INSTANTANEOUS GROWTH AND MORTALITY ESTIMATES

OF AGE-0 CARPSUCKERS (*CARPIODES* SPP.) IN

THE OCONEE RIVER, GEORGIA

by

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(Under the Direction of CECIL A. JENNINGS)

ABSTRACT

Instantaneous growth and mortality of age-0 carpsuckers (*Carpiodes* spp.) during 1995-2001 were estimated for Oconee River in middle Georgia. Estimates of instantaneous growth (G) ranged from 0.10 to 0.90; instantaneous mortality (Z) could be estimated only for 1995 and that rate was 0.45. Single linear regression analysis indicated that instantaneous growth rates were significantly related to summer river discharge ($r^2 = 0.95$ $p = <0.01$). The abundance of age-0 carpsuckers also was significantly related to number of days river discharge was above 3,000 cfs ($r^2 = 0.61$ $p = 0.04$). These results suggest that: 1) moderate flows during spawning and rearing are important for producing strong-year classes of carpsuckers, and 2) river discharge is variable among years, with suitable flows for strong year-class occuring every few years. River management should attempt to regulate river discharge to simulate historic flows typical for the region when possible.

INDEX WORDS: Instantaneous growth, Instantaneous mortality, Abundance, River discharge, Age-0 fishes, Young-of-the-year, Larvae, Suckers, Carpsucker, *Carpiodes*, Georgia, Dams, Warmwater system

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## DEDICATION

To my parents, Jay and Eileen Cull, who have always been both my rock and the wind beneath my wings. Also to Jim Peterson, my wonderful husband and best friend.

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# CHAPTER 1

## INTRODUCTION

Many rivers and large streams have been impounded for uses such as hydro-electrical power generation, flood control, navigation, and drinking water. Dams alter natural ecosystems and stress native plants and animals because the once-continuous, lotic system becomes a lentic system above the dam and an altered lotic system below the dam (Edwards 1978, Yeager 1993). Sediment trapping by dams cause downstream erosion, while dam releases alter water temperatures, dissolved oxygen, and nutrients. Dam releases also cause short cycle fluctuations of river discharge that can displace plants and animals to marginal or unsuitable habitats (Yeager 1993).

Environmental changes in regulated rivers can have major effects on the integrity of a river and may adversely affect fish populations. Abiotic and biotic characteristics of river ecosystems must be evaluated to determine the integrity of the environment (Lorenz et al. 1997). Abiotic information includes hydrology (e.g., river order, flood-pulses, river discharge) and geomorphology (e.g., channel width and depth, substrate) of the river (Lorenz et al. 1997). Biotic information includes aquatic species (e.g., fishes, invertebrates) abundance, diversity, and habitat (Lorenz et al. 1997).

Obligate riverine fishes that inhabit regulated systems may be poorly adapted to the changing environmental conditions that result from anthropogenic changes to river flows. Age-0 fishes (e.g., larval fishes) usually require different habitats and may react differently than adults to various environmental conditions (Scheidegger and Bain 1995). For example, age-0 fishes are vulnerable to changes in flow because nursery areas (i.e., habitats necessary for growth and survival) may be degraded or eliminated under changing flow conditions (Scheidegger and Bain 1995). Additionally, changes in flow can alter water chemistry that might lead to unsuitable conditions for some species (Edwards 1978).

Year-class strength of a species is an indication of survival during the first year; therefore, a strong year-class leads to good recruitment (Cada and Hergenrader 1980; Houde 1987; Gadomski and Barfoot 1998; Ruetz and Jennings 1999). Recruitment is defined as the number of larval fish in a given year that survive to reproductive size (Willis and Murphy 1996). Previous studies have indicated that survival rate of age-0 fishes may be significantly influenced by minor changes in environmental conditions such as river discharge, precipitation, and temperature (Mills and Mann 1985; Mann 1997; Barfoot et al. 1999). However, early life histories of many fishes are not well documented. Information on growth and mortality rates among age-0 fishes is rare, and these data are important indicators of recruitment.

Indicator species have been useful for assessing potential effects of habitat alteration (Schleiger 2000). Some suckers (Catostomidae; Schleiger 2000) are good indicator species (e.g., highfin carpsucker *Carpiodes velifer*; Pfliger 1997) because they are intolerant of unfavorable environmental conditions such as high turbidity. High sediment load and associated turbidity has plagued the Oconee River (Georgia) in the past (Dilts 1999). High-flow events in the system increase turbidity by orders of magnitude, and flow regulation (i.e., hydropeaking) increases the frequency of high-flow events compared to pre-dam conditions.

The status of *Carpiodes* spp. in the Oconee River may serve as an indicator of turbidity-associated habitat degradation. These are two undescribed carpsuckers and are most closely related to the quillback (*C. cyprinus*) and highfin carpsuckers. These two species of carpsuckers in the Oconee River are indistinguishable from each other at larval sizes. If these species have overlapping spawning periods the instantaneous growth and mortality estimates may be biased. However, quillback (Iowa Department of Natural Resources (DNR) 2005a) and highfin (Bowfishing Association of Iowa 2005) carpsuckers begin spawning at the same temperature (i.e., 55 ºF). Little is known about these two undescribed species, but they are believed to have similar life history requirements as their better known congeners.

The main goal of this research was to provide estimates of selected population parameters for carpsuckers and to relate these parameters to riverine conditions. Specific objectives for this study were to: 1) estimate instantaneous growth and mortality estimates of age-0 carpsuckers from a 60 river kilometer (rkm) reach of the Oconee River, in middle Georgia, and 2) determine if there are meaningful relationships between instantaneous growth and specific response variables (i.e., river discharge and air temperature). Baseline data of age-0 fishes are lacking in many species, including suckers. Results of this study will provide baseline information on age-0 carpsuckers (*Carpiodes* spp.) found in the Oconee River Georgia, and their response to select environmental variables.

# CHAPTER 2

# LITERATURE REVIEW

## Rivers

Rivers are complex, lotic ecosystems that continuously transport nutrients and sediments downstream, while providing habitats for many organisms (Yeager 1993). Lotic systems have been characterized in a variety of ways, and several conceptual models such as the zonation concept (Huet 1954, cited in Lorenz 1997), stream hydraulics concept (Statzner and Higler 1986, cited in Lorenz 1997), and serial discontinuity concept (Ward and Standford 1983, cited in Lorenz 1997) have been advanced to explain how rivers function. However, the river continuum concept (Vannote et al. 1980) and the flood pulse concept (Junk et al. 1989) are the two most widely accepted models of how rivers function.

The river continuum concept (RCC) describes the river system from headwaters to the mouth of the river. The RCC is based on stream orders, which are determined by either physical examination or United States Geological Survey (USGS) topographical maps. First through third orders streams are considered headwaters or small streams, fourth through sixth order streams are considered mid-sized rivers, and rivers greater than sixth order are considered large rivers (Vannote et al. 1980; Johnson et al. 1995). Mid-order streams are thought to produce the highest biotic diversity because there is the highest diversity of physical habitats and food resources (Vannote et al. 1980; Dettmers et al. 2001). Changes in aquatic species diversity as river order increases can be correlated to changes in: river discharge, water temperature, substrate size or composition, riparian zone width, and food abundance (Vannote et al. 1980). For example, headwaters are dependent on riparian input for nutrients, whereas mid-sized rivers depend on algal or aquatic plants and on transport of nutrients from headwaters. As rivers become larger, riparian input is less important, and primary production may be affected by depth and turbidity (Vannote et al. 1980).

Although the RCC is widely accepted among ecologist, physical geomorphologists find the concept incomplete and have proposed a complimentary idea called the Process Domains Concept (PDC; Montgomery 1999). This concept puts river systems into watershed context. Both the PDC and the RCC are based in part on stream channel orders (i.e., 1$^{st}$, 2$^{nd}$, 3$^{rd}$ order), but the PDC suggests that rivers have patchy characteristics at landscape levels, which means that river systems are not always continuous (Montgomery 1999, Wright and Li 2002). The patchy characteristics are a result of differences in the geomorphology, which affect the local physical habitat type, structure and dynamics (Montgomery 1999). Montgomery (1999) suggests that the PDC improves on the RCC by providing a mechanism to identify spatial differences in the range of disturbances within a river and for evaluating how habitats and biota respond to disturbances. This method works best in areas where there is fluctuating climate, and complex geomorphology (e.g., mountain ranges; Montgomery 1999).

The flood pulse concept (FPC) states that occasional flood-pulses both directly and indirectly drive the biota in rivers with floodplains (Junk et al. 1989). The aquatic/terrestrial transition zone (ATTZ) is an area of the floodplain where the river and terrestrial ecosystems interact (Junk et al. 1989). Unpredictable floods in lower ordered streams may be considered catastrophic because organisms may not be adapted to those conditions; however, annual floods in large rivers are necessary to support the natural ecosystem by supplying nutrients stored in the floodplains (Junk et al. 1989).

Johnson et al. (1995) found deficiencies with these two concepts because neither theory encompasses all large river systems. The river continuum theory is based on longitudinal perception, while the flood pulse theory is based on lateral perception (Lorenz et al. 1997). Riverine habitats span both spatial and temporal scales, and an appropriate scale must be determined when trying to characterize a river (Johnson et al. 1995, Montgomery 1999).

## Dams

Dams alter the natural flow and change the natural physical and chemical components of a lotic system by modifying current velocities, water temperatures, turbidity, and nutrients (Ligon et al. 1995). Changes to flow rate and variability, river discharge levels, and frequency of extreme flows affect most physical, chemical, and biological components in a river, including fishes (Yeager 1993). Dams can have a beneficial effect on fish habitat by creating high flows, which cleanse fine sediment from gravel beds (Reiser et al. 1989), which are necessary for successful spawning of several families (e.g., Catostomidae, Salmonidae). However, dams also can have adverse effects on native riverine fauna. For instance, high artificial flows during or soon after spawning events may dislodge eggs from gravel beds, as well as disperse larval fishes from favorable habitat to locations that may not fulfill necessary biological requirements (Scheidegger and Bain 1995; Robinson et al. 1998; Dilts 1999).

In some rivers, the lack of flood-pulses and not the flood-pulses themselves are the disturbance (Bayley 1995). For example, the Oconee River near Milledgeville, Georgia has become incised downstream of Sinclair Dam and is affected by lower frequency of inundation of the floodplain (Ligon et al. 1995). Floodplains generally have slower moving water than rivers, are rich in nutrients, and can be excellent nursery areas for some fish species. The Oconee River seems to have lower species diversity than other southeastern rivers, and some biologists have speculated that the reduction of fish diversity is caused by lower frequency of floodplain inundation that resulted from the incising of the channel (Evans 1994; Ligon et al. 1995).

Physical and chemical factors are two main components that affect river biota (Gore and Shields 1995; Ligon et al. 1995). Examples of physical factors include; particle size of the river bed and banks (e.g., sand, gravel, boulder), turbidity, velocity, and water temperature. Examples of chemical factors include; dissolved oxygen (D. O.) and nutrients (Gore and Shields 1995). These factors are interdependent, but can change independently and may influence the distribution and abundance of organisms (Winger 1981).

Small changes in physical habitat can affect stream ecosystems (Ligon et al. 1995). For example, turbidity might increase during high flows because of soil erosion or suspension of bed sediments cause an increase in the amount of sediment suspended in the water column (Ligon et al. 1995). Increased turbidity might lower ability of larval fishes to find food, but also may reduce level of predation (Johnson and Hines 1999). Water temperature is another important physical factor of river systems, and it can affect larval fishes in a variety of ways (Mills and Mann 1985). For example, warmer water temperatures indirectly affect larvae by increasing prey abundance, and directly by increasing larval digestive rates (Mills and Mann 1985).

Low concentrations of D. O. create highly stressful environments for most fishes and can affect fish physiology, growth, and behavior (Matthews 1998; Dilts 1999). Nutrients are another important chemical factor of river systems. Primary production occurs in floodplains and transforms inorganic material into organic material, which is then available for biotic consumption (DeBusk 1999). Many rivers have floodplains, which during periods of floods generate most of the necessary nutrients required by fishes (Junk et. al 1989). Often, dams prevent or lower the frequency of floodplain inundation, which benefits human communities, but can have negative effects for biota in river systems.

Instream Flow Methods

Flow regulation by dams is managed for a variety of purposes such as water supply, flood control, recreation, and biotic integrity. To sustain stream communities, approaches were developed for reducing detrimental effects of flow alteration. One approach was to determine the minimum amount of river discharge needed to sustain biota (Stalnaker 1981). For example, minimum flow requirements based on 7Q10 used the lowest mean streamflow for 7 consecutive days occurring on average once in a 10-year period. Minimum flow requirements smooth out the natural hydrograph and do not allow for streamflow variation. Natural streamflow variation has been identified as necessary for maintaining healthy lotic systems (Poff et al. 1997).

Natural streamflows vary through time (e.g., hours, days, seasons); therefore, historical streamflow data are necessary for implementing a more natural anthropogenic river discharge (Poff et al. 1997). Natural variations of streamflow include magnitude, frequency, duration, timing, and rate of change of an event (Gore, and Shields 1995, Richter et al. 1996, Poff et al. 1997). Several methods have been developed to determine flow requirements in regulated rivers. There is not an optimum method, but the method applied should depend on management goals and knowledge of limitations and assumptions of each model (Jowett 1997). These methods can be divided into historical flow approaches (abiotic), habitat approaches (biotic), and hybrid approaches that combine abiotic and biotic factors (Jowett 1997).

Historic flow-based methods for determining minimum instream flows rely on recorded or estimated river discharge over a period of time (Jowett 1997), generally a minimum of 10 years or long enough to document climate variation (e.g., droughts, floods). The Montana method, developed by Tennant (1976), is an example of historical flow approach. This method uses data reported by United States Geological Survey (USGS) records of average annual streamflow from gages, and monthly variation of stream width, depth, and velocity (from areas where USGS cable crossings are located). The Montana method is a quick and easy method for determining minimum instream flow requirements; however, this method disregards biological components and their interactions with the physical environment (Karim et al. 1995) and needs to be calibrated to the stream being studied (Estes and Osborn 1986).

Habitat-based methods for determining instream flow examine how the physical environment affects aquatic organisms to try to determine best streamflow regimes (Jowett 1997). Instream Flow Incremental Methodology (IFIM; Bovee 1982) evaluates the effect of change in streamflow on channel structure, water quality, water temperature and available suitable habitat (Orth 1987) and is an example of habitat-based method. Part of the IFIM method includes the physical habitat simulation (PHABSIM: Milhous et al. 1984), which is used to model physical habitat in relation to flow regime, water quality, and physical structures (Milhous et al. 1984). Using both biological and hydraulic components, the habitat values for a stream can be assessed for fishes at different life stages (Kondolf et al. 2000). This method is effective for deciding which management plan is most effective and is useful for regional comparisons if sediment load and basic physical and chemical components are similar (Milhous et al. 1984).

Hybrid methods for managing stream flow combine hydrological and historical flow data to assess the availability of fish habitats. Indicators of Hydrologic Alteration (IHA; Richter et al.

1996) is an example of a hybrid method. This index is composed of five categories that are related to magnitude, timing, frequency, duration, and rate of change of river flow. These five categories combine to identify thirty-two biologically significant hydrological attributes (Table 1). The IHA compares historical river discharge (at least 20 years pre-dam construction) with present river discharge to determine if, and how much, a river is degraded. The information obtained from the IHA is then used to develop the Range of Variability Approach (RVA), which identifies potential management targets based on predetermined objectives (Richter et al. 1997). The RVA is an adaptive tool and is used to determine how to best meet management targets. RVA is intended to connect scientific theories with applied river management of aquatic ecology (Richter et al. 1997). This approach is used when conservation of native biota and ecosystem integrity are the management objectives (Richter et al. 1997) and might be useful in restoring the natural ecosystem in regulated rivers (Galat and Lipkin 2000).

Riverine Fishes

Riverine fishes have been categorized in three different habitat-based groups: facultative riverine species, partially obligate riverine species, and totally obligate riverine species (Winston et al. 1991). Facultative riverine species, such as carp (*Cyprinus carpio*), are fishes that can live in lentic or lotic systems. Partial obligate species, such as Pacific salmon (*Oncorhynchus* spp.), have at least one stage in their life cycle that requires lotic habitat. Total obligate species, such as most darters (*Ethostoma* spp., *Percina* spp.), are fishes that depend entirely on lotic conditions and cannot exist in lentic systems (Holden 1979; Winston et al. 1991).

Dams are one of the main reasons for the decline of partially obligate and obligate-riverine fish species (Holden 1979). Dams affect fishes by altering physical and chemical components of the river, prey item diversity and abundance, and susceptibility to predation (Winston 1991). Other effects of dams include blocking migrations and altering riverine habitat (Yeager 1993). These factors can negatively affect reproduction, survival, and food supply. Changes in habitat may allow non-native fishes, which tend to be habitat generalists, to thrive and out-compete native fishes, which tend to be habitat specialists (Galat and Zweimuller 2001). Dams also fragment home ranges of some species and can lead to local extirpation and possibly extinction (Winston et al. 1991). Adult fishes may be more capable of adapting to changes in a regulated river system than larvae and juveniles because larval fish habitats (i.e., nursery areas) often are small, shallow areas vulnerable to sudden changes in water levels, water temperature, and levels of dissolved oxygen (Houde 1994).

Some studies have examined the effects of environmental variables on larval riverine suckers. For example, a study on the effects of turbidity on predation of endangered razorback suckers (*Xyrauchen texanus*) found that while the larval suckers preferred lower turbidity environments, predation by both native (Colorado pikeminnow, *Ptychocheilus lucius*) and non-native (green sunfish, *Lepomis cyanellus*) fishes increased (Johnson and Hines 1999). Other examples are studies on threatened larval robust redhorse (RRH; *Moxostoma robustum)*: in one study larval RRH were strong enough swimmers to withstand currents that are available during hydropower generation (Ruetz and Jennings 2000). In another study, growth and survival of larval RRH and notch-lip redhorse (*M. collapsum*) exposed to high-flow velocities were lower than when these fishes were exposed to low-flow velocities (Weyers et al. 2003). These studies suggest that larval suckers would be appropriate indicator species of environmental degradation.

Growth and Mortality of Fishes

Growth and mortality estimates for early life stages are important tools used to determine the level of recruitment in fish populations. These estimates may be taxa-specific or ecosystem-specific (Houde 1994). Intuitively, riverine fishes in highly-variable flowing environments have high metabolic costs associated with living under such conditions compared to stable environmental conditions. Increased metabolic costs can result in reduced growth rates and higher mortality for resident fishes compared to fishes in stable flow environments (e.g., Ruetz and Jennings 1999). Further, fluctuating river discharge affects variables such as water temperature, dissolved oxygen, turbidity, current velocity, and loss or deterioration of nursery and rearing habitats, which also can influence growth and mortality (Barfoot et al. 1999). Small differences in growth and mortality rates of early life stages can produce large annual fluctuations in year-class strength (Houde 1987; Claramunt and Wahl 2000). Divergence from typical environmental characteristics can produce extremely poor or extremely favorable year-classes, which if continued over time, can have profound affects on the population (Houde 1987). Studies of growth and recruitment success over time can help identify environmental conditions that cause high stress for fish populations.

Hackney and Webb (1978) developed a length-based equation to estimate instantaneous growth and mortality of age-0 fishes. For these equations to be accurate, sampling must be done at regular intervals throughout the reproductive season (Cada and Hergenrader 1980). This length-based model has been used in several studies and has been shown to be an effective tool for understanding fish populations when sample sizes are large (Cada and Hergenrader 1980; Zigler and Jennings 1993; Ruetz and Jennings 1999). Effects of specific environmental variables on the population can be inferred when such studies are done routinely (i.e., among years; Hatch and Underhill 1988). Instantaneous estimates have shown that environmental factors (e.g., river discharge, water temperature, turbidity) affect the growth and mortality of early life stages of fishes (Cada and Hergenrader 1980; Barfoot et al. 1999).

## Growth

Growth rates of fishes are highly variable because environmental factors such as water temperature, dissolved oxygen (Moyle and Cech 1988), and river discharge (Weyers et. al 2003) can influence growth. Growth also is affected by density-dependent factors such as competition and prey availability (Moyle and Cech 1988) or because of genetic differences among individuals (Ricker 1975).

Growth is assessed in several ways (e.g., absolute growth, relative growth, and instantaneous growth), each of which is based on change in length or weight (Ricker 1975). Absolute growth rate is measured $l_2 - l_1$ or $w_2 - w_1$ per unit of time, relative growth $(l_2 - l_1)/ l_1$ or $(w_2 - w_1)/ w_1$ per unit of time, and instantaneous growth $\log_e l_2 - \log_e l_1$ or $\log_e w_2 - \log_e w_1$ per unit time (Ricker 1975; Busacker et al. 1990; Van Den Avyle 1993).

Determining growth of larval fishes usually is achieved by one of two common methods: estimating daily growth from marks on bony structures or obtaining instantaneous estimates from length or weight (Zigler and Jennings 1993). Annuli are marks on hard structures such as bones, fin spines, otoliths and scales that show growth from year to year. Back-calculations of these marks are used to determine age and growth (Bagenal and Tesch 1978; Moyle and Cech 1988). Instantaneous estimates use an exponential equation to measure the ratio change in weight (Bagenal and Tesch 1978) or length (Hackney and Webb 1978) over the change in time.

Generally, growth and mortality are not exponential over a long period of time, but are acceptable approximations over a short period of time (Bagenal and Tesch 1978).

Comparisons of estimates of growth and mortality rates based on an exponential equation between length-based and otoliths methods found both methods effective (Zigler and Jennings 1993). The method used for estimating instantaneous growth and mortality for larval fishes depends on results of sampling. Length-based methods require large numbers of fish to obtain accurate estimates, whereas the otolith method involves fewer fish but more laboratory work that is more time consuming.

## Mortality

Mortality is assessed several ways (e.g., annual and instantaneous). Annual mortality is caused by predation, disease, and environmental (Ricker 1975; Van Den Avyle 1993) and is measured by catch-curve analysis of field data (Essig and Cole 1986). Instantaneous mortality uses differential equations to estimate year-class strength (Essig and Cole 1986). Observations have shown that the number of fish in a year-class decline at a rate proportional to the number of fish alive at a particular point of time (Everhart and Youngs 1981).

Ricker (1954) discussed a theory that mortality levels are set by density-dependent mechanisms and that these could affect the abundance of both adult and young fishes. Many mechanisms of mortality can be either strongly or weakly density-dependent or not at all because the mechanism of mortality can occur over a variety of densities (Ricker 1954). Most physical causes of mortality (e.g., water temperature, floods) are compensatory, and the extent of the rate of mortality depends on the density of the fish population (Ricker 1954). Some types of compensatory mortality include: density-dependent spawning and competition (Ricker 1954).

Suckers (Catostomidae)

Suckers belong to the order Cypriniformes, which numerically dominate the freshwaters of North America and Eurasia (Moyle and Cech 1988). Suckers are soft-rayed fishes with toothless jaws, scaleless head, cycloid scales, forked tail, and a continuous dorsal fin (Pflieger 1997; Jenkins and Burkhead 1993; Iowa DNR 2005b). Most species in this family have protractile mouths and use teeth on the pharyngeal arch, which is a modification of the last gill arch (Jenkins and Burkhead 1993), to grind food items such as invertebrate shells (Pflieger 1997; Moyle and Cech 1988). Suckers are able to find food items by touch, taste, and sight (Becker 1983; Iowa DNR 2005b).

Suckers have been used as indicator species (e.g., as a metric in Index of Biotic Integrity) because many species are sensitive to physical and chemical habitat degradation (e.g., turbidity, D.O., temperature; Karr 1981) during various life stages. For example, the abundance and distribution of suckers in Iowa has declined over the last century, and the decline has been attributed to the decrease in environmental habitat quality (Iowa DNR 2005b). Suckers generally inhabit environments with clean gravel beds, which are important for feeding and reproduction. Suckers consume primarily benthic invertebrates such as freshwater mussels, which require clean substrate for survival (Jenkins and Burkhead 1993). Suckers are lithophilous spawners and require clean gravel beds to successfully spawn (Emery et al. 1999). Egg hatch and larval emergence from gravel are dependent on low rates of sedimentation in gravel beds (Jenkins and Burkhead 1993; Rabeni and Smale 1995; Dilts 1999). Sediment deposition can fill interstitial spaces in gravel beds, which results in reduced water flow through the substrate. Reduced water flow through the interstitial spaces lowers dissolved oxygen levels, partly caused by the accumulation of metabolic waste of eggs and newly-hatched larvae (Dilts 1999). Swim-up success also may be lowered with increased sedimentation by obstructing larvae from emerging from the gravel (Dilts 1999).

The two carpsucker species that I am studying are currently undescribed, but are related to the quillback carpsucker (*C. cyprinus*) and the highfin carpsucker (*C. velifer*; H. Bart Tulane University - pers. comm.). Dr. Bart presently is collecting specimens in the eastern region of the United States to describe these carpsuckers. Both quillback and highfin carpsuckers are classified as being intermediately tolerant for North Carolina's Index of Biotic Integrity program (North Carolina Department of Environmental and Natural Resources 2001). Quillback and highfin carpsuckers have a lower tolerance of turbidity and pollution than other carpsuckers (Jenkins and Burkehead; 1993; Kay et al. 1994). For example, the river carpsucker replaces quillback and highfin carpsuckers when waters become turbid (Pflieger 1997). These species' intolerance of high turbidity makes them a good indicator species for assessing the aquatic environment.

## Synopsis

River ecosystems are dynamic and native fishes are well adapted to the rivers natural hydrograph. However, when a dam regulates a river, changes in the natural hydrograph can have short-term (e.g., sudden change in water-temperature) and long-term (e.g., increased sedimentation) consequences for the ecosystem. Variable flows caused by dams can displace fishes to marginal or unsuitable habitats. Such displacement can affect growth and mortality rates of age-0 fishes. Age-0 fishes are more vulnerable than adult fishes to sudden environmental changes; therefore, they are a delicate link to a successful adult population. Some catostomids such as quillback and highfin carpsuckers may be used as an indicator for a river's overall integrity because they are intolerant of adverse environmental conditions. By assessing different flow regimes and biotic response of indicator species, predictable patterns of response might be uncovered and used for adaptive-management of hydropower regulation for the benefit of both humans and aquatic species in river systems.

# CHAPTER 3

## MATERIALS AND METHODS

Study Area

The Oconee River is part of the Altamaha River basin, which includes the Altamaha, Oconee, and Ocmulgee rivers (Figure 1). The Oconee River passes through two large reservoirs, Lakes Oconee and Sinclair. Sinclair Dam, which closes the lower reservoir, is located in Milledgeville, Georgia above the Fall Line at about 235 river kilometers (rkm) from the mouth of the Altamaha River. The study area is located near Toomsboro, Georgia (between Milledgeville and Dublin) and encompasses rkm 130 - 190 (Figure 1), which is in the transitional zone between the Piedmont and the Upper Costal Plain physiographic regions. About half the total area of the study site was sampled during this study.

The Oconee River at the study area is a fourth-order river (USGS topo map 1:2400 scale 1973), with substrate composed primarily of coarse sand and pea gravel (Evans 1994). The gradient of the study reach is 0.27 meters/ kilometer (DeLoreme 3-D TOPO Quad 1999). The main channel is sinuous with alternating deep channels on one side and sandbars on the other. The Oconee River below Sinclair Dam is highly incised, and the floodplain inundates less frequently than prior to the construction of Sinclair Dam (Ligon et al. 1995). Sinclair Dam (completed in 1953) uses two turbines to generate power during peak demands and also is used as the reserve for pump-storage operations of Wallace Dam (completed in 1980) above Lake Sinclair (Hendricks 2002). Prior to the construction of Sinclair Dam, the mean river discharge at

Dublin, Georgia was 5,243 cfs (SD = 1,714; 1898 - 1953); after construction of the dam the mean river discharge was 4,549 cfs (SD = 1,455; 1954 - 2001; USGS 2005a).

Beginning in 1997, a negotiated flow agreement for Sinclair Dam (Table 2) was implemented to enhance reproductive success of a Georgia-threatened fish (robust redhorse: *Moxostoma robustum*; Hendricks 2002). The flow agreement calls for run-of-the-river flows during the robust redhorse spawning and early rearing period (SERP; May 1st June 10th) and increased the minimum flow as well as lowering flow variability throughout SERP (Hendricks 2002).

Fish Sampling and Water Quality Measurements

Fish and water quality data were collected from 1995 through 2001 as part of a study on reproductive and recruitment success of robust redhorse. For that project, light traps, push-nets, and seines were used to collect fishes. Carpsuckers were the most abundant suckers caught in the samples and were caught most frequently in seine nets. As a result, data used for this study were limited to carpsuckers captured in seines.

A seine net (6.1 x 1.8 m, 4.76-mm mesh) was used to sample fishes from the littoral zones along sand bars from May through July each year. The seine was stretched perpendicular to shore and pulled parallel to shore, and the distance from shore and length of tow were recorded. Generally, tows were made downstream to a predetermined point. There were many sandbars throughout the study area, and three sandbars were chosen at random during each sampling event. Sandbars were sampled once a week from 1995 to 1999; and once a week during May and June, three times a week during July for 2000 and 2001. Each sandbar was sampled in three different areas. Sandbars were sampled uniformly and at random without replacement until all sandbars were sampled. This process was continued through the sample season. Samples were preserved immediately in 10 - 12% buffered formalin from 1995 to 2000. In 2001, one third of the samples were preserved in 90% ethanol to allow for genetic identification of robust (*M. robustum*) and notch-lip (*M. collapsum*) redhorse.

Water temperature was measured with a VWR® digital temperature probe, dissolved oxygen was measured with a YSI® dissolved oxygen meter, and turbidity was measured with a Hach® portable turbidimeter (Model 2100P). These measurements were made immediately after sampling had been conducted. Daily river discharge (cfs) for the Oconee River, near Oconee, Georgia (i.e., Ball's Ferry boat ramp, USGS gauge number 02223248) was downloaded from US Geological Survey website (USGS 2005b) at a later date.

Sample Processing and Fish Identification

Seine samples were processed at the Whitehall Fisheries Laboratory (University of Georgia, School of Forest Resources). Sample processing included draining and rinsing formalin or ethanol from the samples, extracting fishes from debris, identifying species to lowest possible taxa, and separating carpsuckers from other fishes. A dissecting scope (10x eye pieces, option for polarized light) was used to identify morphometric (e.g., body depth, melanophores) and meristic (e.g., myomeres, fin rays) characteristics (Hogue et al.1976; Kay et al.1994) to separate carpsuckers from other fishes. The two species were grouped together because carpsucker larvae cannot be visually differentiated at this size. Total length of carpsuckers was measured to the nearest 0.1 mm with jaw-type dial calipers. Carpsuckers were grouped into size-classes by 1-mm increments (e.g., 15.0 - 15.9 = 15 mm, TL).

Instantaneous Growth and Mortality

Instantaneous growth and mortality rates were estimated using the method described by Hackney and Webb (1978). This model assumes that instantaneous growth and mortality rates for larval carpsuckers are constant with age, larval carpsuckers initially recruit to the sample gear (i.e., seine net) at about the same size, and all size-classes used for estimates are equally vulnerable to the sampling gear. Also, to reduce bias associated with sampling efficiency, the size range of carpsuckers used to estimate instantaneous growth was based on the ascending arm of the catch curve, and mortality was based on the descending arm of the catch curve. To ensure a high rate of accuracy and precision, only samples that have five or more carpsuckers per size-class per Julian date should be used for instantaneous growth and mortality estimates (Van Den Avyle 1993).

Three formulas were used in this length-based method: abundance mean date (an intermediate step to determine instantaneous growth and mortality), instantaneous growth, and instantaneous mortality. Abundance mean date is the Julian date at which a given size-class is most abundant (Equation 1):

$$D = (\Sigma LJ)/(\Sigma L) \qquad (1)$$

where L is the total larval abundance for each collection date of 1-mm size-class, and J is the Julian date of collection. Age (t) was calculated for each 1-mm size-class by subtracting D (abundance mean date) for the smallest size-class from each of the subsequent size-classes. An exponential equation was then fit to the size-class (L) and age data to estimate instantaneous growth (G) and mortality (Z) for each year.

Instantaneous growth is a point estimate of the average rate at which larval fish grow for a given unit of time (Equation 2):

$$\ln (L) = \ln (a) + Gt \tag{2}$$

where ln is the natural logarithm, L is the total length of the lower limit of each size-class, a is the length intercept, G represents the instantaneous growth rate, and t represents age in days.

Instantaneous mortality is a point estimate for a given species of the average rate at which larval fish die for a given unit of time (Equation 3):

$$\ln (N_t) = \ln (N_o) - Zt \tag{3}$$

where ln is the natural logarithm, $N_t$ is the predicted larval abundance at age t, $N_o$ is the abundance axis intercept, Z represents instantaneous mortality rate, and t is age in days.

<u>Data Analysis</u>

Estimates of instantaneous growth were compared using analysis of covariance to compare slopes of the regressions among years. Instantaneous mortality estimates were evaluated using the same method. There were not enough data to analyze instantaneous growth for 1997 because only 1 carpsucker between 8 – 29 mm TL was collected during the sampling period. Also, instantaneous mortality could only be estimated for 1995 because in subsequent years the abundance mean date of some of the larger size-classes occurred earlier than the abundance mean date for smaller size-classes.

Kolmogorov-Smirnov was used to test for normality, and the Levene Median test for constant variance (e.g., SAS 2005, Sigma Plot 2000) for growth and air temperature (°F) plots and growth and discharge (cfs) plots. Data for instantaneous growth and air temperature, and river discharge were normal with homogeneous variances; therefore, data were modeled using linear regression (Sigma Plot 2000).

Instantaneous Growth as a Function of Air Temperature and River Discharge

Air temperature and river discharge (April through July) were modeled with linear regression to determine if estimated instantaneous growth rates were related to these variables. Because data were highly variable among years, an alpha level of 0.10 was used to indicate significance.

Water temperatures were only taken on days when samples were collected; therefore, continuous water temperature data were not available for the study area. Instead, monthly mean air temperatures from Macon, Georgia were analyzed (Georgia State Climatology Office, 2005). Macon was the closest city to the study area for which continuous air temperature data were available. April through July data were used because carpsuckers begin spawning in April, and sampling did not occur after July in 2000 and 2001.

Daily mean river discharge (cfs) data were obtained from the U.S. Geological Survey web site from the Oconee River, near Oconee, Georgia (i.e., Ball's Ferry gauging station,USGS gauge no. 02223248; USGS 2005b). Another gauging station (Avant Mine, USGS gauge no. 02223056; USGS 2005c) is located at the upper end of the study area, but records for Avant Mine site are not continuous. However, Avant Mines's flow pattern closely resembles Ball's Ferry (Figure 2).

Linear regression was used to determine if instantaneous growth estimates among years were related to minimum, mean, maximum monthly air temperatures of April, May, June, and July; as well as spring (April - May), summer (June - July) and spring-summer (April - July) monthly mean air temperatures. Also, linear regression was used to determine if instantaneous growth estimates were related to daily mean river discharge for: peak flow (cfs); low flow (cfs); number of days above 3,000, 2,000, and 1,000 cfs; number of days below 6,000, 3,000, 2,000, and 1,000 cfs. Percentiles of flows from 1995 - 2001 were used as a guideline to determine number of days river discharge was above or below river discharge levels (Figure 3). Also, seasonal river discharge (cfs), spring (April - May) discharge (cfs) monthly mean, summer (June - July) discharge (cfs) monthly mean, and spring-summer discharge (cfs) monthly mean were selected for analysis.

Abundance

Data for instantaneous growth and mortality were limited, so linear regression was used to determine if total annual abundance of age-0 carpsuckers (Table 8) was related to air temperature, river discharge, and instantaneous growth estimates. Most of the data used to model the relationship between abundance and air temperature and with river discharge were normal with homogenous variances. Data for May maximum air temperature, spring and summer mean discharge, and number of days below 3,000 cfs were not normal and were square-root transformed. The transformed abundance data were then modeled using linear regression (Sigma Plot 2000) to evaluate the relationship between age-0 carpsucker abundance to air temperature and to river discharge. However, there were no significant relationships with transformed data to either river discharge or air temperature.

## CHAPTER 4

## RESULTS

Fish Sampling and Water Quality

During 1995 and 1996, hydropeaking occurred during the SERP; however, run-of-the-river during SERP began in 1997. Precipitation was high in the beginning of 1998, which resulted in high river discharge (i.e., flood stage) from January through mid-May. A drought began that summer and continued throughout the duration of the study (Appendix A1).

Sampling effort and results were highly variable among years (Table 3), partly because of logistic constraints. Sampling opportunity was inversely related to water levels; therefore, fewer seine samples were collected during high water years than in drought years because of reduced access to sandbars (i.e., flooded partially or completely). The number of seine hauls ranged from 55 to 263 annually, and the number of fishes collected ranged from about 5,000 to 61,000 annually. Total area sampled ranged from about 2,500 $m^2$ to 17,000 $m^2$. The size of captured carpsuckers range was constrained to between 8 and 29 mm (TL), since the length-frequency curve suggests that this is the range carpsuckers are most susceptible to the gear (i.e., there were few specimens collected outside this range). The number of carpsuckers (8 - 29 mm TL) collected ranged from 1 to 1,182 annually.

May – July monthly mean water temperature measured during sampling ranged from 21.6 to 31.5 °C, and increased as the season progressed. During study years, May water temperatures ranged from 21.6 to 25.3 °C, June ranged from 23.9 to 28.2 °C, and July ranged from 27.6 to 31.5 °C (Table 4). Monthly mean dissolved oxygen varied among sites and days throughout the sample season and ranged from 6.5 to 8.5 mg/l (Appendix A2). Turbidity ranged from 6.9 to 48.4 ntu's (Appendix A2). Turbidity levels were lowest during drought years with stable flows, but increased when water released from the dam for hydro-generation purposes or river flows increased naturally (i.e., from rainfall).

Air temperatures for monthly minimum, mean, maximum as well as seasonal means for spring (April – May), summer (June – July) and spring through summer (April – July) were variable among years. Coolest monthly mean air temperatures were April 2000 (60.6 EF), May 1999 (70.2 EF), June 1995 (76.3 EF), and July 2001 (80.5 EF), and the warmest monthly mean air temperatures were April 1999 (67.5 EF), May 2000 (75.2 EF), June 1998 (81.9 EF), and July 1998 (84.4 EF;). Spring monthly mean air temperature ranged among years from 67.6 - 69.3 EF; summer ranged from 78.8 - 83.2 EF; spring through summer ranged from 73.2 - 75.8 EF (Appendix 3).

River discharge was highly variable from April through July among study years (lowest river discharge was 373 cfs in July 2000; highest river discharge was April 12,530 cfs in 1998 Appendix A4). In general, the lowest monthly mean river discharge (cfs) occurred during April - July 2000, and the highest river discharge occurred during April - May 1998, June 2001, and July 1997 (Appendix A4). Daily mean river discharge also varied highly among years (Appendix A5).

Instantaneous Growth and Mortality Estimates

The catch-curve mode varied among years, so that the range of size-classes analyzed for instantaneous growth and mortality were different among years (Table 5). The original intent outlined in Material and Methods was to use samples containing ≥ 5 carpsuckers per size-class per Julian date. The number of days that age-0 carpsuckers were collected was highly variable for all years. When examining data with ≥ 5 individuals, the number of days age-0 carpsuckers were collected were low (n=33); therefore, although using ≤5 individuals is not ideal, capture days with n = 1 age-0 carpsucker were used in instantaneous growth equations because they increased the number of days (n = 43) when age-0 carpsuckers were collected. Carpsucker data for 1997 were not analyzed for instantaneous growth or mortality because only 1 carpsucker between 8 and 29 mm's (TL) was caught from April - July.

Estimated instantaneous growth rates were variable and ranged from a high of 0.90 ($r^2$ = 0.94, $p$= 0.01) in 1995 to a low of 0.10 ($r^2$ = 0.54, $p$= 0.01) in 2000 (Table 6). Significant differences ($p < 0.05$) occurred for 10 out of 15 among-year comparisons (Table 7). There were only enough data to estimate instantaneous mortality for 1995 (0.45, $r^2$ = 0.72, $p$= <0.01).

Instantaneous Growth as a Function of Air Temperature and River Discharge

Estimates of instantaneous growth were not related to air temperatures ($r^2$ ranged between <0.01 to 0.44; Appendix A6). Estimates of instantaneous growth showed a strong relationship with summer mean river discharge ($r^2$ = 0.71, $p$= 0.04; Appendix A7). Other river discharge variables had $r^2$'s that ranged from <0.01 to 0.40 (Appendix A7). However, if an exponential model was used, the $r^2$ increased from 0.71 to 0.95 (Figure 4). This result suggests that this model fits the data best and that there may be a strong relationship between summer mean river discharge and instantaneous growth of carpsuckers in the Oconee River near Toomsboro Georgia.

Abundance

Age-0 carpsuckers abundance was not related to air temperature ($r^2$ ranged from <0.01 to 0.37 Appendix A8) or to river discharge ($r^2$ ranged from 0.05 to 0.36; Appendix A9). Although age-0 carpsuckers were collected in a large geographic area (~30 rkm), the river discharge data used in the analysis were from Ball's Ferry gage (USGS gauge no. 02223248), and sampling was more concentrated in this reach (~10 rkm); therefore, age-0 carpsucker abundance from Ball's Ferry (BFA) (Table 8) was analyzed with river discharge, air temperature, and instantaneous growth. Significant relationships were not detected between BFA and air temperature ($r^2$ ranged from 0.02 to 0.48; Appendix A10) or to instantaneous growth estimates ($r^2 = 0.12$; Appendix A11). There was a significant relationship between BFA and the number of days river discharge was > 3,000 cfs ($r^2 = 0.61$ $p = 0.04$; Appendix A12). Other river discharge variables had $r^2$'s that ranged from 0.16 to 0.56 (Appendix A12).

# CHAPTER 5

# DISCUSSION

## Growth and Mortality

Attempts to obtain estimates of instantaneous growth and mortality for age-0 carpsuckers in the Oconee River, Georgia were partly successful. There were sufficient data to produce estimates of instantaneous growth for all study years except 1997. Conversely, there was only one year (1995) for which there were sufficient data to estimate instantaneous mortality. Estimates of growth and mortality can be influenced by method used and data available. For example, at least 5 fish per size-class per Julian day should be used to obtain unbiased estimates of growth and mortality (Van Den Avyle 1993). The data in the present study included n< 5 age-0 carpsuckers per size-class to ensure there were sufficient data available to estimate instantaneous growth and mortality. Previous estimates for other age-0 carpsucker species were not available for comparison; therefore, estimates of this study were compared with instantaneous growth and mortality estimates (i.e., Hackney and Webb 1978) of age-0 warm- and cold- water species (Table 9). Instantaneous growth estimates for this study were substantially higher, and the instantaneous mortality estimate was relatively higher than similar estimates of other species (Table 9). Nonetheless, the growth estimates presented here are useful for examining the relative differences in growth among years for age-0 carpsuckers in the Oconee River, GA, and can serve as a baseline for comparisons with other southeastern age-0 carpsuckers in the future.

Age-0 carpsucker growth was significantly related to river discharge during the first few months of life. River discharge affects growth in many ways, including quantity and quality of appropriate nursery habitat. Edge-habitats generally have warmer temperatures and slower water currents than main channels and are considered good nursery areas (Scheidegger and Bain 1995). Observations of the Oconee River during the study period suggest that during years of low river discharge (i.e., 1999 and 2000 were drought years), edge-habitat was increased (e.g., sandbars more exposed, increasing extent of habitat). The years that had highest growth (i.e., 1995, 1996, and 2001) had variable water discharge and may have provided better access to nursery habitats than years with low-stable flows. However, timing and periodicity of flows is highly relevant, especially for swim-up larvae. For example, under higher current velocities, newly hatched redhorse larvae had difficulty swimming to the surface to inflate their swim bladders during high-velocities; these fishes also had decreased growth that was most likely a result of the amount of energy larvae expended maintaining position in the water column (Weyers et al. 2003). Similarly, Archer et al. (2000) observed that growth of larval fishes was negatively related to abnormally high summer river discharges. Some studies (Toneys and Coble 1979, Archer et al. 2000, Braaten and Guy 2004) have suggested that smaller age-0 fishes in the fall might experience increased winter mortality.

Abundance

Total abundance of age-0 fishes is another method used to assess year-class strength (e.g., Jowett et al. 2005). Although age-0 carpsucker abundance from the total study area (~30 rkm) was analyzed, there was a stronger relationship between age-0 carpsuckers abundance and the selected environmental variables from part of the study area referred to as Ball's Ferry (~10 rkm). Ball's Ferry was sampled most frequently; and for at least three years, > 60% of the total abundance of age-0 carpsuckers were collected in this sample area. Total abundance and abundance from BFA of age-0 carpsuckers were highest in 1995, 1999, and 2000. Sampling efficiency may have resulted in higher abundance of age-0 carpsuckers collected in 1999 and 2000 because these years were drought conditions with low stable flows that provided more abundant edge-habitat. Greater sampling effort (i.e., the number of seine hauls for 1999 - 2001 were almost double from 1995 - 1998) might explain higher abundance of age-0 carpsuckers in 1999 and 2000, however, this was not the case in this study because the catch was not related to effort. Instead, greater abundance during 1999 and 2000 may be a result of natural variability in year-class strength among years. Such a life-history strategy would allow carpsuckers to produce a strong year-class every few years to maintain a stable population.

In this study, age-0 BFA was significantly related to the number of days river discharge was greater than 3,000 cfs. Previous studies of warm-water larval fish (including catastomids) abundance have suggested that abundance may be linked to timing and duration of shallow-water habitats (Bowen et al. 1998, Freeman et al. 2001). However, the abundance of larval catastomids in another warm-water system was positively related to extended periods of strong flows (Scheidegger and Bain 1995). A positive effect of high, prolonged flows might decrease density-dependent mortality of age-0 fishes by dispersing age-0 fishes (Nilo et al. 1997). Density-dependent factors may include cannibalism, competition, and predation (Ricker 1954, Crecco and Savoy 1987). In this study, there was a weak relationship between age-0 carpsuckers instantaneous growth estimates and BFA, which does not support the density-dependent theory for carpsuckers in the Oconee River during study years.

Management of River Systems

Several methods have been developed to determine the amount of water needed in a river to maintain aquatic species (IFIM, RVA; Jowett 1997). However, responses of aquatic species are variable along a gradient of hydrological alteration and are not always linear (Jowett 1997). River systems are highly dynamic, and aquatic species have evolved to adapt to changing environments within a range of lower and higher river discharge. Thus, specific minimum flow to sustain all species is probably not plausible (Jowett 1997) because fishes have different optimum requirements to sustain populations. For example, some *Lepomis* spp. have poor year-class strength when flows are low, whereas some *Micropterous* spp. in the same system have high year-class strength (Bonvechio and Allen 2005). In contrast, the highest growth of age-0 carpsuckers observed in this study occurred during median flows. This suggests that river systems with *Lepomis* spp., *Micropterous* spp, and *Carpiodes* spp. populations require low-, median- and high-flows among years during spawning and rearing periods to sustain these species populations.

River systems are managed to the extent that environmental conditions permit. During years with high precipitation, dams must release considerable quantities of water to prevent flooding above the dam or to prevent the dam from being washed out. During droughts, certain water levels in a reservoir need to be maintained for purposes such as irrigation and drinking water, and releasing more than the minimum flow requirement (mandated by a dams' license with FERC) may be difficult. Natural environmental cycling (e.g., seasons with high, normal or low precipitation) affects the flow regime and should help maintain diverse river conditions, which would allow different species to produce high year-classes at different times (e.g., seasons, years; Poff et al. 1997, Richter et al. 1997). However, if unfavorable environmental conditions persist over several years, populations of short-lived species (*Lepomis* spp. ~5 years) might be drastically reduced or eliminated from a riverine system (Bonvechio and Allen 2005). However, longer-lived species (e.g. *Micropterous* spp. ~12 years) may not be affected as severely (Bonvechio and Allen 2005). Quillback and highfin carpsuckers (species most closely related to carpsuckers in this study) are considered relatively long-lived because their life spans are estimated between eight and 11 years (Woodward and Wissing 1976); consequently, carpsucker populations probably do not require strong year-classes annually, but an occasionally strong year class (e.g., every 2 to 3 years, as observed in this study) should be sufficient to sustain a population.

Sampling Considerations

The ability to obtain instantaneous growth and mortality estimates were limited by the number of age-0 carpsuckers in a size-class per Julian day (e.g., number of age-0 carpsucker in size class 15 mm on Julian day 140), as well as difficulty in evaluating effects of environmental variables on growth, mortality, and abundance because of lack of water temperature data. To correct these limitations, I suggest the following sampling protocol for age-0 carpsuckers (or other larval fishes). Sampling should take place over a period of years in an attempt to include many different environmental conditions (e.g., floods, droughts); for the southeast, a four - six year study should provide enough environmental variation to obtain a range of river discharges. Sampling should begin during the spring shortly before carpsuckers initiate spawning to avoid missing first larvae. Spawning generally begins at about 18 ºC (Woodward and Wissing 1976). Sampling should continue through early fall because carpsuckers have a prolonged and intermittent spawning period (Parker and Franzin 1991, D’ Amours et al. 2001). Because the majority of age-0 carpsuckers were collected in a few days over the sample period, sampling should take place frequently (e.g., 3 to 5 days a week). Continuous water temperature data would be extremely useful rather than using air temperatures because water temperatures have direct effects on age-0 fishes.

Results of data analysis may appear simple, but driving forces behind results may be complex (Railsback et al. 2002). In this study, growth seems to be driven primarily by river discharge; however, higher growth estimates during median flows might actually be a result of habitat availability, food availability, and competition, which in turn may be affected by river discharge. Therefore, subsequent studies should carefully consider the types of data to collect when designing a study. Some data that might be included are: river discharge, water temperature, prey type, prey availability, turbidity levels (i.e, factors that affect successful prey capture), and predation. Lastly, if there are not enough individuals (i.e., $n < 5$) per size class per Julian date, then daily marks on otoliths may be a better method for estimating instantaneous growth and mortality (Zigler and Jennings 1993).

## Conclusion

Altered rivers can create challenges for native fishes, especially age-0 individuals, which may be more vulnerable to changes in the environment than older age classes. If river alterations lower the quality of the environment, larval fishes may have lower growth and higher mortality than larvae in higher quality environments, which would lower population levels over time. Suckers often make good indicator species of determining the degree of degradation of river ecosystems (Schleiger 2000) for several reasons. For example, they generally prefer environments with clean gravel beds (e.g., important for feeding and reproduction; Jenkins and

Burkhead 1993), and also are sensitive to river discharge (Travnichek and Macenia 1994, Bowen et al. 1998, Weyers et al. 2003).

Year-class strength is an important indicator of potential recruitment, with higher frequency of strong recruitment leading to greater population sustainability. Since many rivers in the United States and elsewhere are impounded, studying early life requirements of many fish species is important for determining species response to flow alterations. River discharge can affect year-class strength by altering several characteristics such as water temperature, turbidity, and habitat availability that affect growth and survival of age-0 fishes. This study only considered river discharge and air temperature and was able to identify general relationships between discharge and growth and abundance of age-0 carpsuckers. Future studies that assess possible factors affecting year-class strength should consider multiple factors or combination of factors because simple models may be insufficient for determining mechanisms that drive year-class strength.

Year-class strength can be assessed with several methods (e.g., growth, mortality, abundance). Growth estimates obtained in this study were higher than estimates found for other species (Zigler and Jennings 1993, Barfoot et al. 1999, Ruetz and Jennings 1999). Instantaneous growth estimates and abundance were related to moderate summer river discharge. These results suggest that year-class strength of suckers is strongly influenced by discharge during the first few months of life. In addition, moderate river discharge may lead to greater growth and year-class strength of age-0 carpsuckers compared to when river discharge was higher or lower; these moderate river discharges differ from river discharges that benefit other fishes in riverine systems (e.g., *Lepomis* spp. and *Micropterous* spp.; Bonvechio and Allen 2005). Therefore, management of regulated rivers should include variable river discharges that are similar to pre-dam hydrographs (i.e., historical hydrograph) when possible.

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Table 1. Summary of 32 hydrological parameters used in the Indicators of Hydrologic Alteration (IHA), and their characteristics (Ricther et al. 1997).

| IHA statistics group | Regime characteristics | Hydrological parameters |
|---|---|---|
| Group 1: Magnitude of monthly water conditions | Magnitude<br>Timing | Mean value for each calendar month (12) |
| Group 2 : Magnitude and duration of annual extreme water conditions | Magnitude<br>Duration | Annual minima 1-day means<br>Annual maxima 1-day means<br>Annual minima 3-day means<br>Annual maxima 3-day means<br>Annual minima 7-day means<br>Annual maxima 7-day means<br>Annual minima 30-day means<br>Annual maxima 30-day means<br>Annual minima 90-day means<br>Annual maxima 90-day means<br>(10) |
| Group 3: Timing of annual extreme water conditions | Timing | Julian date of each annual 1 day maximum<br>Julian date of each annual 1 day minimum<br>(2) |
| Group 4: Frequency and duration of high and low pulses | Frequency<br>Duration | No. of high pulses each year<br>No. of low pulses each year<br>Mean duration of high pulses within each year<br>Mean duration of low pulses within each year<br>(4) |
| Group 5: Rate/Frequency of water condition changes | Rates of change<br>Frequency | Means of all “+” differences between consecutive daily means<br>Means of all “-” differences between consecutive daily values<br>No. of rises<br>No. of falls<br>(4) |

Table 2. Negotiated flows for the Oconee River, below Sinclair Dam starting June 1996 (Hendricks 2002).

| Month | Flow | Operation |
|---|---|---|
| December – February | 500 cfs minimum | normal peaking |
| March - April | 1500 cfs minimum | modified peaking[1] |
| May | run-of-the-river | run-of-the-river |
| June[2] - November | 700 cfs minimum | normal peaking |

[1] Modified peaking refers to the use of one or two turbines generating depending on the amount of inflow to the reservoir.

[2] Run-of-the-river flow is from June 1 - 10th, unless electric demands require generation.

Table 3. Sampling data for age-0 carpsuckers (cs[1]) in the Oconee River between Milledgeville and Dublin, Georgia, during May through July 1995 - 2001.

| Year | No. of seine hauls | No. of fishes collected | No. cs | No. of days cs collected | No. of hauls cs collected | Total area ($m^2$) sampled | Total area ($m^2$) sample w/cs |
|---|---|---|---|---|---|---|---|
| 1995[2] | 73 | 5,603 | 1,182 | 3 | 20 | 11,941 | 5,788 |
| 1996[2] | 71 | 9,186 | 275 | 4 | 11 | 2,544 | 906 |
| 1997[2] | 75 | 6,031 | 1 | 1 | 1 | 6,420 | NM |
| 1998[2] | 55 | 4,846 | 79 | 4 | 11 | 4,677 | 6,867 |
| 1999[2] | 115 | 36,029 | 610 | 9 | 36 | 7,170 | 5,674 |
| 2000[3] | 263 | 61,000 | 403 | 20 | 50 | 16,965 | 3,064 |
| 2001[3] | 144 | 10,019 | 31 | 2 | 5 | 9,315 | 188 |

NM= No measurement

[1] Carpsuckers between 8 and 29 mm's (TL)
[2] Sampled once a week in May - July
[3] Sampled once a week in May and June, three times a week during July

Table 4. Monthly mean (SD) water temperature (EC) for May through July of 1995 - 2001. Measurements were taken during sampling (generally, 3x's/week) on the Oconee River, between Milledgeville and Dublin, Georgia.

| | Month | | |
|---|---|---|---|
| Year | May | June | July |
| 1995 | 24.9 (1.78) | 26.9 (1.36) | 30.0 (1.27) |
| 1996 | 22.0 (2.12) | 26.6 (0.93) | 29.1 (0.87) |
| 1997 | 21.6 (1.85) | 23.9 (1.61) | 28.3 (0.80) |
| 1998 | 23.8 (2.36) | 28.0 (1.03) | 31.5 (0.71) |
| 1999 | 23.5 (1.94) | 27.4 (0.95) | 27.8 (1.53) |
| 2000 | 25.3 (2.11) | 28.2 (1.64) | 29.0 (1.39) |
| 2001 | 24.2 (1.16) | 26.0 (0.95) | 27.9 (1.38) |

Table 5. Range of size-classes (total length, mm) used to estimate instantaneous growth and mortality of age-0 carpsuckers collected from the Oconee River, between Milledgeville and Dublin, Georgia May through July 1995 - 2001.

| | Range of size-classes used for Instantaneous | |
|---|---|---|
| Year | Growth | Mortality |
| 1995 | 8-12 | 13-29 |
| 1996 | 8-15 | 16-29 |
| 1997 | NM | NM |
| 1998 | 8-16 | 17-29 |
| 1999 | 8-14 | 15-29 |
| 2000 | 8-21 | 22-29 |
| 2001 | 8-14 | 15-29 |

NM= No measurement

Table 6. Instantaneous growth estimates (inferred as a daily rate) for age-0 carpsuckers (8-29 mm TL) from May through July of years 1995 - 2001. Carpsuckers collected from the Oconee River, between Milledgeville and Dublin, Georgia.

| Year | Growth Estimate | Standard Error | $r^2$ | *p* |
|---|---|---|---|---|
| 1995 | 0.90 | 0.13 | 0.94 | 0.01 |
| 1996 | 0.51 | 0.08 | 0.89 | <0.01 |
| 1997 | NA | NA | NA | NA |
| 1998 | 0.42 | 0.16 | 0.64 | 0.06 |
| 1999 | 0.23 | 0.03 | 0.92 | <0.01 |
| 2000 | 0.10 | 0.03 | 0.54 | 0.01 |
| 2001 | 0.84 | 0.24 | 0.86 | 0.07 |

NA = Not Applicable

Table 7. Results for differences among years of instantaneous growth estimates of age-0 carpsuckers[1].

| | 1995 | 1996 | 1998 | 1999 | 2000 | 2001 |
|---|---|---|---|---|---|---|
| 1995 | | D | D | D | D | ND |
| 1996 | | | ND | D | D | ND |
| 1998 | | | | ND | D | ND |
| 1999 | | | | | D | D |
| 2000 | | | | | | D |
| 2001 | | | | | | |

D = difference between instantaneous growth estimates
ND = no difference between instantaneous growth estimates

[1] Age-0 carpsuckers were collected from the Oconee River, between Milledgeville and Dublin, GA from May - July 1995, 1996, 1998-2001.

Table 8. Abundance of age-0 carpsuckers for the entire study area and Ball's Ferry study reach, on the Oconee River, Georgia, 1995 - 2001.

| Year | Total Abundance | Ball's Ferry Abundance |
|---|---|---|
| 1995 | 1,182 | 220 |
| 1996 | 275 | 39 |
| 1997 | 1 | 0 |
| 1998 | 79 | 79 |
| 1999 | 610 | 168 |
| 2000 | 403 | 246 |
| 2001 | 31 | 31 |

Table 9. Estimates of instantaneous growth and mortality estimates[1] for warm- and cold-water age-0 fishes and citation for the sources.

| Species | Instantaneous growth estimate (SE) | Instantaneous mortality estimates (SE) | Source |
|---|---|---|---|
| *Lepomis* spp. | 0.06 (NA) | 0.26 (0.07) | Zigler and Jennings 1993 |
| | 0.03 (NA) | 0.09 (0.05) | |
| | 0.06 (NA) | 0.49 (0.02) | |
| Channel catfish (*Ictalurus punctatus*) | 0.01 (<0.01) | 0.09 (0.06) | Ruetz and Jennings 1999 |
| Northern pikeminnow (*Ptychocheilus oregonensis*) | 0.04 (<0.01) | 0.14 (<0.01) | Barfoot et al. 1999 |
| | 0.04 (<0.01) | 0.10 (0.01) | |
| *Carpiodes* spp. | 0.90 (0.13) | 0.45 (0.10) | Cull 2005 |
| | 0.51 (0.08) | NA | |
| | 0.42 (0.16) | NA | |
| | 0.23 (0.03) | NA | |
| | 0.10 (0.03) | NA | |
| | 0.84 (0.24) | NA | |

NA = Not available

[1] Instantaneous growth and mortality were estimated using Hackney and Webb 1978.

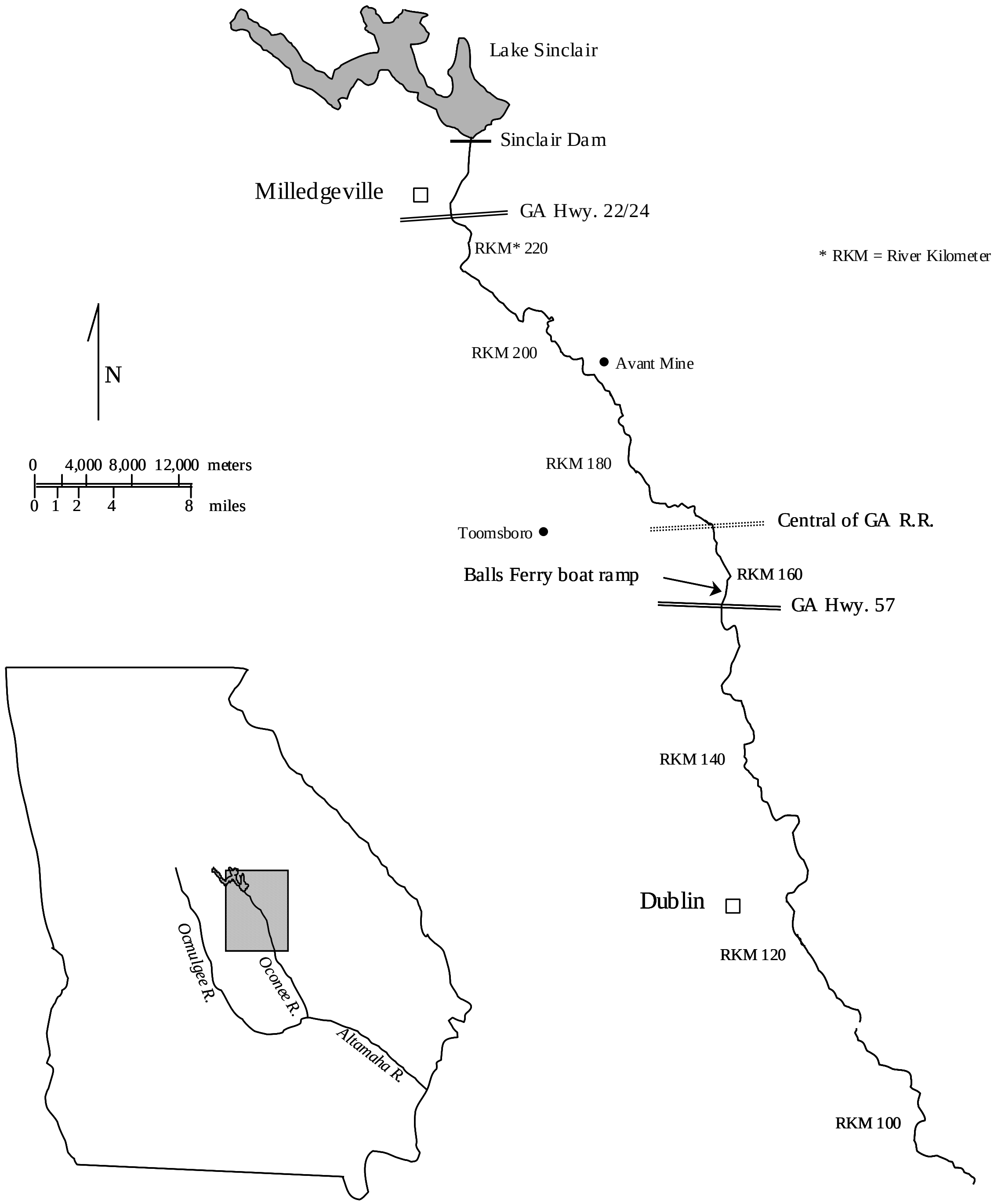


Figure 1. Oconee, Ocmulgee and Altamaha Rivers below the fall line in Georgia. Study Area on the Oconee River (in shaded box) is located between river kilometer 130 and 190.

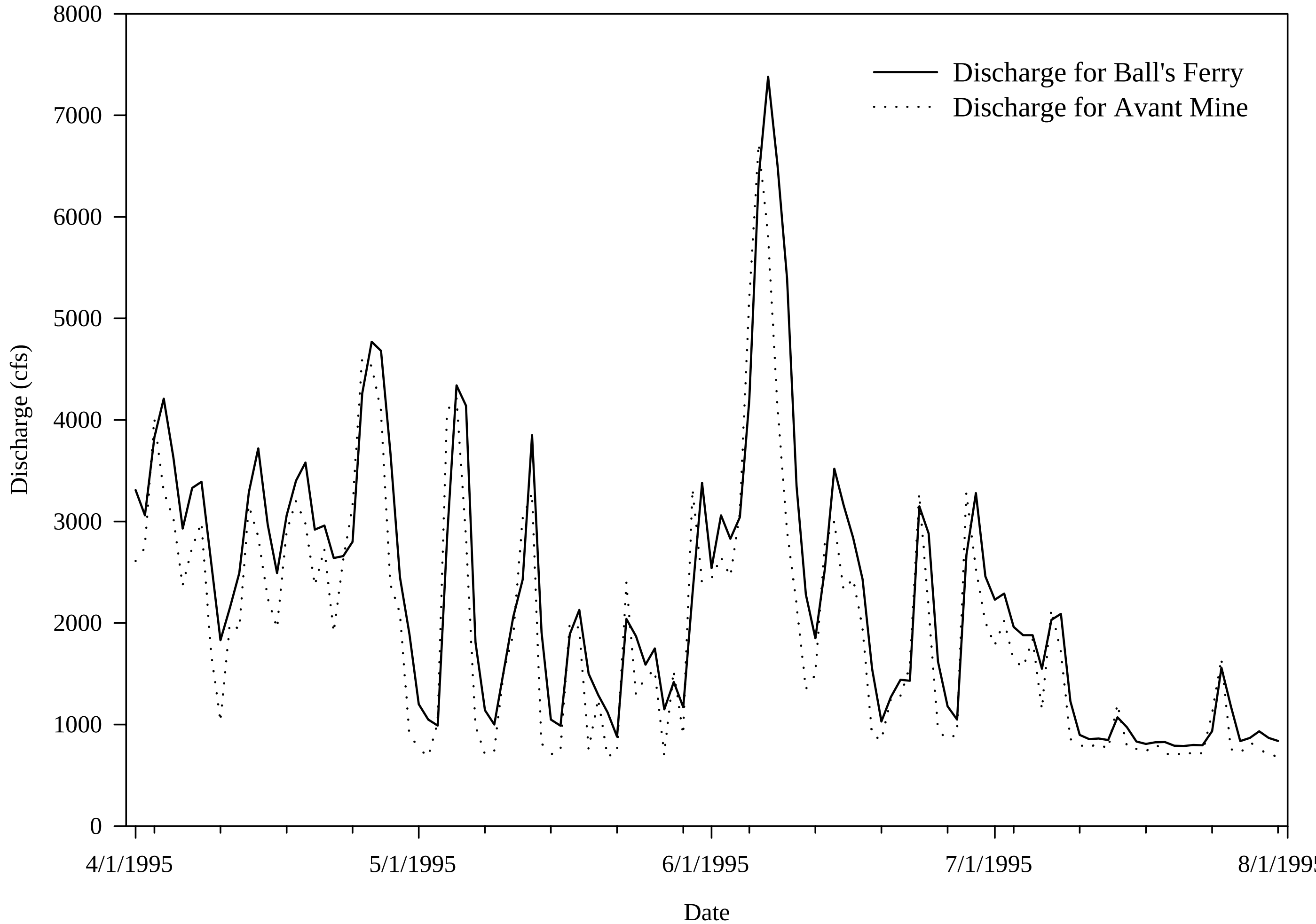


Figure 2. Comparison of Oconee River, Georgia water discharge (cfs) between Ball’s Ferry (USGS gauge02223248) and Avant Mine (USGS gauge02223056) water discharge (cfs) for spring and summer 1995.

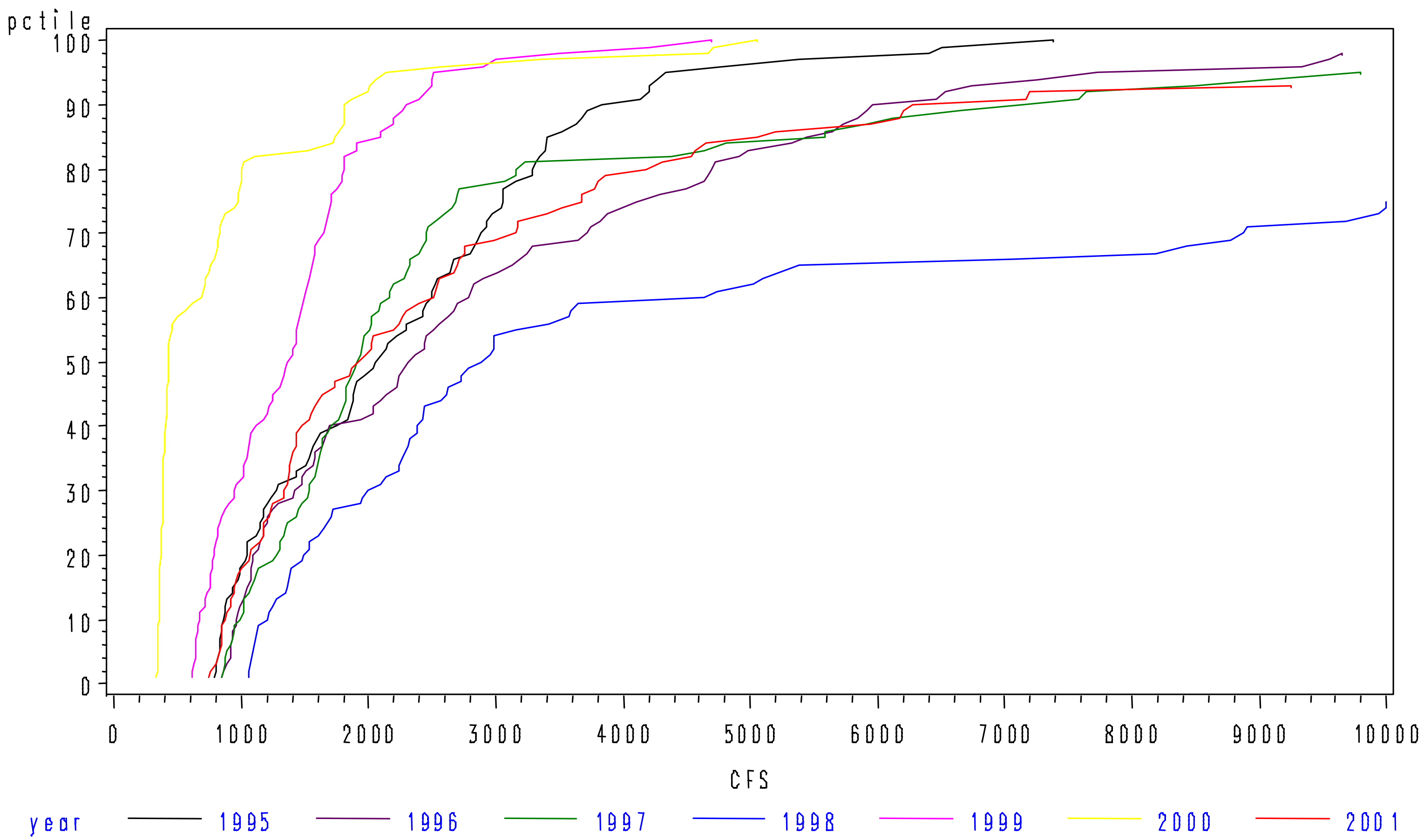


Figure 3. Discharge (%ile) for the Oconee River, near Oconee (USGS gauge02223248; Ball's Ferry) for 0 -10,000 cfs, April through July 1995 to 2001.

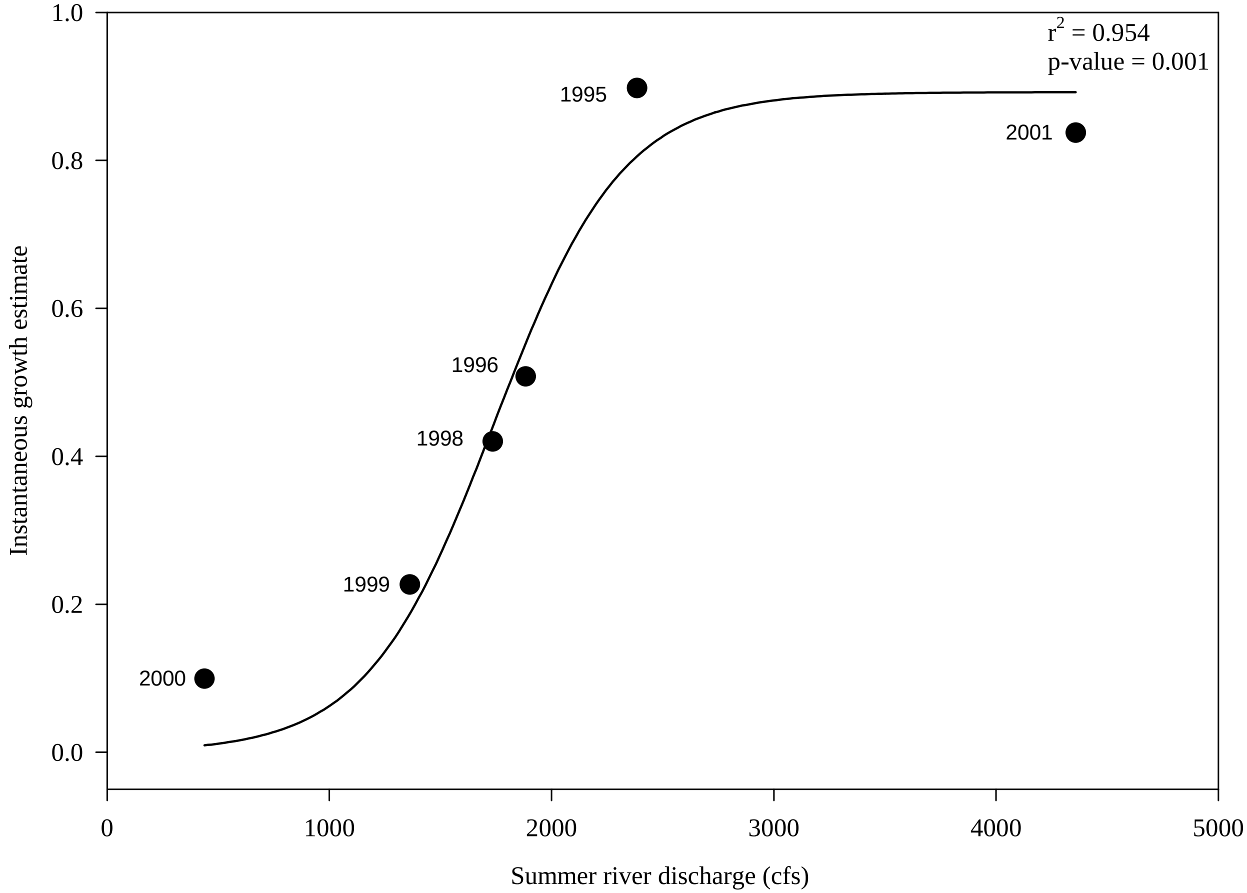


Figure 4. Instantaneous growth estimates of age-0 carpsuckers[1] and summer (June and July) mean river discharge (cfs)[2].

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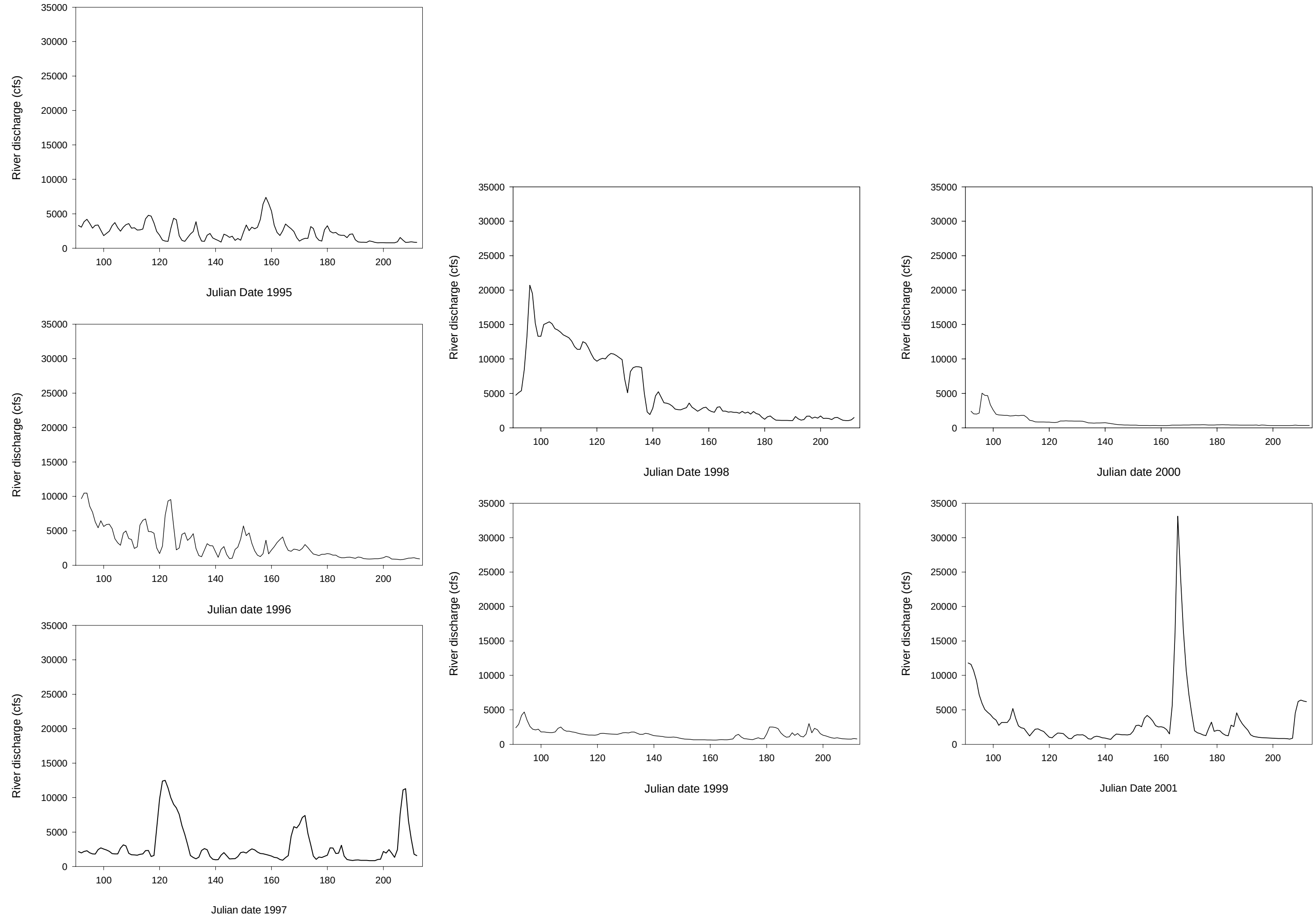
[1] Age-0 carpsuckers were collected from the Oconee River between Milledgeville and Dublin, Georgia from May through July 1995, 1996, 1998-2001. Only one carpsucker (8-29 mm TL) was collected during the study period in 1997, so instantaneous growth could not be estimated for that year.
[2] Daily river discharge was taken from USGS gage 02223248 Oconee River near Oconee, GA. for April - July http://nwis.waterdata.usgs.gov/ga/nwis/discharge/?site_no=02223248&agency_cd=USGS

# APPENDICES

Appendix A1. Oconee River mean daily discharge (cfs) at Ball’s Ferry (USGS gauge 02223248) from April through July 1995 – 2001.



Appendix A2. Mean (SD) dissolved oxygen (mg/l) and turbidity (ntu) for May through July of 1995 - 2001[1].

| Year | May | | June | | July | |
|---|---|---|---|---|---|---|
| | Dissolved Oxygen (mg/l) | Turbidity (ntu) | Dissolved Oxygen (mg/l) | Turbidity (ntu) | Dissolved Oxygen (mg/l) | Turbidity (ntu) |
| 1995 | 7.7 (1.4) | NM | 6.7 (0.3) | NM | 7.1 (0.8) | NM |
| 1996 | NM | 28.4 (1.3) | 7.1 (0.2) | 26.9 (12.1) | 7.2 (0.5) | 12.3 (4.2) |
| 1997 | 7.9 (0.5) | 42.3 (12.6) | 7.5 (1.1) | 29.0 (6.7) | 6.9 (0.3) | 21.0 (10.1) |
| 1998 | 7.5 (0.3) | 45.9 (7.2) | 7.4 (0.4) | 32.1 (5.7) | 7.0 (0.2) | 11.5 (3.0) |
| 1999 | 8.5 (1.3) | 12.5 (3.0) | 7.3 (0.4) | 13.7 (8.9) | 6.8 (0.5) | 48.4 (24.1) |
| 2000 | 7.7 (0.4) | 12.1 (1.7) | 7.3 (0.6) | 6.9 (1.3) | 6.9 (0.3) | 8.0 (2.6) |
| 2001 | 7.7 (0.3) | 32.3 (9.8) | 6.6 (0.7) | 48.2 (13.1) | 6.5 (0.6) | 22.0 (9.4) |

NM= No measurement

[1] Measurements were taken during sampling (generally, 3x's/week) in the Oconee River between Milledgeville and Dublin, GA.

Appendix A3. Monthly minimum (min), mean, and maximum (max) air temperatures (EF) for April - July, and seasonal mean for spring (April, May) summer (June, July) and spring through summer (April-July)1995 - 2001[1] from Macon, GA[2].

| | April | | | May | | | June | | | July | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | min | mean | max | min | mean | max | min | mean | max | min | mean | max |
| 1995 | 49.9 | 61.1 | 77.9 | 60.5 | 74.4 | 87.6 | 65.3 | 76.3 | 86.7 | 70.9 | 82.9 | 94.3 |
| 1996 | 47.6 | 61.4 | 74.7 | 60.2 | 73.7 | 86.5 | 65.3 | 77.2 | 88.7 | 70.4 | 81.5 | 91.8 |
| 1998 | 51.0 | 62.3 | 73.1 | 62.5 | 74.7 | 86.6 | 69.1 | 81.9 | 94.2 | 73.2 | 84.4 | 95.4 |
| 1999 | 54.9 | 67.7 | 80.1 | 56.2 | 70.2 | 83.7 | 67 | 77.8 | 88.1 | 71.1 | 81.0 | 90.5 |
| 2000 | 46.9 | 60.6 | 73.8 | 60.8 | 75.2 | 89.0 | 65.3 | 79.2 | 92.7 | 69.0 | 81.7 | 93.9 |
| 2001 | 51.5 | 64.5 | 77 | 57.5 | 70.9 | 83.8 | 67 | 77.0 | 86.4 | 70.4 | 80.5 | 90.1 |

| | Season | | |
|---|---|---|---|
| Year | Spring | Summer | Spring - Summer |
| 1995 | 69.3 | 79.6 | 74.4 |
| 1996 | 67.6 | 79.3 | 73.4 |
| 1998 | 68.5 | 83.2 | 75.8 |
| 1999 | 69.0 | 79.4 | 74.2 |
| 2000 | 67.9 | 80.5 | 74.2 |
| 2001 | 67.7 | 78.8 | 73.2 |

[1] There were not enough data to analyze instantaneous growth for 1997.
[2] Daily air temperatures were taken from Macon, GA. from April - July http://climate.engr.uga.edu/macon/index.html.

Appendix A4. Monthly mean water discharge (cfs) Oconee River, Georgia from April through July 1995 – 2001 and 13 year average[1].

| Year | April | May | June | July |
|---|---|---|---|---|
| 1995 | 3,166 | 1,865 | 2,944 | 1,198 |
| 1996 | 5,363 | 3,523 | 2,248 | 1,036 |
| 1997 | 2,479 | 3,822 | 2,691 | 2,564 |
| 1998 | 12,530 | 6,427 | 2,405 | 1,320 |
| 1999 | 2,099 | 1,356 | 845 | 1,389 |
| 2000 | 1,946 | 706 | 391 | 373 |
| 2001 | 4,185 | 1,257 | 5,707 | 2,256 |
| 13 year average | 4,725 | 3,033 | 2,524 | 2,330 |

[1] Daily river discharge was taken from USGS gage 02223248 Oconee River near Oconee, GA. for April - July http://nwis.waterdata.usgs.gov/ga/nwis/discharge/?site_no=02223248&agency_cd=USGS

Appendix A5. Daily mean river discharge[1] metrics for the Oconee River discharge (cfs) selected for comparison to instantaneous growth estimates of age-0 carpsuckers for April – July, 1995 – 2001[2].

| | | | Number of days below (cfs) | | | | Number of days above (cfs) | | | Seasonal mean (cfs)[3] | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Peak (cfs) | Low (cfs) | 1,000 | 2,000 | 3,000 | 6,000 | 1,000 | 2,000 | 3,000 | sp | sum | spsm |
| 1995 | 7,380 | 788 | 23 | 59 | 90 | 119 | 99 | 63 | 32 | 2,722 | 2,385 | 2,554 |
| 1996 | 10,500 | 790 | 15 | 51 | 78 | 110 | 107 | 71 | 44 | 4,961 | 1,884 | 3,422 |
| 1998 | 20,700 | 1,060 | 0 | 37 | 66 | 80 | 122 | 85 | 56 | 9,897 | 1,736 | 5,817 |
| 1999 | 4,700 | 603 | 39 | 103 | 119 | 122 | 83 | 19 | 4 | 2,203 | 1,362 | 1,693 |
| 2000 | 5,050 | 331 | 98 | 113 | 118 | 122 | 24 | 9 | 4 | 1,545 | 438 | 992 |
| 2001 | 33,100 | 705 | 22 | 63 | 85 | 107 | 100 | 59 | 37 | 3,309 | 4,359 | 3,834 |

[1] Daily river discharge was taken from USGS gage 02223248 Oconee River near Oconee, GA. for April - July
http://nwis.waterdata.usgs.gov/ga/nwis/discharge/?site_no=02223248&agency_cd=USGS
[2] There were not enough data to analyze instantaneous growth for 1997.
[3] Seasonal mean for spring (sp; April, May) summer (sum; June, July) and spring through summer (spsm;April-July)

Appendix A6. Selected monthly and seasonal air temperature (EF)[1] variables, $r^2$ and *p* -value used to evaluate relationship between instantaneous growth estimates of age-0 carpsuckers[2] and air temperature during the study period from 1995, 1996, 1998-2001.

| Variable | $r^2$ | *P* |
|---|---|---|
| April minimum | <0.01 | 0.91 |
| May minimum | <0.01 | 0.95 |
| June minimum | 0.01 | 0.89 |
| July minimum | 0.03 | 0.76 |
| April mean | 0.03 | 0.76 |
| May mean | 0.01 | 0.83 |
| June mean | 0.29 | 0.27 |
| July mean | <0.01 | 0.97 |
| April maximum | 0.06 | 0.63 |
| May maximum | 0.05 | 0.68 |
| June maximum | 0.44 | 0.15 |
| July maximum | 0.01 | 0.85 |
| Spring mean | 0.02 | 0.82 |
| Summer mean | 0.11 | 0.52 |
| Spring and summer mean | 0.07 | 0.61 |

[1] Daily air temperatures were taken from Macon, GA. from April - July http://climate.engr.uga.edu/macon/index.html

[2] Instantaneous growth estimates were taken from age-0 carpsucker sampled from May - July in the Oconee River between Milledgeville and Dublin, GA.

Appendix A7. Selected monthly and seasonal river discharge variables, $r^2$ and *p* -value used to evaluate relationship between instantaneous growth estimates of age-0 carpsuckers[1] and river discharge (cfs)[2] collected during 1995, 1996, 1998-2001.

| Variable | $r^2$ | *p* |
|---|---|---|
| Peak flow | 0.27 | 0.29 |
| Low flow | 0.23 | 0.34 |
| Days below 1,000 | 0.36 | 0.21 |
| Days below 2,000 | 0.40 | 0.18 |
| Days below 3,000 | 0.30 | 0.26 |
| Days below 6,000 | 0.02 | 0.82 |
| Days above1,000 | 0.36 | 0.21 |
| Days above 2,000 | 0.40 | 0.18 |
| Days above 3,000 | 0.30 | 0.26 |
| Spring mean | <0.01 | 0.90 |
| **Summer mean** | **0.71** | **0.04** |
| Spring and summer mean | 0.14 | 0.46 |

[1] Instantaneous growth estimates were taken from age-0 carpsucker sampled from the Oconee River between Milledgeville and Dublin, GA during May - July.
[2] Daily river discharge was taken from USGS gage 02223248 Oconee River near Oconee, GA. for April - July http://nwis.waterdata.usgs.gov/ga/nwis/discharge/?site_no=02223248&agency_cd=USGS

Appendix A8. Selected monthly and seasonal air temperature variables, $r^2$ and *p* -value used to evaluate relationship between air temperature (EF)[1] and abundance of age-0 carpsuckers[2] during the study period from1995, 1996, 1998-2001.

| Variable | $r^2$ | *p* |
|---|---|---|
| April minimum | 0.05 | 0.62 |
| May minimum | 0.05 | 0.64 |
| June minimum | 0.09 | 0.52 |
| July minimum | 0.02 | 0.78 |
| April mean | 0.18 | 0.34 |
| May mean | 0.13 | 0.42 |
| June mean | 0.01 | 0.81 |
| July mean | 0.01 | 0.81 |
| April maximum | 0.37 | 0.15 |
| May maximum | 0.22 | 0.28 |
| June maximum | <0.01 | 0.95 |
| July maximum | 0.05 | 0.62 |
| Spring mean | 0.36 | 0.15 |
| Summer mean | <0.01 | 0.94 |
| Spring and summer mean | 0.12 | 0.45 |

[1] Daily air temperatures were taken from Macon, GA. from April - July http://climate.engr.uga.edu/macon/index.html

[2] Abundance of age-0 carpsucker sampled from May - July in the Oconee River between Milledgeville and Dublin, GA.

Appendix A9. Selected monthly and seasonal river discharge variables, $r^2$ and *p* -value used to evaluate relationship between river discharge (cfs)[1] and abundance of age-0 carpsuckers[2] collected during 1995, 1996, 1998-2001.

| Variable | $r^2$ | *p* |
|---|---|---|
| Peak flow | 0.36 | 0.16 |
| Low flow | 0.05 | 0.62 |
| Days below 1,000 | 0.05 | 0.64 |
| Days below 2,000 | 0.05 | 0.64 |
| Days below 3,000 | 0.10 | 0.49 |
| Days below 6,000 | 0.34 | 0.17 |
| Days above1,000 | 0.07 | 0.56 |
| Days above 2,000 | 0.12 | 0.45 |
| Days above 3,000 | 0.23 | 0.28 |
| Spring mean | 0.15 | 0.39 |
| Summer mean | 0.13 | 0.43 |
| Spring and summer mean | 0.23 | 0.28 |

[1] Daily river discharge was taken from USGS gage 02223248 Oconee River near Oconee, GA. for April - July http://nwis.waterdata.usgs.gov/ga/nwis/discharge/?site_no=02223248&agency_cd=USGS

[2] Instantaneous growth estimates were taken from age-0 carpsucker sampled from the Oconee River between Milledgeville and Dublin, GA during May - July.

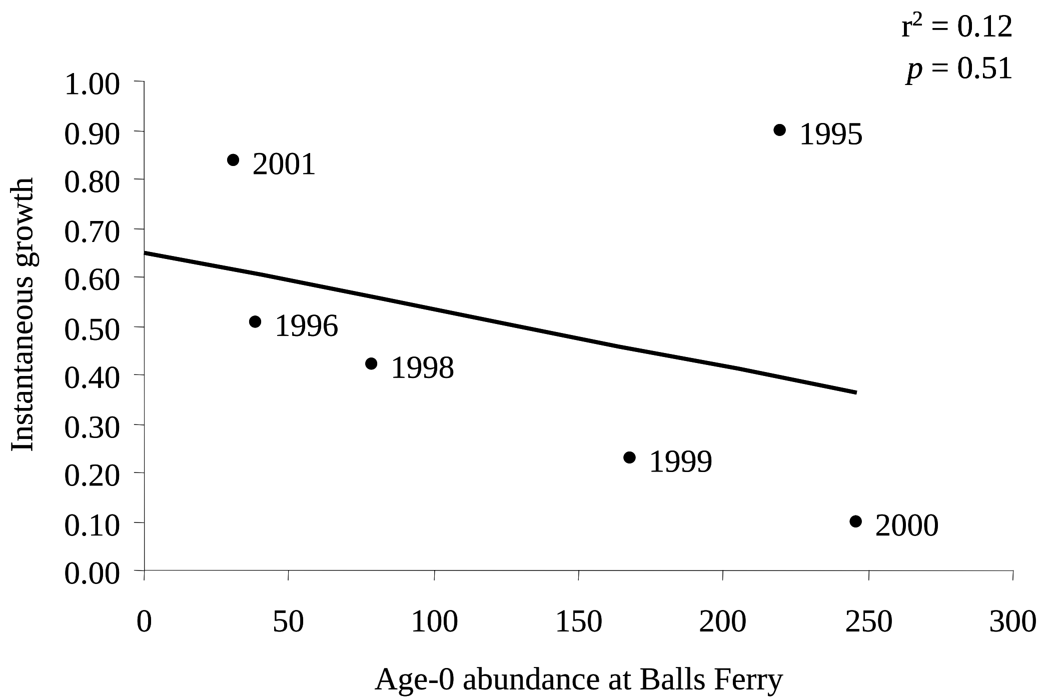
Appendix A10. Selected monthly and seasonal air temperature variables, $r^2$ and $p$ -value used to evaluate relationship between air temperature (EF)[1] and abundance at Ball's Ferry of age-0 carpsuckers[2] during the study period from1995, 1996, 1998-2001.

| Variable | $r^2$ | $p$ |
|---|---|---|
| April minimum | 0.02 | 0.74 |
| May minimum | 0.15 | 0.39 |
| June minimum | 0.02 | 0.75 |
| July minimum | 0.10 | 0.50 |
| April mean | 0.07 | 0.57 |
| May mean | 0.32 | 0.19 |
| June mean | 0.08 | 0.53 |
| July mean | 0.02 | 0.77 |
| April maximum | 0.13 | 0.43 |
| May maximum | 0.48 | 0.08 |
| June maximum | 0.17 | 0.36 |
| July maximum | 0.14 | 0.41 |
| Spring mean | 0.41 | 0.12 |
| Summer mean | 0.07 | 0.57 |
| Spring and summer mean | 0.28 | 0.23 |

[1] Daily air temperatures were taken from Macon, GA. from April - July http://climate.engr.uga.edu/macon/index.html

[2] Instantaneous growth estimates were taken from age-0 carpsucker sampled from May - July in the Oconee River between Milledgeville and Dublin, GA.

Appendix A11. Relationship between instantaneous growth estimate[1] and abundance from Ball's Ferry[2].

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[1] There were insufficient data to analyze instantaneous growth for 1997.

[2] Instantaneous growth estimates and abundance from Ball's Ferry were for age-0 carpsuckers sampled from the Oconee River between Milledgeville and Dublin, GA during May – July 1995, 1996, 1998 - 2001.

Appendix A12. Selected monthly and seasonal river discharge variables, $r^2$ and *p* -value used to evaluate relationship between river discharge (cfs)[1] and abundance at Ball's Ferry of age-0 carpsuckers[2] collected during 1995, 1996, 1998-2001.

| Variable | $r^2$ | *p* |
|---|---|---|
| Peak flow | 0.39 | 0.14 |
| Low flow | 0.36 | 0.16 |
| Days below 1,000 | 0.50 | 0.07 |
| Days below 2,000 | 0.36 | 0.15 |
| Days below 3,000 | 0.35 | 0.16 |
| Days below 6,000 | 0.31 | 0.19 |
| Days above1,000 | 0.56 | 0.05 |
| Days above 2,000 | 0.54 | 0.06 |
| **Days above 3,000** | **0.61** | **0.04** |
| Spring mean | 0.16 | 0.37 |
| Summer mean | 0.46 | 0.09 |
| Spring and summer mean | 0.37 | 0.15 |

[1] Daily river discharge was taken from USGS gage 02223248 Oconee River near Oconee, GA. for April - July http://nwis.waterdata.usgs.gov/ga/nwis/discharge/?site_no=02223248&agency_cd=USGS

[2] Instantaneous growth estimates were taken from age-0 carpsucker sampled from the Oconee River between Milledgeville and Dublin, GA during May - July.