	0.61
6/7/04	CS	2	1	50	33	29	62	34	67	0.68
6/7/04	CS	3	1	56	33	27	60	34	67	0.77
6/7/04	CS	4	1	57	35	28	63	34	69	0.77
6/7/04	CS	5	1	47	30	28	57	34	64	0.67
6/7/04	CS	6	1	62	34	26	60	34	68	0.84
6/7/04	CS	7	1	67	34	29	63	34	68	0.92
6/7/04	CS	9	1	59	31	29	58	34	65	0.84
6/7/04	CS	11	1	52	30	28	57	34	64	0.75
6/7/04	CS	12	1	45	29	24	53	34	63	0.65
6/7/04	CS	13	1	49	29	28	57	34	63	0.71
6/7/04	CS	14	1	54	35	27	63	34	69	0.72
6/7/04	CS	15	1	58	33	30	63	34	67	0.80
6/7/04	CS	16	1	41	30	30	60	34	64	0.57
6/7/04	CS	17	1	55	34	31	65	34	68	0.74
6/7/04	CS	18	1	51	32	31	62	34	66	0.71

6/7/04	CS	20	1	56	33	28	61	34	67	0.77
6/7/04	CS	21	1	50	33	29	61	34	67	0.68
6/7/04	CS	22	1	53	32	30	62	34	66	0.74
6/7/04	CS	23	1	46	32	30	61	34	66	0.63
6/7/04	CS	24	1	54	32	30	62	34	66	0.75
6/7/04	CS	25	1	47	30	29	60	34	64	0.66
6/7/04	PM	1	1	51	32	33	64	34	66	0.71
6/7/04	PM	2	1	58	34	34	68	34	68	0.79
6/7/04	PM	3	1	56	31	34	65	34	65	0.79
6/7/04	PM	4	1	57	30	33	63	34	64	0.82
6/7/04	PM	5	1	61	34	33	67	34	68	0.83
6/7/04	PM	6	1	61	30	34	64	34	64	0.88
6/7/04	PM	7	1	48	31	32	62	34	65	0.67
6/7/04	PM	8	1	67	34	32	66	34	68	0.93
6/7/04	PM	9	1	61	34	31	66	34	68	0.83
6/7/04	PM	10	1	61	32	32	64	34	66	0.86
6/7/04	PM	11	1	52	30	33	63	34	64	0.74
6/7/04	PM	12	1	53	35	31	65	34	69	0.71
6/7/04	PM	13	1	63	34	35	69	34	68	0.86
6/7/04	PM	14	1	54	32	31	63	34	66	0.75
6/7/04	PM	15	1	57	31	33	64	34	65	0.81
6/7/04	PM	16	1	54	33	32	65	34	67	0.74
6/7/04	PM	17	1	50	31	33	63	34	65	0.71
6/7/04	PM	18	1	67	32	33	66	34	66	0.94
6/7/04	PM	20	1	45	30	33	64	34	64	0.63
6/7/04	PM	21	1	63	33	35	68	34	67	0.88
6/7/04	PM	22	1	66	33	35	67	34	67	0.93
6/7/04	PM	23	1	50	30	34	64	34	64	0.71
6/7/04	PM	24	1	57	32	34	66	34	66	0.80
6/7/04	PM	25	1	61	33	33	66	34	67	0.85
6/7/04	PM	26	1	58	33	32	65	34	67	0.80
6/7/04	PM	27	1	50	29	32	61	34	63	0.72
6/7/04	PM	28	1	56	33	32	65	34	67	0.77
6/7/04	PM	29	1	62	32	34	66	34	66	0.88
6/7/04	PM	30	1	51	31	32	63	34	65	0.72
6/7/04	PM	31	1	45	28	32	59	34	62	0.66
6/7/04	PM	32	1	42	30	30	60	34	64	0.59
6/7/04	PM	33	1	43	31	34	65	34	65	0.59
6/7/04	PM	34	1	52	29	32	61	34	63	0.76
6/7/04	PM	35	1	54	30	32	62	34	64	0.77
6/7/04	PM	36	1	43	30	33	62	34	64	0.61
6/7/04	PM	37	1	51	30	34	64	34	64	0.73
6/7/04	PM	38	1	48	33	32	65	34	67	0.65

6/7/04	PM	39	1	50	34	33	67	34	68	0.67
6/7/04	PM	40	1	48	30	31	61	34	64	0.68
6/7/04	PM	41	1	49	31	32	63	34	65	0.69
6/7/04	PM	42	1	43	31	33	64	34	65	0.59
6/7/04	PM	43	1	61	32	34	65	34	66	0.86
6/7/04	PM	44	1	48	30	32	62	34	64	0.68
6/7/04	PM	45	1	58	29	33	62	34	63	0.85
6/7/04	PM	46	1	53	31	32	63	34	65	0.75
6/7/04	PM	47	1	44	29	32	61	34	63	0.63
6/7/04	PM	48	1	46	31	32	63	34	65	0.64
6/7/04	PM	49	1	49	31	31	61	34	65	0.69
6/7/04	PM	51	1	50	32	31	63	34	66	0.69
6/7/04	PM	52	1	61	35	34	69	34	69	0.82
6/7/04	PM	53	1	48	30	32	62	34	64	0.68
6/7/04	PM	54	1	59	32	34	65	34	66	0.83
6/7/04	PM	55	1	58	31	33	64	34	65	0.82
6/7/04	PM	56	1	51	34	34	67	34	68	0.69
6/7/04	PM	57	1	41	32	33	65	34	66	0.55
6/7/04	PM	58	1	58	33	33	66	34	67	0.80
6/7/04	PM	59	1	58	33	30	64	34	67	0.80
6/7/04	PM	60	1	44	30	32	62	34	64	0.62
6/7/04	PM	61	1	50	34	32	66	34	68	0.67
6/7/04	PM	62	1	44	29	32	62	34	63	0.63
8/2/04	MFD	1	1	58	34	66	100	91	125	0.43
8/2/04	MFD	4	1	61	34	65	98	91	125	0.45
8/2/04	MFD	6	1	52	32	62	93	91	123	0.39
8/2/04	MFD	7	1	53	31	58	89	91	122	0.40
8/2/04	MFD	9	1	54	33	68	101	91	124	0.40
8/2/04	MFD	10	1	55	34	65	99	91	125	0.40
8/2/04	MFD	11	1	55	35	62	97	91	126	0.40
8/2/04	MFD	12B	1	59	35	66	101	91	126	0.43
8/2/04	CS	1	1	68	36	57	93	91	127	0.50
8/2/04	CS	2	1	70	31	65	96	91	122	0.54
8/2/04	CS	6	1	79	37	54	91	91	128	0.58
8/2/04	CS	8	1	65	35	53	88	91	126	0.48
8/2/04	CS	9	1	72	32	70	102	91	123	0.55
8/2/04	CS	10	1	75	36	58	94	91	127	0.56
8/2/04	CS	11	1	73	32	62	94	91	123	0.56
8/2/04	CS	13	1	73	36	54	90	91	127	0.54
8/2/04	CS	14	1	69	35	61	95	91	126	0.51
8/2/04	CS	15	1	79	36	62	98	91	127	0.59
8/2/04	CS	18	1	64	33	52	85	91	124	0.48
8/2/04	CS	19	1	70	37	53	89	91	128	0.51

8/2/04	CS	21	1	82	35	63	98	91	126	0.62
8/2/04	CS	22	1	77	35	56	91	91	126	0.58
8/2/04	CS	23	1	75	34	61	95	91	125	0.56
8/2/04	CS	24	1	62	31	64	95	91	122	0.47
8/2/04	CS	26	1	80	34	57	91	91	125	0.60
8/2/04	CS	27	1	78	32	57	89	91	123	0.60
8/2/04	CS	29	1	80	34	59	93	91	125	0.60
8/2/04	CS	30	1	68	32	59	91	91	123	0.52
8/2/04	CS	32	1	71	33	54	87	91	124	0.54
8/2/04	PM	1	1	91	35	68	102	91	126	0.69
8/2/04	PM	2	1	82	33	66	99	91	124	0.63
8/2/04	PM	3	1	76	34	73	107	91	125	0.58
8/2/04	PM	5	1	94	34	67	101	91	125	0.72
8/2/04	PM	6	1	100	36	72	108	91	127	0.75
8/2/04	PM	8	1	97	33	72	105	91	124	0.75
8/2/04	PM	9	1	68	32	63	95	91	123	0.52
8/2/04	PM	10	1	100	34	83	116	91	125	0.77
8/2/04	PM	13	1	88	32	69	100	91	123	0.68
8/2/04	PM	14	1	74	31	69	100	91	122	0.57
8/2/04	PM	15	1	105	31	74	105	91	122	0.83
8/2/04	PM	17	1	65	32	61	93	91	123	0.49
8/2/04	PM	19	1	71	31	67	98	91	122	0.55
8/2/04	PM	20	1	57	32	67	99	91	123	0.43
8/2/04	PM	22	1	90	35	62	96	91	126	0.68
8/2/04	PM	23	1	79	36	70	105	91	127	0.59
8/2/04	PM	25	1	79	35	61	95	91	126	0.59
8/2/04	PM	27	1	64	32	61	93	91	123	0.49
8/2/04	PM	28	1	75	29	62	91	91	120	0.59
8/2/04	PM	29	1	83	35	66	101	91	126	0.63
8/2/04	PM	31	1	59	34	63	96	91	125	0.44
8/2/04	PM	36	1	68	34	60	94	91	125	0.51
8/2/04	PM	37	1	69	32	63	95	91	123	0.53
8/2/04	PM	40	1	68	32	61	93	91	123	0.52
8/2/04	PM	41	1	58	31	53	83	91	122	0.44
8/2/04	PM	42	1	66	36	59	95	91	127	0.49
8/2/04	PM	43	1	54	29	63	92	91	120	0.41
8/2/04	PM	44	1	63	35	61	96	91	126	0.47
8/2/04	PM	45	1	62	31	67	97	91	122	0.47
8/2/04	MFD	18	2	71	62	28	90	54	116	0.58
8/2/04	MFD	19	2	92	72	40	109	54	126	0.70
8/2/04	MFD	20	2	94	74	43	112	54	128	0.70
8/2/04	CS	3	2	71	65	24	95	54	119	0.56
8/2/04	CS	4	2	93	66	30	97	54	120	0.74

8/2/04	CS	5	2	85	68	25	97	54	122	0.66
8/2/04	CS	12	2	98	54	41	93	54	108	0.87
8/2/04	CS	28	2	73	61	18	84	54	115	0.60
8/2/04	CS	31	2	78	65	24	93	54	119	0.62
8/2/04	PM	4	2	93	70	41	110	54	124	0.72
8/2/04	PM	16	2	88	76	38	113	54	130	0.65
8/2/04	PM	18	2	108	67	42	109	54	121	0.86
8/2/04	PM	26	2	96	60	43	103	54	114	0.81
8/2/04	PM	30	2	86	71	46	112	54	125	0.66
8/2/04	PM	33	2	92	59	38	95	54	113	0.78
8/2/04	PM	34	2	92	70	39	106	54	124	0.71
8/2/04	PM	35	2	85	70	41	108	54	124	0.65

Appendix 3. Size, age, and growth for juvenile largemouth bass captured during June and August 2004 with backpack electrofishing from the Chattahoochee River, Georgia.

Date	Site	Fish ID	Total length (mm)	Age (days)	Growth (mm/day)
6/7/04	Cochran Shoals	1	46	47	0.85
6/7/04	Cochran Shoals	2	40	50	0.68
6/7/04	Cochran Shoals	3	42	53	0.68
6/7/04	Cochran Shoals	4	38	39	0.82
6/7/04	Paces Mills	1	57	51	1.00
6/7/04	Paces Mills	2	51	55	0.82
6/7/04	Paces Mills	3	44	53	0.72
6/7/04	Paces Mills	4	52	45	1.02
6/7/04	Paces Mills	5	43	46	0.80
6/7/04	Paces Mills	6	36	52	0.58
6/7/04	Paces Mills	7	40	42	0.81
6/7/04	Paces Mills	8	46	50	0.80
8/2/04	Morgan Falls Dam	1	60	90	0.60
8/2/04	Morgan Falls Dam	2	59	74	0.72
8/2/04	Morgan Falls Dam	3	54	87	0.55
8/2/04	Morgan Falls Dam	4	55	86	0.57
8/2/04	Morgan Falls Dam	5	48	85	0.49
8/2/04	Cochran Shoals	1	61	93	0.59
8/2/04	Cochran Shoals	2	72	92	0.71
8/2/04	Cochran Shoals	3	56	87	0.57
8/2/04	Cochran Shoals	4	63	80	0.72
8/2/04	Paces Mills	1	69	88	0.72
8/2/04	Paces Mills	2	56	92	0.55
8/2/04	Paces Mills	3	57	82	0.62
8/2/04	Paces Mills	4	66	77	0.78
8/2/04	Paces Mills	5	70	85	0.76
8/2/04	Paces Mills	6	71	84	0.77
8/2/04	Paces Mills	7	71	110	0.59
8/2/04	Paces Mills	8	61	91	0.61
8/2/04	Paces Mills	9	56	78	0.64
8/2/04	Paces Mills	10	47	69	0.60
8/2/04	Paces Mills	11	89	102	0.82

Appendix 4. Daily otolith growth increment measurements pre- and post-stocking for juvenile shoal bass collected during June and August 2004 using backpack electrofishing from the Chattahoochee River, Georgia.

Date	Site	Fish ID	OTC	Increment Pre-OTC (mm)	Increment Post-OTC (mm)
6/7/04	MFD	3	1	0.28	0.14
6/7/04	MFD	4	1	0.25	0.14
6/7/04	MFD	5	1	0.28	0.16
6/7/04	MFD	6	1	0.30	0.17
6/7/04	MFD	7	1	0.26	0.18
6/7/04	MFD	8	1	0.27	0.17
6/7/04	MFD	9	1	0.26	0.12
6/7/04	MFD	10	1	0.27	0.14
6/7/04	MFD	12	1	0.26	0.17
6/7/04	MFD	13	1	0.26	0.14
6/7/04	MFD	14	1	0.21	0.14
6/7/04	MFD	15	1	0.31	0.20
6/7/04	MFD	16	1	0.29	0.14
6/7/04	MFD	17	1	0.25	0.15
6/7/04	MFD	18	1	0.21	0.13
6/7/04	MFD	19	1	0.28	0.14
6/7/04	MFD	20	1	0.28	0.15
6/7/04	MFD	21	1	0.25	0.13
6/7/04	MFD	23	1	0.29	0.11
6/7/04	MFD	24	1	0.23	0.13
6/7/04	MFD	25	1	0.24	0.12
6/7/04	CS	2	1	0.49	0.26
6/7/04	CS	3	1	0.58	0.32
6/7/04	CS	4	1	0.43	0.27
6/7/04	CS	5	1	0.40	0.20
6/7/04	CS	6	1	0.20	0.13
6/7/04	CS	7	1	0.31	0.20
6/7/04	CS	11	1	0.25	0.14
6/7/04	CS	12	1	0.35	0.16
6/7/04	CS	13	1	0.28	0.16
6/7/04	CS	14	1	0.25	0.14
6/7/04	CS	15	1	0.30	0.21
6/7/04	CS	16	1	0.24	0.14
6/7/04	CS	17	1	0.34	0.14
6/7/04	CS	18	1	0.34	0.23
6/7/04	CS	20	1	0.26	0.16

6/7/04	CS	21	1	0.26	0.13
6/7/04	CS	22	1	0.24	0.13
6/7/04	CS	23	1	0.27	0.14
6/7/04	CS	24	1	0.28	0.11
6/7/04	CS	25	1	0.28	0.11
6/7/04	PM	1	1	0.24	0.14
6/7/04	PM	2	1	0.24	0.17
6/7/04	PM	3	1	0.23	0.14
6/7/04	PM	4	1	0.24	0.16
6/7/04	PM	5	1	0.24	0.16
6/7/04	PM	6	1	0.23	0.16
6/7/04	PM	7	1	0.20	0.15
6/7/04	PM	8	1	0.27	0.18
6/7/04	PM	9	1	0.20	0.12
6/7/04	PM	10	1	0.33	0.20
6/7/04	PM	11	1	0.27	0.16
6/7/04	PM	12	1	0.28	0.16
6/7/04	PM	13	1	0.20	0.17
6/7/04	PM	14	1	0.27	0.17
6/7/04	PM	15	1	0.24	0.17
6/7/04	PM	16	1	0.27	0.14
6/7/04	PM	17	1	0.32	0.21
6/7/04	PM	18	1	0.27	0.15
6/7/04	PM	20	1	0.21	0.13
6/7/04	PM	21	1	0.23	0.16
6/7/04	PM	22	1	0.23	0.17
6/7/04	PM	23	1	0.25	0.17
6/7/04	PM	24	1	0.26	0.19
6/7/04	PM	25	1	0.24	0.15
6/7/04	PM	26	1	0.25	0.14
6/7/04	PM	27	1	0.30	0.18
6/7/04	PM	28	1	0.31	0.18
6/7/04	PM	29	1	0.27	0.15
6/7/04	PM	30	1	0.24	0.16
6/7/04	PM	31	1	0.27	0.15
6/7/04	PM	32	1	0.35	0.19
6/7/04	PM	33	1	0.21	0.12
6/7/04	PM	34	1	0.32	0.18
6/7/04	PM	35	1	0.26	0.15
6/7/04	PM	36	1	0.32	0.16
6/7/04	PM	37	1	0.21	0.13
6/7/04	PM	38	1	0.35	0.19
6/7/04	PM	39	1	0.30	0.21

6/7/04	PM	40	1	0.32	0.19
6/7/04	PM	41	1	0.32	0.22
6/7/04	PM	42	1	0.23	0.15
6/7/04	PM	43	1	0.23	0.13
6/7/04	PM	44	1	0.30	0.21
6/7/04	PM	45	1	0.27	0.18
6/7/04	PM	46	1	0.24	0.16
6/7/04	PM	47	1	0.27	0.15
6/7/04	PM	48	1	0.30	0.19
6/7/04	PM	49	1	0.25	0.18
6/7/04	PM	51	1	0.25	0.16
6/7/04	PM	52	1	0.38	0.27
6/7/04	PM	53	1	0.23	0.15
6/7/04	PM	54	1	0.23	0.14
6/7/04	PM	55	1	0.31	0.19
6/7/04	PM	56	1	0.30	0.16
6/7/04	PM	57	1	0.22	0.12
6/7/04	PM	58	1	0.25	0.16
6/7/04	PM	59	1	0.26	0.16
6/7/04	PM	60	1	0.29	0.19
6/7/04	PM	61	1	0.23	0.16
6/7/04	PM	62	1	0.25	0.15
8/2/04	MFD	18	2	0.30	0.15
8/2/04	MFD	19	2	0.21	0.13
8/2/04	MFD	20	2	0.60	0.29
8/2/04	CS	3	2	0.54	0.16
8/2/04	CS	4	2	0.37	0.18
8/2/04	CS	5	2	0.55	0.29
8/2/04	CS	12	2	0.25	0.13
8/2/04	CS	28	2	0.49	0.26
8/2/04	CS	31	2	0.26	0.20
8/2/04	PM	4	2	0.16	0.15
8/2/04	PM	16	2	0.25	0.19
8/2/04	PM	18	2	0.19	0.15
8/2/04	PM	26	2	0.33	0.19
8/2/04	PM	30	2	0.43	0.26
8/2/04	PM	33	2	0.20	0.13
8/2/04	PM	34	2	0.26	0.15
8/2/04	PM	35	2	0.24	0.16

VITA

Michael James Porta

Candidate for the Degree of

Master of Science

Thesis: EFFECTS OF ENVIRONMENTAL VARIATION ON STOCKING SUCCESS OF AN ENDEMIC BLACK BASS SPECIES IN THE CHATTAHOOCHEE RIVER, GEORGIA

Major Field: Natural Resource Ecology and Management

Biographical:

Education:

Completed the requirements for the Master of Science Natural Resource Ecology and Management at Oklahoma State University, Stillwater, Oklahoma in December, 2011.

Completed the requirements for the Bachelor of Science in Wildlife and Fisheries Management at Frostburg State University, Frostburg, Maryland in 2006.

Experience:

Fisheries Biologist, PA Fish and Boat Commission, May 2011-Present

Graduate Research Assistant, Oklahoma State University, Aug. 2009-May 2011

Biological Science Technician, U.S. Geological Survey, Aug. 2007- Aug. 2009

Fisheries Research Technician, U.S. Geological Survey, May 2006-Aug. 2007

Professional Memberships:

American Fisheries Society
Oklahoma Chapter of the American Fisheries Society
Oklahoma State University Student Subunit of the American Fisheries Society

Name: Michael James Porta Date of Degree: December, 2011

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: EFFECTS OF ENVIRONMENTAL VARIATION ON STOCKING SUCCESS OF AN ENDEMIC BLACK BASS SPECIES IN THE CHATTAHOOCHEE RIVER, GEORGIA

Pages in Study: 87 Candidate for the Degree of Master of Science

Major Field: Natural Resource Ecology and Management

Scope and Method of Study:

In the upper Chattahoochee River, Georgia, the shoal bass is limited to only small reaches of river because of the many impoundments that have eliminated habitat, impeded their movements, and reduced river temperatures. Below Morgan Falls Dam, urbanization of Atlanta, Georgia has caused water temperatures to warm due to increased impervious surface area. The increased temperature resulted in several trout kills below Morgan Falls Dam, and has created a transitional zone that currently supports populations of coldwater and warmwater fish species. Although this complicated stocking decisions, it gave fisheries managers an opportunity to restore an endemic warmwater black bass to historic population numbers. In 2003, the Georgia Department of Natural Resources and the National Park Service initiated a five-year stocking program below Morgan Falls Dam to re-establish a shoal bass population to historic numbers and to provide further sport-fishing opportunities.

Findings and Conclusions:

Stocked shoal bass dominated the total sample of adult fish collected and most of these fish were stocked at the larger size class. Based on results from multiple regression modeling, age-3 shoal bass relative abundance (catch-per-unit-effort) was positively related to mean size at stocking and spring water temperatures. Natural mortality of shoal bass in this population was low with increased longevity and low growth rates. After stocking, juvenile shoal bass growth was greatly reduced, which was visible on the otolith as a constricted daily growth increment. Daily rings subsequent to the natural mark were constricted and difficult to discern resulting in underestimated ages depending on stocking location. Shoal bass and largemouth bass tended to be older and grow faster at warmer, more downstream sites. Overall, the five-year shoal bass stocking program was successful in increasing shoal bass abundance in the Chattahoochee River below Morgan Falls Dam, but demonstrates the effects of an unnaturally cold environment on warmwater fish species.

ADVISER’S APPROVAL: Dr. James M. Long