AGE AND SIZE STRUCTURE FOR AN INTRODUCED POPULATION OF BLUE CATFISH (*ICTALURUS FURCATUS*) IN LAKE OCONEE, GEORGIA AND A COMPARISON OF AGE DETERMINATION TECHNIQUES

by

MICHAEL DARYLL HOMER JR.

(Under the Direction of Cecil A. Jennings)

ABSTRACT

Data from annual gillnetting surveys were used to determine sizes, age structure, and relative growth of an introduced population of blue catfish in Lake Oconee, Georgia. Age and back-calculated growth were estimated with three determination-techniques and compared for precision. Blue catfish catch increased from 1997 to 2009; there was a concurrent decline in catch of native white catfish. Blue catfish ages ranged from 1 to 8 years old (mean=3.7 years, SD=1.4 years) and annual relative growth was 86.1 mm (SD=36.1 mm). Age assignment-precision was highest for otoliths (83.5%) and lowest for basal recesses (71.4%). Mean back-calculated total lengths were significantly variable among fish from ages 1-3 for each technique compared. Otoliths produced smaller estimates for mean total length from ages 1-6. The blue catfish population in Lake Oconee is relatively young and individuals are growing rapidly; otoliths and articulating processes of pectoral spines suffice for blue catfish age determination.

INDEX WORDS: Invasive, Growth, back-calculation, Gillnets, Ictaluridae

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DEDICATION

To my daughter Averie, my wife Nikki, my parents Michael Sr. and Mary Jo Homer, my brothers Marc and Alex Homer, my Wiemann family, and to my friends and colleagues that have helped me throughout the duration of my thesis project.

"Einstein's Three Rules of Work: 1) out of clutter find simplicity, 2) from discord find harmony, and 3) in the middle of difficulty lies opportunity" - Albert Einstein

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CHAPTER 1

INTRODUCTION

The blue catfish *Ictalurus furcatus* is the biggest of the North American catfish species and among one of the largest species of freshwater fish in North America (Graham 1999). Blue catfish are native to the Mississippi, Missouri, and Ohio river drainages and Gulf Coast streams in Alabama, south into Mexico, Guatemala, and Belize (Graham 1999). Blue catfish are a popular species for sport and commercial fisheries and have been stocked in multiple locations throughout the US (Graham 1999; Goeckler 2003). Reasons for stocking include increasing sportfish diversity, commercial fishing, and providing a predator control for shad (*Alosa* spp. and *Dorosoma* spp.) and Asiatic clams *Corbicula fluminea* populations (Graham 1999; Grist 2002). Over the last decade, blue catfish have received increased research attention because of their importance in recreational and commercial fisheries (Graham 1999; Michaletz and Dillard 1999; Arterburn et al. 2002; Grist 2002; Goeckler 2003) and because of their range expansion into Atlantic slope drainages.

Blue catfish are native to the Coosa River in northwestern Georgia (Glodeck 1980). However, multiple introduced populations have been and continue to be discovered throughout Georgia. During 1996 and 1997, non-native blue catfish were captured in two mainstem reservoirs of the Oconee River in central Georgia. In 1996, blue catfish were first caught in Lake Sinclair (Greene, Hancock, Putnam, and

Washington counties, Georgia) during an annual survey conducted by Georgia Department of Natural Resources (GADNR) personnel (Ramon Martin, GADNR-personal communication). In 1997, two individuals were captured in Lake Oconee (Greene, Morgan, and Putnam counties, Georgia), which is located north of Lake Sinclair. Subsequently, the numbers of blue catfish captured in the annual surveys in Lake Oconee have been increasing (GADNR, unpublished data). Within the last decade, the species has expanded its range into the upstream and downstream reaches of the Oconee River (Ramon Martin, GADNR—personal communication). Since the initial occurrence in Lake Sinclair, multiple introductions of blue catfish have been documented throughout Georgia, but the status of each population is unknown. Prior to the start of this project, the blue catfish population in Lake Oconee had not been studied. However, shortly after the project began, GADNR began investigating the population demographics and the ecological effects of the expanding blue catfish population in the Oconee River south of Lake Sinclair and farther south in the Altamaha River (Tim Bonvechio, GADNR-personal communication).

Rivers in southeast Georgia have faced other ecological problems resulting from introductions of another ictalurid (i.e., flathead catfish *Pylodictis olivaris*).. Flathead catfish were introduced into the Altamaha River during the 1970s and have since spread to the Satilla River. Further, multiple native aquatic species have been imperiled by these introductions. Drastic declines of the red breast sunfish *Lepomis auritus* and native bullheads *Ameiurus* spp. are attributed to the flathead catfish introductions (Thomas 1995; Grabowski et al. 2004; Kwak et al. 2006; Sakaris et al. 2006).

Blue catfish introductions may displace other species and blue catfish predation on native fishes and mussels and could potentially cause declines in the abundance of native species. Blue catfish and flathead catfish are the largest members of the family Ictaluridae, and both species share multiple common life history characteristics: both grow to large maximum size, are piscivorous, are habitat generalists, and have high fecundity. Blue catfish grow to larger sizes (up to 165 cm total length [TL]), are opportunistic and omnivorous, and are more migratory than other catfishes, including flathead catfish (Graham 1999; Timmons 1999; Grist 2002; Boxrucker 2007). Such life history characteristics may allow blue catfish to be better competitors for prey and habitat. The introduction of blue catfish into Lake Oconee threatens native fish and mussel populations.

To properly manage blue catfish populations, state fisheries biologists need a better understanding of the population dynamics, growth, diet, and the ecological consequences caused by the introduction of the species. Currently, literature regarding the life history and ecology of introduced populations of blue catfish in Georgia is deficient. Obtaining this information would help identify the effects of introduced blue catfish populations on native aquatic fauna. Furthermore, this information will be vital in developing sound management strategies for the blue catfish population in Lake Oconee, Lake Sinclair, the Oconee and Altamaha rivers, and wherever else they may occur in Georgia.

Age and growth information has been the most common population demographic information collected by fish biologists for blue catfish populations. Such information has been useful for comparing the dynamics of blue catfish populations among various systems, time periods, between sexes, and among size classes (Graham 1999). Collecting age and growth information for the introduced population of blue catfish in Lake Oconee would be useful for determining the size and age structure, predicting condition of individuals, and evaluating habitat suitability and success of establishment. To our knowledge, methods for age determination of blue catfish have not been validated for accuracy. Age determination methods validated for other catfish species have been used for collecting age and growth information for blue catfish populations (Jenkins 1956; Kelly and Carver 1965; Kelley 1968; Graham 1999; Grist 2002; Boxrucker and Kuklinski 2006; Boxrucker and Mauck 2006). Multiple studies have compared precision of pectoral spines versus lapilli for age determination of catfishes (Turner 1982; Crumpton et al. 1984; Nash and Irwin 1999; Buckmeier et al. 2002; Colombo et al. 2010). Studies to compare the precision of age estimates derived from such age determination techniques for blue catfish populations have not been conducted.

This research project was the first to collect life history information for the blue catfish population in Lake Oconee, Georgia (Figure 1-1). The project consisted of two studies that fulfilled four primary objectives: 1) collect and present demographic information for the introduced blue catfish population in the Lake Oconee; 2) use annual gillnetting data (1989-2009) to identify trends in the catch of blue catfish and two other common catfishes; 3) compare precision of age and growth estimates determined by employing two traditional, non-lethal and one lethal method used for age determination of blue catfish; and 4) discuss how the findings of our project can be applied to the management of catfish populations.

The information presented in this thesis is divided into four additional chapters. Chapter Two is divided into two literature review sections: the first literature review discusses the life history of blue catfish; the second literature review describes age determination methodology for catfishes and their relevance to collecting age and growth information for blue catfish populations. Chapters Three and Four were written as stand-alone research papers. Chapter Three describes the age structure, size structure, relative growth for the introduced blue catfish population and the examination of the data from the annual gillnetting surveys conducted in Lake Oconee. Chapter Four discusses the comparison of traditional catfish age and growth determination techniques commonly used for blue catfish. Chapter Five summarizes the key findings of chapters three and four, discusses implications for management of the catfish fisheries in Lake Oconee, information needs, and how the information presented in this thesis can be used.

CHAPTER TWO

LITERATURE REVIEWS[1]

[1] This chapter will not be submitted for publication.

A REVIEW OF THE LIFE HISTORY OF BLUE CATFISH

Morphology

The blue catfish is the largest known North American catfish and fourth largest freshwater fish in North America (Graham 1999). Blue catfish can grow to maximum lengths of about 165 cm TL (Page and Burr 1991). The only other North American freshwater fishes that grow to larger sizes include white sturgeon *Acipenser transmontanus*, lake sturgeon *A. fulvescens*, and alligator gar *Lepisosteus spatula* (Graham 1999; Grist 2002). The blue catfish's appearance is similar to other ictalurids; they have a scale-less, torpedo-shaped body with a wide and slightly laterally compressed head, with the lower jaw not extending past the upper jaw (Page and Burr 1991). Blue catfish eyes are small and found on the anterior region of the head and placed to the sides. Blue catfish have four pairs of barbels around their mouth: two maxillary, one chin, and one nostril (Page and Burr 1991). Typically, the maxillary barbels are short and do not reach the gill openings (Perry 1968). Blue catfish have prominent, stiff pectoral spines and a dorsal fin spine. This species is similar in appearance to channel catfish *I. punctatus* (Graham 1999), but blue catfish lack the dark spots on their sides and back. Mature blue catfish appear bluish to silver on their dorsum, and silvery-white on their ventrum; this coloration can be variable depending on water clarity (Graham 1999). Blue catfish can also have a blunt rostrum and their heads can have a slight hump that runs distally from the head. Immature blue catfish (250-450 mm) appear more whitish and silvery in color (Graham 1999). Blue catfish tend to have 30-35 anal fin rays (Graham 1999; Perry 1968), which can be used to differentiate them from channel catfish that typically have less than 30. A blue catfish anal fin is comb-like with a straight margin (Graham 1999), whereas channel catfishes' anal fins have a rounded margin. Blue catfish have constriction in their swim bladders that gives the organ a two-lobed appearance; this can be used to differentiate the species from channel catfish (Graham 1999; Page and Burr 1991).

Taxonomy and Systematics

Blue catfish belong to Division Teleostei, Subdivision Ostarioclupeomorpha, Superorder Ostariophysi, Order Siluriformes, and Family Ictaluridae (Helfman et al. 1997). The oldest known relatives of blue catfish in the Order Siluriformes date back to the Paleocene epoch; the fossils are believed to be members of the Family Ictaluridae and belonged to the genus *Astephus* (Gayet and Meunier 2003). The first appearance of the genus *Ictalurus* dates back to the Oligocene in Saskatchewan, Canada. Blue catfish likely first appeared during the Pliocene epoch in Texas (Gayet and Meunier 2003). The genus *Ictalurus* is Greek for "cat" or "catfish," and *furcatus* is Greek meaning "forked," referring to the species' deeply forked caudal fin (Graham 1999).

Distribution

The blue catfish is native to the drainages of the Mississippi River, Ohio River, and Missouri River, but presently it persists in many places throughout most of the continental United States (Glodek 1980; Graham 1999). Since the 1940's, blue catfish have been stocked in many locations throughout most of the continental states for sport and commercial fisheries, as well as to control Asiatic clams *Corbicula fluminea* and shad populations (i.e., *Alosa* spp. and *Dorosoma cepedianum*) (Graham 1999; Grist 2002). As of the late 1990's, 29 states reported having blue catfish populations in some of their waters (Graham 1999). In Georgia, the blue catfish is native to the Coosa River drainage in the northwestern part of the State (Glodek 1980). However, introduced populations exist within the Chattahoochee River, the Oconee River, Lake Sinclair, Lake Oconee, and possibly the Appalachee River (Ramon Martin, GADNR-WRD—personal communication), and the Altamaha River.

The status of blue catfish within its native and introduced Georgia range is poorly understood, and literature regarding other populations in North America is scarce. The most comprehensive study of blue catfish life history was conducted by Graham (1999). Throughout much of the eastern portion of their native range, blue catfish populations have declined as a result of the impoundment of rivers by dams and reservoirs (Graham 1999). The blue catfish is listed as a "Species of Concern" in Minnesota but is not listed in any other state (Graham 1999). Blue catfish once existed in Pennsylvania, but were extirpated close to the beginning of the 20th century. In the Southeast, native blue catfish populations are decreasing because of increased levels of development, turbidity, sedimentation and siltation, changes in flow regimes, increased pollution, habitat modification, and the impoundment of rivers (Graham 1999). Presently, the blue catfish is not protected in Georgia, and its status is unknown.

Reproduction

Currently, there have been few studies that have investigated blue catfish reproduction. Studies that have investigated blue catfish reproduction have identified that blue catfish mature at about ages 5-7 and at lengths between 420–480 mm TL (Hale and Timmons 1989; Graham 1999). However, blue catfish become sexually mature sooner (at about 4 to 5 years of age and at 350–662 mm TL) in the southern portion of their range (Henderson 1972; Perry and Carver 1973; Hale and Timmons 1989; Graham 1999). Blue catfish spawn in the late months of spring from April to July (Perry and Carver 1973; Graham 1999).

Blue catfish are the most migratory of the North American catfishes and will travel upstream hundreds of kilometers to find optimal spawning habitat (Graham 1999). Blue catfish spawning habitats are suspected to be similar to those of channel catfish, but there is little known about their preferred spawning habitat (Graham 1999). Blue catfish are likely to spawn in areas with abundant cover. Female blue catfish can produce between 900–1,350 eggs/kg of body weight (Graham 1999). The eggs incubate for 7- 8 days at water temperature between 21-24 ^{o}C before hatching (Graham 1999). Blue catfish hatching success is approximately 90 % (Tave and Smitherman 1982). Male blue catfish will guard nests (Graham 1999).

<u>Mortality</u>

Blue catfish recruitment and survival varies by year and system. For example, the population of blue catfish in the Tombigbee River in Alabama had about 39% annual mortality (Kelly 1969). By comparison, annual mortality of blue catfish in the upper Lake of the Ozarks, MO was 12-32% (Graham and DeSanti 1999). Furthermore, only 2-3% of blue catfish less than age 1 reach trophy catfish sizes in Oklahoma reservoirs (Boxrucker and Kuklinski 2007). Mortality of blue catfish in Georgia systems is unknown.

Habitat

Specific habitat preferences of blue catfish are poorly understood, but are suspected to be similar to those of the channel catfish (Hubert 1999; Grist 2002). Blue catfish prefer large rivers with deep water and fast-moving currents (Kelley and Carver 1965; Kelley 1968; Graham 1999; Timmons 1999). The blue catfish's attraction to flowing, deep-water habitats is poorly understood and has made studying the species difficult (Graham 1999; Grist 2002). Moreover, this species can persist in the main channels of rivers, within reservoirs, backwaters, and embayments of large rivers and lakes (Jenkins 1956; Graham 1999; Timmons 1999; Grist 2002). Waters within these habitats are primarily turbid and bottom-substrates are usually silt-mud or sand (Graham 1999). Blue catfish are secondary cavity nesters and will nest in areas with abundant cover such as rock outcrops, boating docks, submerged vegetation, and downed trees.

Few studies have been conducted to investigate the abiotic conditions of blue catfish habitats. Multiple studies have investigated blue catfish tolerance for variable salinity concentrations with the intent to apply the findings towards developing coastal blue catfish aquaculture programs. Blue catfish can persist in high saline conditions for long periods (Perry and Avault 1968; Graham 1999). Additionally, the findings of some studies suggest that blue catfish prefer habitats with salinity levels between 0.8 ppt and 2 ppt (Kelley 1965; Perry 1967; Perry and Avault 1968; Graham 1999). Furthermore, blue catfish have been found in estuaries with salinities up to 11 ppt (Perry 1968) and some waters with salinities near 14 ppt (Allen and Avault 1970).

Feeding Ecology

Blue catfish feeding ecology and preferred prey species have received limited research attention. The studies that have been conducted suggest blue catfish are generally benthic, nocturnal, omnivorous and mostly piscivorous (Perry 1969; Graham 1999; Grist 2002; Eggleton and Schramm 2004). Blue catfish, like other ictalurids, have well-developed sensory and olfactory systems that enable them to detect prey in their turbid habitats (Helfman 1997). In clearer water, blue catfish can detect prey by sight (Graham 1999; Graham and DeSanti 1999). Blue catfish have been observed concentrating below schools of gizzard shard *Dorosoma cepedianum*, which with other clupeids, are important species in their diets (Cyterski 1999; Graham 1999; Grist 2002; Eggleton and Schramm 2004). Blue catfish have also been known to eat mollusks (Edds et al. 2002; Grist 2002), which have made them attractive to use as biological controls for Asiatic mussels, zebra mussels, and aquatic snails *Planorbella* spp. that are hosts for a number of trematode parasites (Ledford and Kelly 2006). Grist (2002) found that blue catfish in Lake Norman, NC preyed mostly on *Corbicula fluminea*. during the spring, summer, and fall seasons and *Chara* sp., filamentous algae, during the winter season.

Throughout saltatory development, blue catfish use various types of prey. Before blue catfish reach lengths of 100 mm TL, they feed on zooplankton (Darnell 1958; Perry 1969). Once blue catfish reach lengths of about 100 mm TL, they begin feeding on invertebrates (Perry 1969) and become more piscivorous once they reach about 200 mm TL (Brown and Dendy 1961; Perry 1969). Once blue catfish grow to sizes to which they can consume other fish, they are opportunistic and will continue to feed on invertebrates, vegetation, and some detritus (Edds 2002; Eggleton and Schramm 2004). The type of prey that blue catfish consume depends on habitat type, location, season, and prey size (Grist 2002; Eggleton and Schramm 2004). Generally, smaller and younger blue catfish rely more on invertebrates, and as they increase in size and age, they rely more on fish such as shads, sunfish, and minnows as primary sources of prey (Brown and Dendy 1961; Perry 1969; Graham 1999; Edds 2002; Grist 2002; Eggleton and Schramm 2004). In some areas where blue catfish have been introduced, the condition and abundance of channel and white catfish have decreased because they have been outcompeted for forage (Grist 2002). Collecting dietary information for introduced catfish populations would aid fisheries managers in determining if these introductions pose a threat to any native aquatic fauna.

Growth

The writings of Meriwether Lewis and William Clark discussed finding blue catfish that were 1.5 m TL (Graham 1999; Grist 2002), but today the largest individuals caught are about 70 cm TL. Other historical writings have described blue catfish being caught as large as 315 lbs., and that catching individuals between 150 – 200 lbs. was common (Graham 1999). In Georgia, the state record of blue catfish is 75.4 lbs., and this fish was captured in a private pond (GADNR 2009). Most studies have stated that blue catfish have the potential to reach large maximum sizes and can live over 30 years (Graham 1999; Graham and DeSanti 1999). Blue catfish growth can be very rapid, especially if food is abundant and once their diets are comprised of mostly fish (Graham 1999). As blue catfish mature, their rate of growth declines (Jenkins 1956; Porter 1969).

Environmental conditions affect the growth, food consumption and conversion, and behavioral activities of fish, especially blue catfish (Tyler and Kilambi 1972). For example, length of the growing seasons, abiotic conditions, forage base, interspecific and intraspecific competition all influence how blue catfish grow and develop within their habitats (Graham 1999). Blue catfish growth occurs best in salinities below 2 parts-per-thousand (ppt), and growth rates decline as water becomes more brackish (Perry and Avault 1969). Blue catfish can be cultured successfully in waters that do not exceed 8 ppt in salinity for any extended period of time (Perry and Avault 1969; Graham 1999). The optimal temperature for growth of blue catfish is about 24^{o}C (Collins 1988; Tidwell and Mims 1990).

Local environmental conditions heavily influence the rate at which catfishes grow. Caution should be taken when comparing age-and-growth data for blue catfish from different regions because local environmental conditions often vary (Graham 1999; Grist 2002). The Southeast in particular, has warmer water temperatures and a more diverse food base which may account for faster growth of blue catfish (Graham 1999). Furthermore, growing seasons last longer in the South, which southern blue catfish populations may grow larger than other populations in northern regions. Moreover, this has not been investigated. Information regarding the environmental conditions faced by blue catfish in the Oconee River, Lake Sinclair, and Lake Oconee is unavailable. The age structure of the blue catfish in the Lake Oconee and that of other populations in the surrounding area are also unknown. An objective of this research project was to identify the age and size structure for the Lake Oconee blue catfish population.

A REVIEW OF AGE AND GROWTH DETERMINATION LITERATURE

Age and growth information are essential for fisheries managers to understand the life histories and ecology for various fish populations and to properly manage them. Obtaining age and growth information for populations has been an integral component of catfish management in the United States. Studies conducted to obtain age and growth information for catfish populations have determined the size and age structure of catfish populations, identified trends in catfish populations, determined catfish populations' responses to management and environmental changes, investigated species interactions, and have made predictions about quality of habitats at a given time (Putnam et al. 1995; Kwak et al. 2006). Furthermore, age and growth information has been used to determine the status of catfish populations in various systems (Grabowski et al. 2006; Kwak et al. 2006).

Age and growth information can be collected from numerous approaches: 1) marked fish of a known age are recovered, 2) the Peterson method, which involves making comparisons of length-frequency distributions for a population over time, and 3) using the hard parts of fish to determine ages of fish in a population (Cailliet et al. 1986; Devries and Frie 1996). Furthermore, methods requiring researchers to cross-section the hard parts of catfish and count growth rings is the most common approach used to collect age and growth information because the techniques are relatively simple to perform and can be applied to a number of species (Cailliet et al. 1986; Devries and Frie 1996; Borkholder and Edwards 2001).

When using chronometric structures (i.e., the hard parts of fish), age information is obtained by counting growth rings called circuli. Circuli represent variations in somatic growth. Annuli, or thick bands of compressed circuli, represent periods of slow growth that occurs annually in the life of a fish. North American catfish populations that inhabit ecosystems with extreme environmental differences between summer and winter can exhibit more obvious seasonal growth variations than populations that inhabit seasonally stable environments. Thus, the distance between annual marks, or annuli, will be more obvious in populations living in less stable environments (Cailliet et al. 1986). Structures such as opercular bones, vertebrae (Appelget and Smith 1951), pectoral (Sneed 1951; Prentice and Whiteside 1974; Nash and Irwin 1999; Buckmeier et al. 2002) and dorsal spines (Turner 1982), and sagittal otoliths (Nash and Irwin 1999; Buckmeier et al. 2002) have been used to determine age and growth of catfishes; these structures have been used for blue catfish as well (Ramsey and Graham 1991; Graham 1999).

To date, techniques for age determination have been developed and compared for precision for a number of catfish species including flathead catfish (Turner 1982; Nash and Irwin 1999) and channel catfish (Sneed 1951; Prentice and Whiteside 1974; Buckmeier et al. 2002). Further, these techniques have only been validated for blue catfish from ages 1-4 (Buckmeier et al. 2002). Sneed (1951), Marzolf (1955), Prentice and Whiteside (1974), and Turner (1982) developed the traditional non-lethal age determination techniques that have been used for most ictalurids including blue catfish. Sneed (1951) developed a traditional age determination method that requires catfish managers to read cross-sections of pectoral spines cut at the basal recess, which is located at the base of the main shaft of each spine. Turner (1982) compared and validated age determination techniques that required managers to read cross-sections of pectoral spines and dorsal fin spines cut at the basal recess and articulating process, and this study found that the articulating process has less loss of annuli from the expansion of the central lumen. Buckmeier et al. (2002) modified the use of the articulating process age determination technique described by Turner (1982) which resulted less influence of the expansion of the central lumen on the appearance of older annuli.

Lethal methods for age determination requiring the use of otoliths have also been developed and are gaining preference among catfish managers. Otoliths are dense, calcareous bodies in the paired labyrinth systems of teleosts, located in the cranial bones near the brain (Cailliet et al. 1986). Otoliths are composed of calcium carbonate crystals embedded in an organic medium layered in concentric shells (Cailliet et al. 1986). In multiple studies that are commonly cited for catfish age determination methods, the authors identified the otoliths as ''sagitta'' or ''sagittal otoliths.'' Three pairs of otoliths are found in teleost fishes: lapilli, sagittae, and asterisci (Secor et al. 1992). Fisheries scientists commonly use the sagitta for determining ages of non-ostariophysean fish because they are the largest among the three types. In ostariophysean fish, such as Siluriformes (catfishes), the lapilli are the largest, and they are located anterior, distal, and above the sagitta (Secor et al. 1992; Long and Stewart 2010). Long and Stewart (2010) confirmed that multiple studies that reported the use of the sagitta for age determination of catfishes were actually using the lapilli.

Multiple studies have identified the limitations of the traditional age and growth determination techniques for catfishes (Turner 1982; Crumpton et al. 1984; Nash and Irwin 1999; Buckmeier et al. 2002). These studies have noted that pectoral spines are more difficult to read and interpret because the central lumen of spines expands and erodes annuli as catfish grow. In older catfish, annuli in spine cross-sections tend to crowd towards the outer margin of the structure (Lai et al. 1996; Kocovsky and Carline 2000; Boxrucker and Mauck 2006). The erosion of earlier annuli and the crowding of annuli toward the outer margins can result in erroneous age assignments because of the underestimation of catfish ages. False annuli read from spine cross-sections taken from younger catfish can result in flawed age assignments because of the overestimation of catfish ages. Otolith cross-sections are often easier to read and interpret than cross-sections made from pectoral spines because the annuli do not crowd towards the outer margins of the structures, and are not lost as the fish grows. Otoliths are also protected by the fish skull, whereas pectoral spines are more prone to trauma; such injuries can result in malformations of the chronometric structures. Nash and Irwin (1999) compared the use of otoliths against the use of pectoral spines when determining the ages of flathead catfish, and Buckmeier et al. (2002) compared the precision and validated an otolith age determination technique for channel catfish ages 1-4.

Fisheries biologists responsible for managing blue catfish populations and other introduced fish populations have been challenged to obtain age and growth information by employing methods that have not been validated for the species. Furthermore, comparisons of the age determination techniques have not been made to assess which provides more precise age estimates for blue catfish. To properly assess the accuracy of each age determination technique, each would have to be performed on a sample of known-age fish and the age estimates would have be compared to the true ages of the fish. Often, known-age fish are unavailable, and the accuracy of the age determination techniques cannot be evaluated.

For this study, we collected age and growth information for a newly introduced population of blue catfish in Lake Oconee, Georgia. Furthermore, our study was the first to collect demographic information for the introduced population in Lake Oconee. The primary goal of this study was to compare commonly used non-lethal and lethal age determination techniques that could be used for blue catfish. A comparison of the techniques would facilitate the decision-making process when trying to choose a technique to use for age determination of individuals from other blue catfish populations. Age and growth information collected from this study provides the size and age structure of the population and growth for each cohort represented in the sample. The growth information provided by this study can be used to predict the population's status in Lake Oconee.

Back-calculation of length-at-age can be used to determine growth of blue catfish collected from Lake Oconee (Devries and Frie 1996). Back-calculation of length-at-age is used by fisheries biologists to obtain information about past growth of a fish based on the relationship between the radius of a hard part and the fish's length (Devries and Frie 1996). To back-calculate growth, there must be a direct relationship between growth of the ossified structure being used to age and the length of the fish. Back-calculations involve translating the relationship between the distance of annuli from the central focus of the ossified structure and length of the fish at the time of capture into annual growth (Devries and Frie 1996). The information required to perform back-calculations for catfish is the length-at-capture for each fish, the radius of the structure being measured at the time of capture, and the distance of each annulus or daily rings from the central focus (Devries and Frie 1996). The Fraser-Lee method was used to back-calculate length-at-age for the fish in our samples. The Fraser-Lee method has been widely accepted by many fisheries biologists as a method of back-calculation (Devries and Frie 1996; Klumb et al. 2001).

The Fraser-Lee method of back calculation can be applied when the plotted intercept assumes of the relationship between the length of the fish and the radius of the structure is not at the origin (Devries and Frie 1996). The formula for back-calculating lengths of fish at previous annuli is:

$$L_i = \frac{L_c - a}{S_c} S_i + a$$

$\frac{Lc - a}{Sc} =$ slope of a two-point regression line to estimate L_i

a= intercept parameter

L_i= back-calculated length of fish when the i^{th} increment was formed,

L_c= length of the fish at capture

S_c= radius of the hard part at capture

S_i= radius of the hard part at the i^{th} increment

The slope of the Fraser-Lee back-calculation equation is calculated for each fish as the slope of the line connecting (S_c,L_c) and (0,a) (Carlander 1982; Devries and Frie 1996). The intercept parameter is calculated as the intercept of regression of fish length at capture and hard-part radius at capture for a range of sizes for fish being examined

(Devries and Frie 1996). The value for *a* can be standardized by species (Carlander 1982), or it can be calculated for an individual sample of fish (Devries and Frie 1996). Campana (1990) suggested that an intercept be developed that is defined by the fish length at which the otolith radius equals zero (Devries and Frie 1996).

The Fraser-Lee method has been effective in determining length-at-age and growth for catfishes (Devries and Frie 1996; Borkholder and Edwards 2001; Klumb et al. 2001). The Fraser-Lee method can be used to calculate earlier lengths-at-age, when the hard parts and fish lengths cannot be used to estimate the intercept *a* (Devries and Frie 1996). Another problem with this method is that the statistical estimation of means from multiple populations or time period can be unreliable because the estimate of back-calculated length is from a sample size of an individual fish on a two-point regression (Devries and Frie 1996). If fish growth is variable, the causes for differences of back-calculated of lengths-at-age can be challenging to identify (Devries and Frie 1996). By using the Frasier-Lee method, we compared the precision of back-calculated mean length-at-age obtained after applying the traditional age determination techniques commonly used for blue catfish.

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CHAPTER THREE

HISTORICAL CATCH, AGE STRUCTURE, SIZE STRUCTURE, AND RELATIVE GROWTH FOR AN INTRODUCED POPULATION OF BLUE CATFISH IN LAKE OCONEE, GEORGIA[2]

[2] Homer M. D., Jr. and C. A. Jennings. 2011. *Conservation, Ecology, and Management of Catfish Populations: The Second International Symposium* 383-394. Reprinted here with permission of the publisher.

ABSTRACT

In Georgia, blue catfish *Ictalurus furcatus* are native in the Coosa River drainage in the northwestern part of the state. However, they were first detected outside this range during an annual gillnet survey of Lake Sinclair conducted by Georgia Department of Natural Resources (GADNR) in 1996, then again in a similar survey of Lake Oconee during 1997. Catch of blue catfish in annual surveys of Lake Oconee continued to increase, but demographics of the populations are unknown. We used annual survey data for the period 1989-2009 to identify trends in catch of blue catfish in the lake. Age- and size-structure of the blue catfish population in Lake Oconee was assessed based on catch data from the 2008 survey. Mean length for blue catfish captured (n=121) was 330 mm (SD = 132 mm) and mean weight was 468 g (S.D. = 683.9 g); the largest fish was 740 mm and weighed 5078 g. Otoliths from the blue catfish collected were cross-sectioned, mounted on glass slides, examined under a dissecting microscope, and annuli on each section were counted independently by two readers. Catch data indicated that blue catfish catch increased rapidly after 1997. Seven year classes (2001-2007) were represented in the 2008 sample, and most fish were from the 2003-year class (mean age: 3.7 years; SD = 1.4 years). These data document a rapidly expanding blue catfish population in Lake Oconee and could serve as the basis for developing management strategies in this reservoir system and others across North America where blue catfish are expanding their range.

INTRODUCTION

Blue catfish *Ictalurus furcatus* are among the largest freshwater fish in North America, and the species has become one of the most sought-after sportfish because of its large maximum size and aggressive behavior (Graham 1999; Grist 2002). Furthermore, increased popularity of catfish angling over the years has led to sanctioned and unsanctioned introductions of the species throughout the United States (Graham 1999). In Georgia, blue catfish are native to the northwest corner of the state and occur in the Coosa River (Glodek 1980). However, multiple introduced populations of blue catfish have been and continue to be identified in Georgia (Straight et al. 2009). Currently, the status of each introduced population is unknown, nor does Georgia have any specific management for them.

Blue catfish were first discovered outside their native range in Georgia in 1996; two individuals were captured during an annual fish survey conducted by Georgia Department of Natural Resources (GADNR) in Lake Sinclair Reservoir, a mainstem reservoir on the Oconee River in central Georgia. The following year, additional blue catfish were captured in a similar survey conducted in Lake Oconee, another mainstem reservoir of the Oconee River located upstream of Lake Sinclair. Sources of blue catfish introductions in both reservoirs are unknown (Ramon Martin, GADNR - personal communication). Since 1997, catch frequencies of blue catfish in annual gillnetting surveys have been increasing (GADNR, unpublished data). Since their introduction to the Lake Sinclair/Lake Oconee system, blue catfish have expanded their range into the upstream and downstream reaches of the Oconee River. These populations have not been investigated, although GADNR compiles catch data based on their annual gillnetting surveys of the lake. Demographics of these expanding populations are unknown, as are the effects of this expansion on other native catfishes. Current management for blue catfish allows unlimited harvest of this species throughout the State.

Previous life history studies of blue catfish are limited, and literature pertaining to reservoir populations is even scarcer. However, most studies on blue catfish populations have focused on determining size and age structure, growth of individuals, estimating mortality, survival, and recruitment as well as examining diets of individuals. Demographic information for introduced populations is useful for evaluating populations' overall success of establishment and to predict possible effects on the ecosystem caused by the introduction (Kwak et al. 2006).

Lake Oconee is home to multiple native catfish species: flat bullhead *Ameiurus platycephalus*, white catfish *A. catus*, brown bullhead *A. nebulosus*, channel catfish *I. punctatus*, yellow bullhead *A. natalis*, and snail bullhead *A. brunneus*. Non-native flathead catfish *Pylodictis olivaris* are also present and were first caught in the lake during routine surveys in 1995. However, only six individuals have been captured in surveys up to 2009 (GADNR, unpublished data). Blue catfish and flathead catfish are the largest members of the family Ictaluridae; although they have differences in life history strategies, they do have some similarities. Both grow to large maximum size, are highly piscivorous, are habitat generalists, and have high fecundity. However, blue catfish grow to larger sizes, are more omnivorous, and more migratory than flathead catfish (Graham 1999; Timmons 1999; Grist 2002; Boxrucker 2007), which such behavior may lead to a greater expansion of their introduced range. Presence of both the blue catfish and flathead catfish in Lake Oconee could potentially lead to declines of other fishes in the community as a result of predation or direct and indirect competition for resources. Anecdotal evidence suggests that a targeted recreational fishery for blue catfish is developing in Lake Oconee. However, development of management strategies for this population as well as the other catfishes in the lake is hampered because the statuses of the various catfishes in Lake Oconee are unknown.

In this study, we examined available catch data and used specimens caught in December 2008 to determine demographic data (e.g., age structure, size structure, and relative growth) for the introduced blue catfish population in Lake Oconee. Examination of gillnetting data could provide managers with information regarding possible biotic interactions between blue catfish and other catfishes in the lake. The goal of our study was to provide data that could serve as a basis for developing sound management strategies for the introduced, rapidly expanding blue catfish population in Lake Oconee and similar reservoirs with introduced blue catfish populations. Our primary objectives were to: 1) use annual gillnetting survey data for Lake Oconee to identify trends in catch of the various catfish species found in Lake Oconee, and 2) determine sizes, ages, and year class composition for the introduced blue catfish population.

METHODS

Study Area

Lake Oconee is a 7,677 ha reservoir with about 602 km of shoreline (Figure 3-1; Georgia Power Company [GPC] 2009). Lake Oconee was formed by impounding the

Oconee and Appalachee rivers by building Wallace Dam, a pump-storage, hydroelectric facility owned and operated by GPC. The dam, constructed during the period 1971 - 1980, is 37 m tall, 730 m long, and has six turbines that are used to release water downstream to generate electricity (GPC 2009). The turbines also are used to pump water from the downstream reservoir (i.e., Lake Sinclair) back into Lake Oconee for reuse. The reservoir is also used for recreation and commercial fishing, and multiple residential and resort communities can be found on its shores. GADNR established 12 sampling stations located throughout the reservoir (Figure 3-2) and has used them since 1989 to conduct annual, standardized fisheries surveys during fall/winter.

Examination of Catch Data

Data on the species, numbers, lengths, and weights of the various catfish species caught during standardized gillnetting surveys of Lake Oconee were provided by GADNR. Standardized gillnetting surveys were conducted each year (1989-2009) during late fall or early winter and involved bottom-setting an experimental gillnet (20.4-m panels; 1.9, 3.8, and 4.5 cm bar meshes) overnight at each of 12 stations on Lake Oconee. Nets were retrieved the following morning by GADNR personnel. Captured fishes were removed from nets, identified to species, enumerated, measured for total length (TL mm) and weight (g), and associated water quality were collected at each station. These data were used to identify trends in catch frequencies of the various catfish species in the lake. Annual catch data were plotted for blue catfish and other catfishes in Lake Oconee. Only annual catch for white catfish and channel catfish were examined and compared pre- and post-introduction of blue catfish because other catfish species were caught infrequently and their numbers sufficiently low that they were excluded from the analysis. Microsoft Office[3] Excel™ (Microsoft, Inc. - Redmond, WA) and SigmaPlot™ (Systat Software, Inc.-Chicago, IL) data management software were used for data manipulation, and interpretation. Total annual catch as well as mean annual catch-per-unit-effort (CPUE) and associated standard deviations were calculated for blue, channel, and white catfish for the period 1997-2009; the plots were created with SigmaPlot™ software. A regression line was fitted to CPUE data for blue catfish to determine if a trend in catch was evident.

Fish Collection

In 2008, GADNR's annual gillnetting survey in Lake Oconee was conducted during December. One experimental gillnet was set at each of the 12 standardized stations and allowed to fish overnight and retrieved the next morning; total soak time was ~18 hours. All blue catfish caught were euthanized, marked with an individually numbered round aluminum tag, measured for total length to the nearest millimeter (mm TL), weighed (g), and were placed on ice inside a cooler and transported to the University of Georgia Fisheries Lab in Athens, Georgia. Fish were stored for two weeks in a walk-in freezer until they could be processed for age determination.

Otolith Preparation and Age Determination

Blue catfish otoliths were extracted as described by Buckmeier et al. (2002). A hacksaw was used to cut through the supraoccipital bone into the cranial cavity, and otoliths were exposed and removed. A cut was made about 5 mm above the pectoral

[3] Use of trade names does not imply US Government endorsement of commercial products.

spines on the dorsoanterior portion of the body cavity (Buckmeier et al. 2002). Forceps were used to remove the lapillar otoliths (Long and Stewart 2010) from the otic capsule. A dissecting scalpel was used to remove excess tissue from the surface of otoliths. Otoliths were rinsed with tap water, air dried for ~5 min, and stored in glass vials (8 mL) labeled with the fish's tag number.

In preparation for cross-sectioning, an otolith from each fish was embedded in West System™ 205 and 206 (Gougeon, Inc.-Bay City, MI) quick-drying, epoxy resin set in plastic ice cube trays. Ice cube trays were first lubricated with Sprayon® Lecithin Mold Release (Krylon Products Group-Cleveland, OH), and a small layer of epoxy-resin was added to the empty well and allowed to cure for ~ 3 hours. Once the layer of epoxy cured, the left otolith from each fish was placed laterally and centered toward the outer margin of the left side of a cured epoxy mold. Fresh epoxy was added until each otolith was submerged and allowed to cure for ~ 3 hours.

Sectioning of otoliths was achieved by first using a dissecting scope to locate the focus of the otolith, and a fine-tipped permanent marker was used to place a reference mark over the focus. Transverse cross-sections of otoliths were made with a Buehler™ low-speed Isomet saw (Buehler-Lake Bluff, IL). The diamond blade (Series H-15; Buehler-Lake Bluff, IL) of the saw was lubricated with mineral oil to provide a smooth cut and prevent breakage of sections. Cuts were made about 0.5 mm above and below the reference mark. Each cross-section was about 0.3 - 0.4 mm thick; the reference mark was visible in the center of the section. Each cross-section was then examined under a dissecting scope to assess readability. If the section was not readable, another section was made from the same otolith or the other otolith was used if available. Each cross-section was mounted to a glass slide by using Cytoseal™ XYL (Richard-Allan Scientific-Kalamazoo, MI) mounting solution. Once the Cytoseal™ XYL dried, the slide was placed under a Leica™ MZ-7 (Leica Microsystems-Wetzlar, Germany) dissecting microscope and annuli were counted. A fiber optic light source also was used for side illumination to facilitate counting of annuli. The dissecting scope was equipped with a Leica™ DFC295 camera that transmitted the image onto a computer monitor.

For most southeastern populations of North American catfishes, annulus formation occurs during fall and winter and ceases around late spring to early summer (Dave Buckmeier-Texas Parks and Wildlife, personal communication); annulus formation in blue catfish is similar (Scott Lamprecht-South Carolina Department of Natural Resources, personal communication). An annulus in a blue catfish otolith cross-section appears as a dark, opaque band with a sharp margin. The band should clearly separate the translucent new growth that occurs in the late spring to early summer. For this study, an annulus was defined as the outermost margin of the dark, opaque band. False annuli appeared "halo-like" and had incomplete margins. Counting of annuli began from the central focus of the cross-sections and moved outward to the edge of the otolith. The last annulus formed was reported as the outer margin of the otolith. Age information is reported by year class. If a fish is referred to as belonging to particular age class, this assignment is reported as the age the fish would have been in spring 2009.

Two readers independently counted annuli from each cross-section. Age of the fish was recorded as the total number of annuli counted, and year class (YC) was assigned by subtracting the age assignment from 2009. If there was a disagreement with an age assignment, annuli were recounted with consultation by the two readers. If readers could not come to an agreement for an age assignment, the fish in-question was eliminated from the dataset. The percentage of reader agreement was recorded after all slides were read.

A length-weight relationship, length-frequency histogram, and age-frequency histogram were plotted for all blue catfish captured to estimate size and age structure of the population. A regression line was fitted to length-at-age data. Mean length-at-age and associated standard deviation were determined for each year class represented in the sample and plotted in Microsoft Excel.

RESULTS

Trends in Catch of Catfishes

Trends in catches of the three most abundant catfish species (i.e., channel, white, and blue catfish) in the lake were variable during the years examined. Catch of blue catfish increased during the period; whereas, white catfish decreased. Blue catfish were discovered in Lake Oconee in 1997, and their abundance in the annual surveys increased rapidly by orders of magnitude (Figure 3-3). Annual catch of white catfish peaked in 1997, but declined as catch of blue catfish increased (Figure 3-3). White catfish were not captured from 2005 to 2008, and only one individual was caught in December 2009 (Figure 3-3). Annual catches of channel catfish were dynamic but high during most of the study. Catches of channel catfish increased after 1997 and remained higher than during the years before blue catfish were discovered (Figure 3-3). However, in December 2009, catch (n=126) was surpassed by that of blue catfish (n=152) for the first time since sampling began (Figure 3-3).

Trends in catfish CPUE followed the same trends as those for total catch (Figure 3-4). CPUE for white catfish peaked in 1997 and declined steadily thereafter (Figure 3-4). After 2004, CPUE of blue catfish continued to increase, and CPUE of white catfish declined steadily (Figure 3-4). CPUE of channel catfish was again dynamic, and catch remained high during the study period. Exponential regression indicated that there was a positive trend in CPUE of blue catfish in Lake Oconee (r^2= 0.9104; y= 0.1239x^2 - 495.3x + 494934; Figure 3-5).

Lengths, Weights, Ages and Relative Growth for Blue Catfish Population in Lake Oconee

During 2008, 121 blue catfish were captured in Lake Oconee. Lengths of blue catfish captured ranged from 138 to 740 mm (mean length: 330 mm, SD=132 mm) and weights ranged from 17 to 5,078 g (mean weight: 468 g, SD=684 g; Figure 3-6 and Figure 3-7). Year-classes were assigned to 88 fish (Figure 3-8). The 33 catfish not assigned to a year-class were excluded because of recording errors in the length-weight data or their otoliths were damaged during collection or cross-sectioning and could not be read. Agreement between both readers for age assignments was 82.7%. The sample was comprised of fish from year-classes spanning a seven-year period (2001 - 2007; Figure 3-8)[4] and relative growth was estimated for these fish (Figure 3-9). Most fish were estimated to belong to year-class 2003, which comprised 26.1% of the overall sample

[4] There was one fish whose age was estimated by both readers at 13 years of age. However, there was an error in the length-weight recording (528 mm TL; 1575 g); therefore this fish was excluded from the analysis. This fish would have been one of the original blue catfish to colonize the lake, so we thought this information was noteworthy; hence its inclusion as a footnote.

(Figure 3-8). Fish from both year-class 2006 and year-class 2005 made up 22.7% of the catch. Fish from year-class 2004 comprised 18.2% of the catch. There was one fish from year-class 2007 and two from year-class 2001 captured in the sample. On average, blue catfish in Lake Oconee had a relative annual growth rate of 86.1 mm (SD=38.1 mm; Figure 3-9).

DISCUSSION

Although information about ecological consequences of blue catfish introductions and range expansion is limited, effects of their introductions and dynamics of the introduced populations are probably similar to those described for introductions of invasive catfish species elsewhere. Established introduced fish populations often exhibit similarities in their dynamics: rapid population growth, somatic growth, and dispersal and colonization rates (e.g., Sakai et al. 2001). Further, introductions of piscivorous species often lead to declines in native species small enough to be preyed upon. Recent examples of this latter phenomenon are common throughout the southeast in general (Grabowski et al. 2004; Brown et al. 2005; Kwak et al. 2006; Sakaris et al. 2006) and specifically in Georgia (Thomas 1993; Bonvechio et al. 2009). Given rapid shifts in catch from white catfish to blue catfish and the rapid decline of white catfish catch in annual species surveys in Lake Oconee, we hypothesize that the population of blue catfish in Lake Oconee may be exhibiting similar early-stage population dynamics comparable to other invasive catfish populations recently studied. Moreover, the blue catfish population in Lake Oconee is relatively new and is probably still expanding.

We attempted to identify temporal trends in relative abundance of catfishes in Lake Oconee following the blue catfish introduction by examining annual total catch and annual CPUE from the GADNR annual survey data. The decline in abundance of white catfish in Lake Oconee was coincident with the arrival of blue catfish in the system. Blue catfish and white catfish have similar preferred prey, preferred habitat, and spawning season; however, their native ranges do not overlap (Rohde et. al. 2009). The mechanism for decline of white catfish when blue catfish colonize is unknown, but it may be related to direct predation or interspecific competition for food and habitat. Grist (2002) noted that declines in white catfish and snail bullhead were concurrent with increases in catch of blue catfish in Lake Norman, NC. Similar declines in white catfish catch have been observed in the Hudson River, NY where channel catfish have been introduced (Jordan et al. 2004). As such, our assessment of any effects may be reflecting early invasion dynamics if the system has not stabilized yet. Catch of channel catfish was variable from 1989-2009. Channel and blue catfish are sympatric in other systems, and both species have similar life histories (Graham 1999; Hubert 1999; Rohde et al. 2009). However, introductions of blue catfish into systems where channel catfish persist could result in adverse biotic interactions such as competition for resources and predation between the species. Other studies have cited decreased growth rates of channel catfish as evidence of interspecific competition between the blue and channel catfish (Jenkins 1956; Grist 2002).

During this study, we attempted to identify the size and age structure of the population, and we also attempted to provide a conservative estimate of relative annual growth. The limited number of year-classes (i.e., seven) present in our study suggests that the blue catfish in Lake Oconee are relatively young. Annual increases in maximum size and weight indicate that this population is growing rapidly. Seven year-classes were represented in our sample, and individuals from the 2003-YC were the most abundant. The relatively higher number of individuals from this year-class could be attributed to year-class strength or to gear selectivity. Our samples lacked representation of young-of-year fish (YC-2008) and fish from YC-2001 or earlier year classes. Our findings suggest the gillnets we used may be ineffective for sampling the youngest (small) and oldest (large) individuals. Buckmeier and Schlechte (2009) found that sampling blue catfish with experimental gillnets had lower capture efficiency and greater size selectivity bias when compared to sampling the species with low-frequency, pulsed DC electrofishing. In the present study, we used gillnet data from a standardized fisheries survey because these were the only data available for this population. As such, data presented here may be considered as conservative estimates of the number of year-classes and maximum size and weight of the blue catfish in Lake Oconee. As this population continues to expand, efforts to update information we present here may benefit from targeted sampling that includes use of low-frequency, pulsed DC electrofishing. This gear may provide better proportional representation of size classes (Buckmeier and Schlechte 2009) in Lake Oconee and could lead to better assessment of population status and better inform management decisions.

During our study, we faced multiple challenges with our age determination methods that limited the amount of data available for our inquiry. Challenges included lack of validation for aging methods for blue catfish and destruction of some of the otoliths during the extraction process or during the sectioning process. We overcame the lack of validated aging techniques for blue catfish by employing methods that have been validated for other large catfishes in the Family Ictaluridae (Nash and Irwin 1999; Buckmeier et. al. 2002). Ultimately, we were able to provide age estimates with relatively high agreement (82.7%) for 88 of the 121 fish captured in the December 2008 gillnetting survey. This agreement rate is comparable to other studies and deemed a "high agreement rate" by Buckmeier et al. (2002), who noted that their 79% reader agreement was high after assigning ages to channel catfish by counting annuli from their otoliths; their age assignments were 97% accurate.

Although we were counting annuli from blue catfish otolith cross-sections, false annuli were present as opaque bands that appeared incomplete and halo-like. In some cases, false annuli would be somewhat transparent or would converge with other annuli. Our assessment of blue catfish maximum length, weight, and ages did not account for gender-related differences in size and age. For example, blue catfish in Lake Wilson, Alabama displayed gender-specific growth and sexual dimorphism in size: males grew faster, grew to larger sizes, and attained larger ages than females (Marshall et al. 2009). Therefore, results from our study should be interpreted as an average relative growth rate of both genders. Including examinations of each fish's gonads in future age and growth determination studies for blue catfish in Lake Oconee would provide information concerning differences in length-at-age between genders, seasonal gamete development, and sexual maturity of blue catfish in the lake. Gender determination of blue catfish could be best achieved by sampling during the spawning season, which typically occurs during late spring and early summer (Graham 1999).

Despite the limited scope (1 year) and sample size (88 fish) used for age determination in our study, information obtained can be used as a preliminary basis for devising management strategies for the Lake Oconee blue catfish population. Our study is among the first to gather life history and population information for blue catfish in Georgia. Furthermore, this study provides a case-history of blue catfish introductions for a region where such data are non-existent and contributes to overall knowledge of dynamics of introduced blue catfish populations. Our attempts to find published literature on biology, ecology, management, and life history of blue catfish did not produce many papers. Apparently, few papers have been published on this species in the decade since Graham (1999) came to the same conclusion. Lack of published information is especially acute for southeast US reservoirs. Prior to this investigation, only anecdotal information from commercial or recreational anglers was available on status of blue catfish in Lake Oconee. Other information needs remain for the blue catfish population as well as the other catfishes in Lake Oconee. First and foremost, demographics of the various catfish populations seem to be changing. Monitoring those changes would document current and future status and provide the basis for sound management strategies. Information about ecological interactions (e.g., competition and predation) among the various catfish species also would be useful for devising meaningful management strategies for catfishes in the system. Finally, how environmental conditions (e.g., water quality, water storage retention time, or prey base) in the reservoir affect ecological interactions of all catfishes in the system also would contribute to establishment of meaningful management of introduced and native catfishes wherever they occur.

Currently, the state of Georgia does not have any concrete management strategies for catfishes in Lake Oconee, and present State regulations do not restrict their daily take or size. However, blue catfish and the other catfishes have supported growing recreational and commercial fisheries in Lake Oconee (Chris Nelson-GADNR, personal communication). Several catfish sportfishing clubs are establishing and beginning to target large fish in the system. However, preferred species and sizes sought by anglers and commercial fishermen in Lake Oconee are unknown. Our findings could provide a foundation of information available to fisheries biologists responsible for managing Lake Oconee's blue catfish fishery and other similar reservoirs where the species has been introduced.

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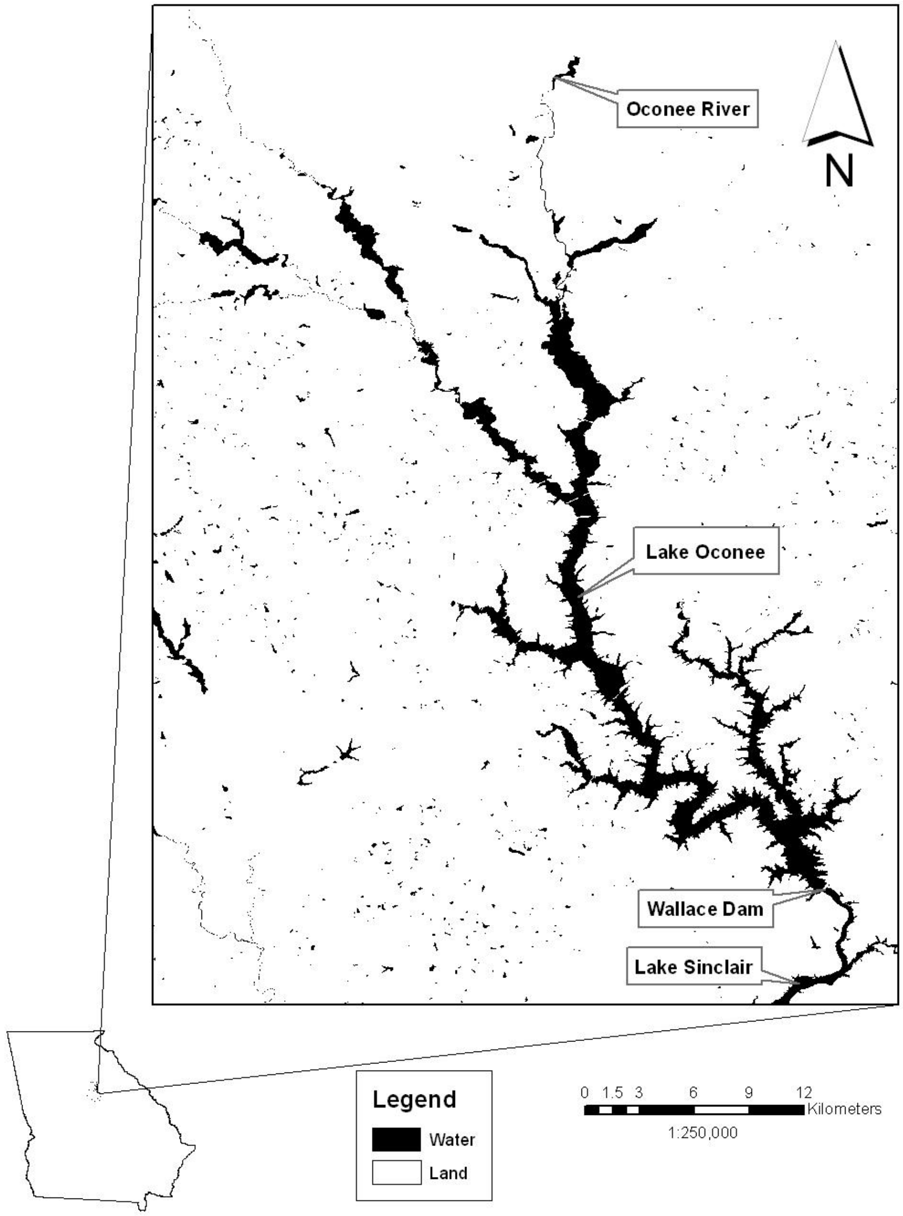

Figure 3-1. Map of Georgia with Lake Oconee study site enlarged; blue catfish were sampled from 1997 to 2009 at 12 stations on the lake.

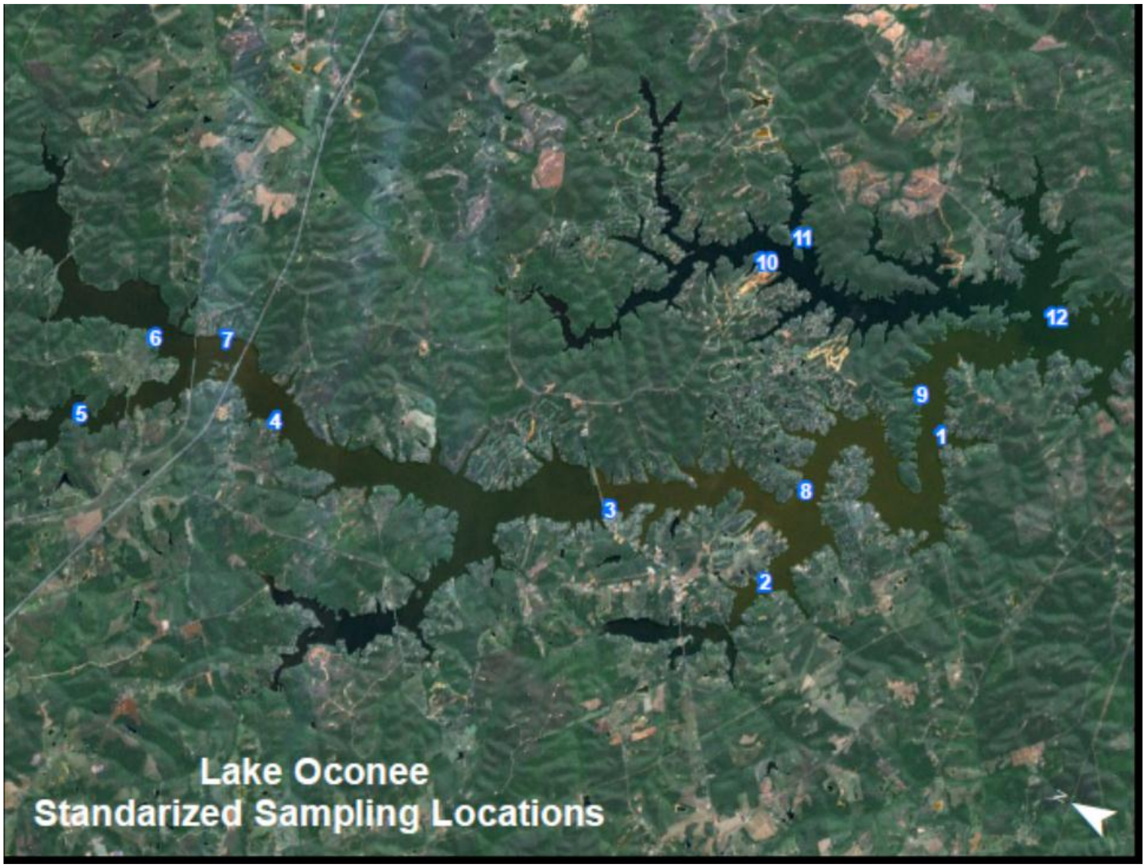

Figure 3-2. Locations of the 12 sampling stations on Lake Oconee, Georgia, where the Georgia Department of Natural Resources (GADNR) has conducted annual fisheries surveys since 1989.

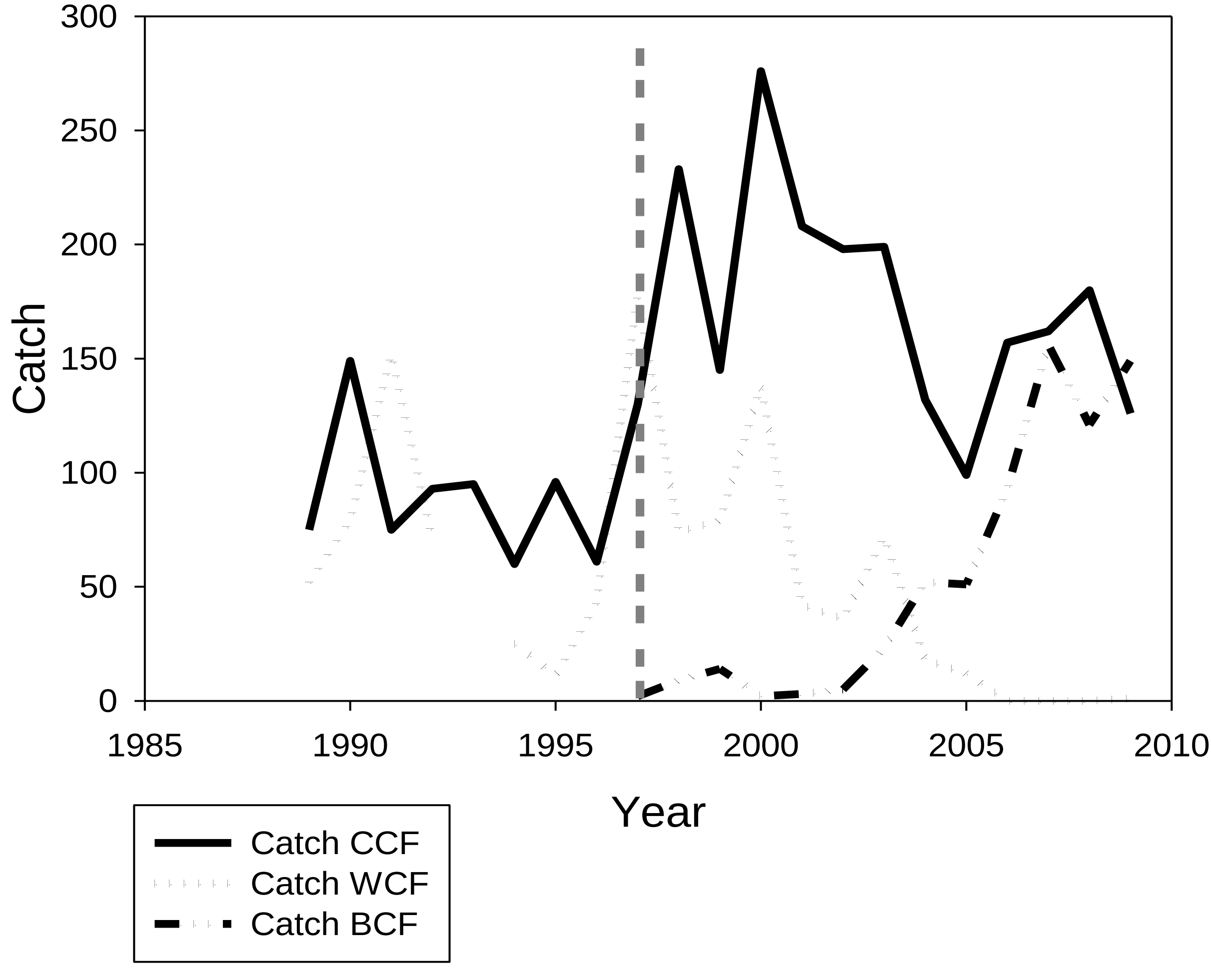

Figure 3-3. The number of white catfish (WCF), channel catfish (CCF), and blue catfish (BCF) caught annually in gillnetting surveys of Lake Oconee, Georgia. The vertical Line at the year 1997 separates time periods before and after the first capture of blue catfish. Note, catch data for white catfish were not recorded for 1993.

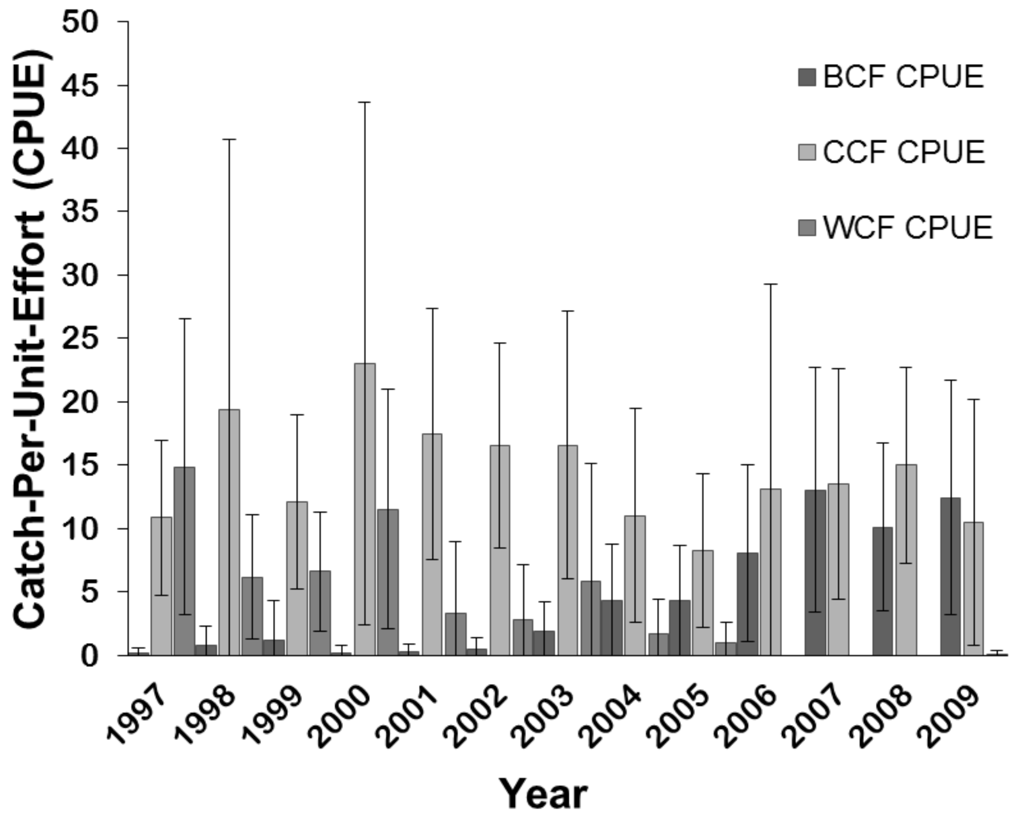

Figure 3-4. The catch-per-unit-effort and associated standard deviations for the catfishes caught in the annual gillnetting surveys post-introduction of blue catfish in Lake Oconee during 1997-2009.

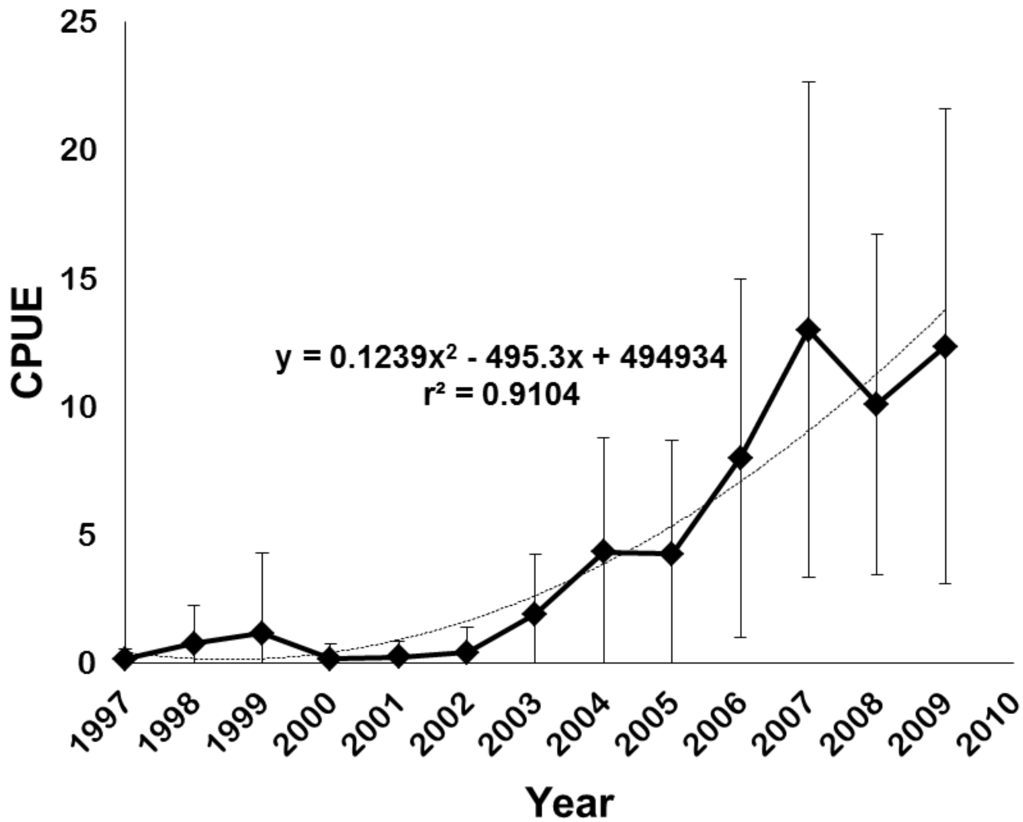

Figure 3-5. The mean annual catch-per-unit-effort and associated standard deviation of blue catfish caught in the gillnetting surveys conducted in Lake Oconee, Georgia (1997-2009).

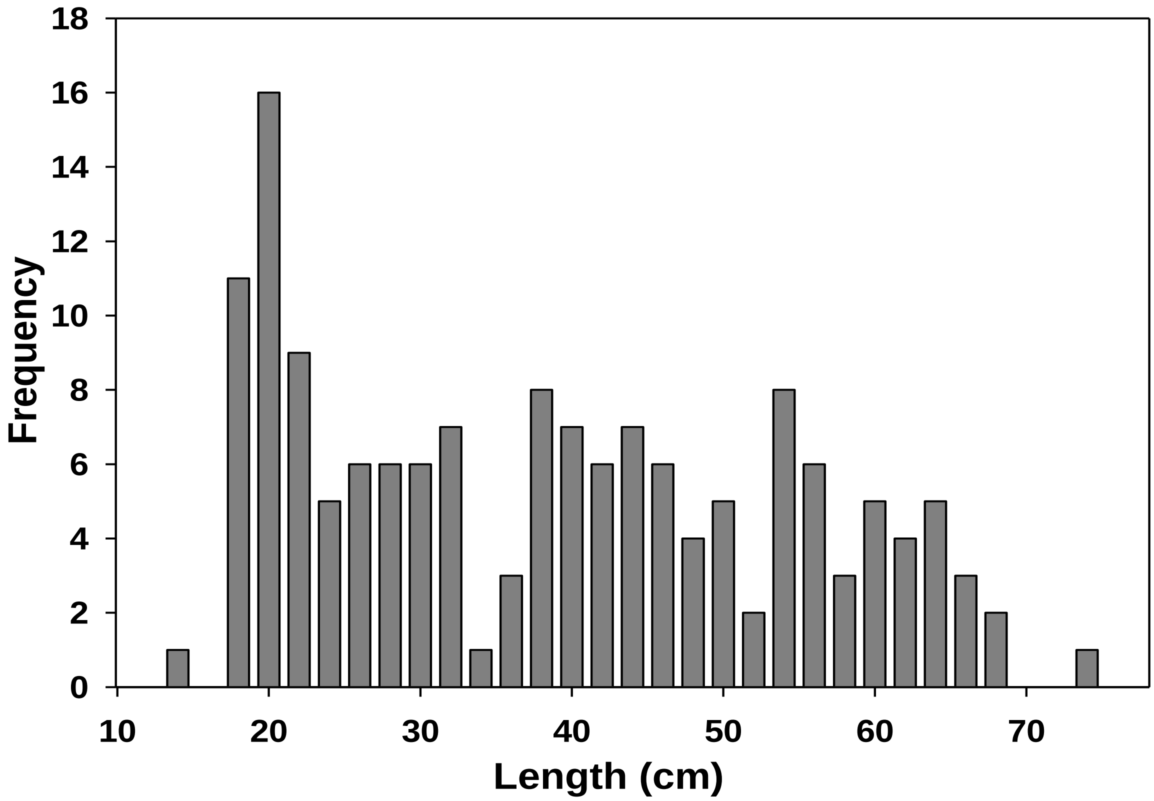

Figure 3-6. Length-frequency histogram for blue catfish captured during the December 2008 gillnetting survey in Lake Oconee, Georgia.

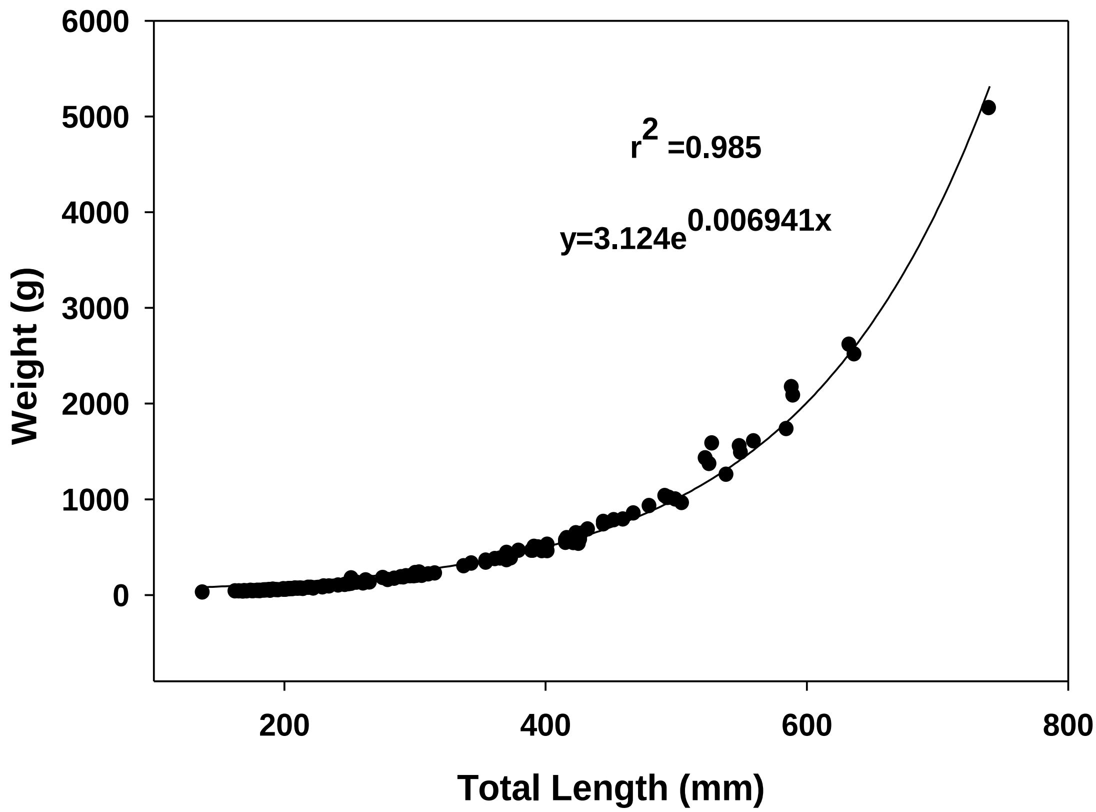

Figure 3-7. Length-weight relationship for blue catfish captured during December 2008 in Lake Oconee, Georgia.

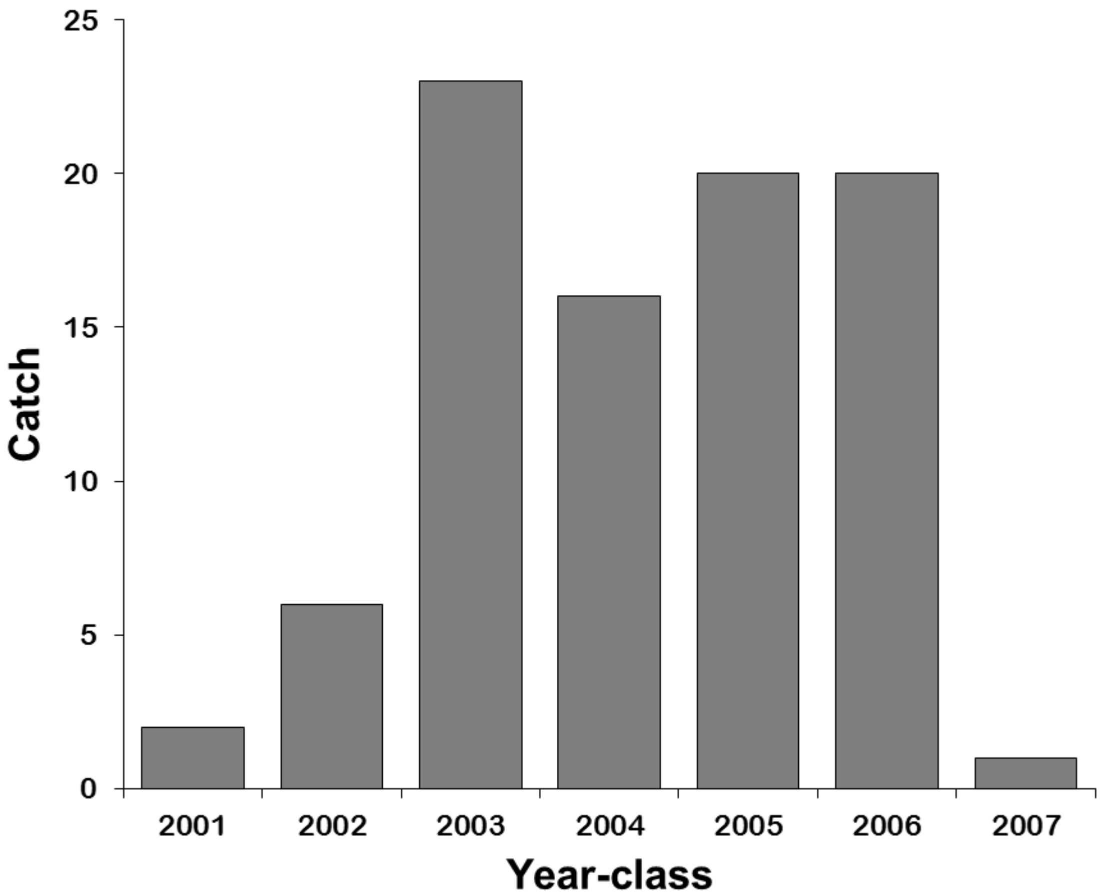

Figure 3-8. Catch-frequency histogram, by year-class, for blue catfish during December 2008 in Lake Oconee, Georgia.

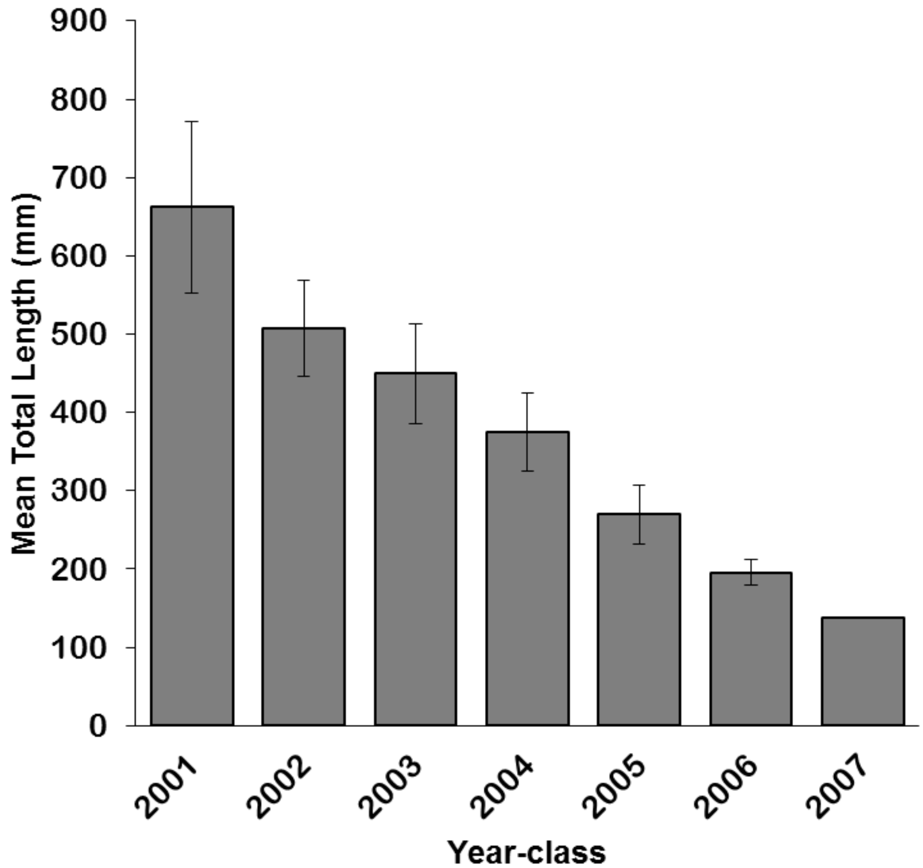

Figure 3-9. Mean total length-at-age distribution by year-class, with associated standard deviations for blue catfish captured during the December 2008 Georgia Department of Natural Resources (GADNR) gillnetting session in lake Oconee, Georgia. Error bars could not be calculated for the 2007 year-class because only one individual was captured.

CHAPTER FOUR

A COMPARISON OF TRADITIONAL AGE AND GROWTH DETERMINATION TECHNIQUES FOR INTRODUCED BLUE CATFISH IN LAKE OCONEE, GEORGIA[5]

[5] Homer M. D., Jr., C. A. Jennings, and J. T. Peterson. To be submitted to *Transactions of the American Fisheries Society*.

ABSTRACT

Age and growth information is used to understand populations' life history and ecology and monitor their trends. Such information is useful for evaluating the success of establishment of introduced populations. Prior studies have validated age determination methods for various catfishes, but none have been validated for blue catfish. We compared precision of age estimates and back-calculated growth after using one lethal and two non-lethal, traditional age determination techniques for introduced blue catfish in Georgia. Blue catfish (n=153) were collected by experimental gillnets set overnight at 12 standardized stations at Lake Oconee, Georgia. Two non-lethal techniques requiring the pectoral spines (articulating process and basal recess) and one lethal technique requiring lapilli were used to determine the ages of the fish. The Frasier-Lee method was used to back-calculate growth for each fish. Hierarchical models we used to compare precision in back-calculated length estimates and growth among the three. Two readers found the highest precision for otolith-based age assignments (83.5%) and lowest for basal recess cross-sections (71.4%). The hierarchical model indicated that back-calculated length was variable among fish from ages 1-3 for the techniques compared. Otolith-estimated growth decreased at the slowest rate and decreased fastest for basal recess-estimated growth. Our study suggests the articulating process and otolith techniques would are adequate for age determination of blue catfish.

INTRODUCTION

Age and growth information is necessary for fisheries managers to understand the life histories and ecology for various fishes and to properly manage them. Obtaining age and growth information for populations has been an integral component of catfish management in the United States. Age and growth studies conducted on catfish have determined the size and age structure of various catfish populations, identified trends in catfish populations over time, assessed catfish populations' responses to management and environmental changes (Sakaris 2006), investigated species interactions (Kwak et al. 2006; Bonvechio et al. 2009; Homer and Jennings 2011), and made predictions about habitat quality at a given time (Putnam et al. 1995; Kwak et al. 2006). Additionally, age and growth data have been used to determine the status of catfish populations in various systems (Grist 2002; Grabowski et al. 2006; Kwak et al. 2006; Boxrucker and Kuklinski 2007; Homer and Jennings 2011).

Age determination techniques that require the use of ossified structures are the most commonly used methods for obtaining growth information for catfish populations (Cailliet et al. 1986; Devries and Frie 1996; Borkholder and Edwards 2001). Such techniques are commonly employed because of their utility for and applicability to a variety of species (Cailliet et al. 1986; Devries and Frie 1996). Structures such as opercular bones, vertebrae (Appelget and Smith 1951), and dorsal spines have been used to determine age and growth of catfishes (Ramsey and Graham 1991; Graham 1999), but pectoral spines and lapillar otoliths (Long and Stewart 2010) have been the preferred structures (Sneed 1951; Marzolf 1955; Jenkins 1956; Prentice and Whiteside 1974; Nash and Irwin 1999; Buckmeier et al. 2002; Michaletz et al. 2009).

Methods for age determination have been developed for a number of catfish species including flathead catfish *Pylodictis olivaris* (Turner 1982; Nash and Irwin 1999) and channel catfish *Ictalurus punctatus* (Sneed 1951; Prentice and Whiteside 1974; Buckmeier et al. 2002), and these techniques have been employed as the traditional age determination techniques used for other catfish species including blue catfish. Sneed (1951) developed techniques for pectoral spine removal and for age determination of channel catfish. This age determination technique requires fish biologists to read cross-sections taken from the basal recess of pectoral spines; the basal recess is located at the base of the main shaft of each spine. Turner (1982) compared and validated methods that required biologists to counting annuli from cross-sections cut at the basal recess and articulating process of pectoral spines and dorsal fin spines. Cross-sections made at the articulating process of pectoral spines had better precision of age estimates than cross-sections made at the basal recess because less annuli had been lost from the expansion of the central lumen (Turner 1982). Buckmeier et al. (2002) modified the use Turner's (1982) articulating process technique for determining ages of channel catfish; this new process resulted in less annuli lost as a result from the expansion of the central lumen.

Multiple studies have compared age and growth determination techniques for various catfishes including flathead catfish (Turner 1982; Nash and Irwin 1999) and channel catfish (Crumpton et al. 1984; Buckmeier et al. 2002), but comparing the precision and accuracy of age estimates derived from blue catfish chronometric structures have not been conducted. Prior studies have noted that cross-sections of pectoral spines can be more difficult to use to count and interpret annuli than lapillar otoliths because the central lumen of spines expands and erodes annuli as catfish grow (Jenkins 1956; Nash and Irwin 1999; Buckmeier et al. 2002; Boxrucker and Kuklinski 2007). Such studies have also noted that annuli in spine cross-sections from older catfish tend to crowd towards the outer margin of the structure. Erosion of earlier annuli in older fish and the crowding of annuli toward the margins in cross-sections from slow-growing fish results in the underestimation of ages (Lai et al. 1996; Buckmeier et al. 2002). Prior investigations of the use of pectoral spines for blue catfish age determination have reported similar problems (Sneed 1951; Kelley and Carver 1965; Kelley 1968). False annuli read from spine cross-sections taken from younger catfish can result in the overestimation ages for those fish (Turner 1982; Koch et al. 2011).

The use of lapillar otoliths for age determination is a lethal method that has gained preference among catfish managers (Nash and Irwin 1999; Buckmeier et al. 2002). Otolith cross-sections often are easier to read and interpret than pectoral spines because the annuli do not crowd towards the outer margins of the structures, and annuli are typically not lost as the fish grows (Buckmeier et al. 2002). Multiple studies have suggested that direct comparisons of age and growth data from spine-aged populations versus otolith-aged populations may be invalid because the use of pectoral spines has been documented to underestimate ages of older fish (Nash and Irwin 1999; Buckmeier et al. 2002; Boxrucker and Kuklinski 2007). Nash and Irwin (1999) found better precision of ages assigned to flathead catfish otolith cross-sections than cross-sections of pectoral spines. Buckmeier et al. (2002) validated an otolith age determination technique as well as two other techniques requiring pectoral spines for channel catfish ranging from ages

1−4. Buckmeier et al. (2002) found better precision and accuracy with age estimates for ages assigned to otoliths than the ages assigned to the two techniques requiring pectoral spines.

To date, comparisons of traditional age determination techniques have not been made to evaluate the precision of blue catfish age estimates. In the current study, we used three common age-determination techniques to estimate age and growth information of a newly introduced population of blue catfish in Lake Oconee, Georgia. We then compared the precision of age and growth estimates with those derived from using traditional non-lethal and lethal techniques. Finally, we advise about which technique to use when deciding which technique is best for a given population of blue catfish.

METHODS

Study Area

Lake Oconee is a 7,677 ha reservoir with about 602 km of shoreline (Figure 4-1; Georgia Power Company [GPC] 2009). Lake Oconee was formed by impounding the Oconee and Appalachee rivers by Wallace Dam, a pump-storage, hydroelectric facility owned and operated by GPC. The dam, constructed during the period 1971 - 1980, is 37 m tall, 730 m long, and has six turbines that are used to release water downstream to generate electricity (GPC 2009). The turbines also are used to pump water from the downstream reservoir (i.e., Lake Sinclair) back into Lake Oconee for reuse. The reservoir is used for recreational and commercial fishing, and multiple residential and resort communities can be found on its shores. Georgia Department of Natural Resources (GADNR) established 12 sampling stations located throughout the reservoir (Figure 4-2) and has used them since 1989 to conduct annual, standardized fisheries surveys during fall/winter.

Fish Collection

GADNR conducted annual gillnetting surveys in Lake Oconee during December 2008 and January 2009. One experimental gillnet was set at each of the 12 standardized stations, allowed to fish overnight and retrieved the next morning; total soak time was ~18 hours. All blue catfish caught were euthanized, marked with an individually numbered round aluminum tag, measured for total length to the nearest millimeter (mm TL), weighed to the nearest gram (g), placed on ice, and then stored in a freezer until they could be processed for age determination.

Preparation of Pectoral Spines

Pectoral spines were removed by employing the method developed by Sneed (1951); briefly, this process involved disarticulating the spine by pressing it against the body of the fish and rotating the tip into the ventrum and upward towards the head. If the spine did not disarticulate, dissecting scissors and a scalpel were used to cut the flesh surrounding the spine so it could be pulled away from the body. Spines were boiled for two minutes and forceps were used to pull off remaining flesh. Next, the spines were rinsed with water and air dried for about five minutes. Spines were stored in coin envelopes labeled with the fish's identification number.

Transverse cross-sections of the pectoral spines were made with a Buehler™[6] low-speed Isomet saw (Buehler-Lake Bluff, IL). The left pectoral spine from each fish was used for cross-sectioning. If the left spine was damaged, the right pectoral spine was used. The diamond blade (Series H-15; Buehler-Lake Bluff, IL) of the saw was lubricated with mineral oil to provide a smooth cut and prevent breakage of cross-sections. Cross-sections (0.3 -0.4 mm thick) were made at two locations on each spine. The first cross-sectioning location was described by Buckmeier et al. (2002); the cut was made diagonally between the articulating process and the main shaft of the spine (Figure 4-3). The second cross-section was made using the method described by Sneed (1951); the cut was made at the basal recess on the main shaft of the spine (Figure 4-4). Each glass slide was labeled with the fish's identification number, date the fish was processed, location on the spine where the cross-section was made, and side of the fish's body from which the spine was taken. The slide was then placed on a hotplate with a small amount of Crystalbond-509 mounting medium (SPI Supplies/Structure Probe, Inc.-West Chester, PA). The dial of the hotplate was set at medium heat. Once the Crystalbond melted, forceps were used to place the cross-sectioned piece of spine in the melted mounting material. Once cooled, the slide was examined under a dissecting microscope to determine the clarity of the cross-sectioned spine and whether it needed to be sanded. If sanding was needed, a small amount of water was applied to the top of the mounted cross-section and then rubbed with a strip of 600-grit sandpaper in a circular motion 15 times. Kimwipes® (Kimberly-Clark, Dallas, TX) were used to wipe excess water and sanding residue off the slide and then the slide was rechecked for clarity under the scope.

[6] Reference to trademarks does not imply U.S. government endorsement of commercial products.

Otolith Preparation

To obtain the otoliths from each fish, a hacksaw was used to cut into the cranial cavity through the supraoccipital bone of each skull and expose the otic capsule. The cut was made about 5 mm above the pectoral spines on the dorsoanterior portion of the body cavity (Buckmeier et al. 2002). Forceps were used to remove the lapillar otoliths from the otic capsule. A dissecting scalpel was used to remove excess tissue from surface of the otoliths. Next, the otoliths were rinsed with water, air dried for about 5 minutes, and stored in glass vials (8 mL) labeled with the fish's identification number.

An otolith from each fish was embedded in West System™ 205 and 206 (Gougeon, Inc.-Bay City, MI) quick-drying epoxy resin within plastic ice cube trays. To do this, the ice cube trays were first lubricated with Sprayon® Lecithin Mold Release (Krylon Products Group-Cleveland, OH) and a small layer of epoxy-resin was allowed to cure. Each otolith was then placed laterally and centered toward the outer margin of the left side of the cured epoxy. If the left otolith was not available, the right otolith was used. Next, epoxy was added until the entire otolith was submerged. A dissecting scope was used to locate the focus of the otolith and an ultrafine tipped permanent marker was used to place a reference mark over the focus. Transverse cross-sections of the otoliths were made with a Buehler™ low-speed Isomet saw. The diamond blade (Series H-15) of the saw was lubricated with mineral oil. The cuts were made about 0.5 mm above and below the reference mark. Each cross-section was made about 0.3-0.4 mm thick with the reference mark visible in the center of the section. Each cross-section was then checked under a dissecting scope to assess the readability. If the section was not readable, another was made from the same otolith. If another cross-section could not be made from the same otolith, the other otolith was used if it were available. Cytoseal™ XYL (Richard-Allan Scientific-Kalamazoo, MI) mounting solution was used to mount each cross-section to a glass slide. Once dried, the slide was placed under a Leica™ MZ-7 (Leica Microsystems-Wetzlar, Germany) dissecting microscope and annuli were counted. A fiber-optic light source was also used for side illumination to facilitate readability. The dissecting scope was equipped with a Leica™ DFC295 camera mount that transmitted the image onto computer monitor to facilitate the counting process.

Age and Growth Determination

To properly assign ages to fish, biologists must know when annuli form in the structures and how to distinguish them in the cross-sections of chronometric structures. Most southeastern populations of North American catfishes form annuli during the fall and winter (Dave Buckmeier-Texas Parks and Wildlife, personal communication). An annulus in a pectoral spine cross-section made at the basal recess or articulating process appears as a dark, opaque band bordered by a translucent band that separates rapid growth that would occur during the late spring and early spring seasons once the annulus formation has ceased. For this study, an annulus read from both cross-sectioning locations of pectoral spines was defined as a crisp translucent band. The last annulus formed was considered as the outer margin of the cross-section. If a fish was referred to as belonging to particular age class, this assignment was reported as the age the fish would have been during the spring of 2009.

For this study, annuli in an otolith cross-section were defined as the outer margin of the dark band and point of transition to where new growth would have begun. False annuli appeared “halo-like” and had incomplete margins. Counting of annuli began from the central focus of the cross-sections and moved outward to the edge of the otolith. The last annulus formed was reported as the outer margin of the otolith. To account for a lost first annulus, a photograph of a reference basal recess cross-section taken at the same magnification was used to mark the first annulus for the cross-section in-question. The photograph was taken from a blue catfish from the same sample and assigned an age of one year. The same approach was used to identify lost annuli at other ages for the basal recess cross-sections.

Ages of blue catfish were determined by two experienced readers who independently counted annuli under a compound microscope with a computer projector. If there was a disagreement with an age assignment, the cross-section was read simultaneously by both readers. If an agreement for an age assignment could not be reached, the fish was not included in the analysis. The percentage of reader agreement was recorded after all slides were read. ImagePro Plus™ 7.0 (Media Cybernetics, Inc.-Bethesda, MD) image-analysis software was used to measure incremental growth for all cross-sections.

Growth measurements were made from the central focus of each cross-section along a specified radius to the outer margin. For example, annual growth was measured from cross-sections of articulating processes along the longest radius from the focus (Figure 4-5). Growth measurements recorded from basal recess cross-sections were measured from the central focus to the outer margin along the anterior radius (Figure 4-6). Growth measurements taken from otolith cross-sections were measured along the radius from the focus vertically to the anterior margin (Figure 4-7). The Frasier-Lee method was used to back-calculate length-at-age for each fish by using Statistical Analysis Software™ (SAS; SAS Institute, Inc.-Cary, NC). Mean length-at-age and the associated standard deviation were then calculated for each cohort.

Model Selection and Comparison of Methods

Mean back-calculated lengths-at-age were evaluated among the methods by fitting linear regression models. Before statistical analysis, age determination methods were binary coded: when the basal recess technique was being used in the model, it was coded as 1; otherwise, it was 0. When the articulating process was being used in the model, it was coded as 1; otherwise, it was 0. Otoliths served as the baseline for the methods comparison. Repeated observations (i.e., measurements) on each fish's structures were possibly dependent, which would prohibit the use of traditional regression models (Table 4-1; Sokal and Rohlf 1981). Thus, a global linear regression model (i.e., model containing all predictors; Table 4-1) for mean back-calculated length-at-age was fit by using the LM procedure in R version 2.13.1 (R Core Development Team-Vienna, Austria). An analysis of variance of the residuals indicated significant dependence ($df=134$, $F=14.5$, $p<0.001$) among observations for a blue catfish.

To account for dependence in the data, mixed linear regression models (i.e., hierarchical models) were used to compare mean back-calculated lengths-at-age determined by each technique. Hierarchical models used in the study varied from traditional regression techniques because dependence among the lower level units (i.e., age increments measured) within upper-level units (i.e., the individual fish and their structures used for age determination), was accounted for by including random effects for lower-level intercepts and slopes (Bryk and Raudenbush 2002; McCargo and Peterson 2004). The intercept and the relationship (i.e., slope) between age increments and length-at-age were each treated as varying normally among individual fish. Fixed effects associated with the lower level intercepts and slopes were interpreted as the average relation between age increment and length-at-age among individual blue catfish. The fixed effects associated with the determination method were interpreted as the effect of method on estimated length-at-age relative. Estimates were compared to those of the baseline method (i.e., otolith). The random effects were interpreted as variation in the relationship between an age increment and length-at-age among individual fish. All hierarchical models were fit using the LME4 statistical software package in R (R Core Development Team-Vienna, Austria).

An information theoretic approach was used to select among competing models used to evaluate the influence of the age increments and the techniques' influence on back-calculated length-at-age (Burnham and Anderson 2002). The primary hypotheses of interest were whether estimated length-at-age differed among age determination techniques used and whether those differences changed with the age of a blue catfish (Table 4-1). Thus, three candidate models were created to represent these hypotheses. All candidate models contained age increment and an age increment quadratic term because they are known to be related to length-at-age (Isley and Grabowski 2006). The first model represented the global hypotheses and contained the two method predictor variables and the interactions between method and age increment. The second model represented the hypothesis that estimated length-at-age differed among age determination techniques and it contained the two method predictor variables. The third model represented the hypothesis that the age determination techniques had no effect on estimated length-at-age.

Akaike's information criterion (AIC; Akaike 1973) with the small-sample bias adjustment was calculated to evaluate the plausibility of each candidate model (Table 4-2; AIC_c; Hurvich and Tsai 1989; McCargo and Peterson 2010). The parameters used to estimate AIC_c included the fixed effects, random effects, and random effect covariance (Burnham and Anderson 2002; Reiman et al. 2006). Models were compared by calculating ΔAIC ranging from zero to one, and the best-approximating model was equal to zero (i.e., ΔAIC=0). Model weights w_i were calculated and used to determine the plausibility of one model over the other (Anderson et. al 2000; Rieman et al. 2006). Thus a confidence set of models was created and included models with Akaike weights w_i within 10% of the best-approximating model (Table 4-2). The precision of fixed effects was estimated by calculating 95% confidence intervals based on a *t*-statistic with $n-1$ degrees of freedom (Littell et al. 1996). Goodness-of-fit for each candidate model was evaluated by examining residual and normal probability plots (i.e., individual fish).

A primary goal was to determine whether estimated length-at-age for a fish would differ depending on the structure used. Differences among estimated mean lengths-at-age for each method were evaluated by estimating length-at-age with the best approximating model. To assess the significance of the differences, 95% confidence intervals for each estimated age increment were calculated. The hierarchical models accounted for variation in length-at-age relationships among individual fish (i.e., the random effects) and within individual fish (i.e., the residual). Thus, two sets of confidence limits were created. The first set incorporated the predictable variation for fish-to-fish (random effects) and to random error (residual) and represented the expected error in method-specific length-at-age estimates from an individual fish selected at random from the population. The second set incorporated on the random error (residual) and represented the expected error in the estimated length-at-age for an individual blue catfish when using each structure.

RESULTS

After the two sampling sessions (December 2008 n_1=121; January 2009 n_2=32), 153 blue catfish were captured in Lake Oconee and processed for age determination. Eighteen fish were discarded and not included in the study because their structures were damaged during processing. The lengths of blue catfish captured during the first sampling occasion ranged from 138−740 mm (mean length: 329.6 mm TL, SD=132.4 mm TL) and weights ranged from 17−5,078 g (mean weight: 467.7 g, SD=683.9). Total lengths for fish captured during the second sampling occasion ranged from 183−677 mm TL (mean length: 553.4 mm TL, SD=97.4 mm TL), and the weights ranged from 44 to 3,054 g (mean weight: 1,715 g, SD=720.9 g). The fish from collected during the second sampling session combined with the first sampling session did not affect the range of sizes (length: 138−740 mm TL; weight: 17−5,078 g), but the mean total length (mean length: 376.4 mm TL, SD= 155.3 mm TL) and mean weight (mean weight: 728.7 g, SD=857.0) increased.

The percentages of reader agreement of age estimates varied among the three age determination techniques compared. Reader agreement was highest for otolith-based age assignments (83.5%), second highest for the articulating process-based age assignments (77%), and lowest for the basal recess-based age assignments (71.4%). Assigned ages for individuals ranged from one to eight years old (i.e., year-classes 2000-2007) for each technique. Some blue catfish were eliminated or not included in each technique's dataset because their structures were damaged during collection and cross-sectioning or because there were recording errors with their length-weight data on the field datasheets; these fish were not included in the analysis. Hence, the numbers of fish included each technique's dataset were unequal. Back-calculated lengths-at-ages derived from blue catfish lapillar otoliths ranged from 83.6−674 mm TL (Table 4-3); back-calculated lengths from articulating processes ranged from 144 – 619 mm TL (Table 4-4); and those derived from basal recess cross-sections ranged from 172−590 mm TL (Table 4-5).

The most plausible model was the global model. Mean back-calculated lengths-at-age were positively and non-linearly related with the age increment, but differed among the methods, and those differences varied with age increment (Table 4-6). The relation between age increment and length-at-age also varied among individual blue catfish. The intercepts varied about 31% among fish ($\sqrt{98.3}/32.4$). The best approximating model suggests that the relationship between the effect of age increment (i.e., the parameter estimate) and back-calculated length varied by about 20% ($\sqrt{664.1}/130.1$) among fish (Table 4-6). Parameter estimates indicated that lengths-at-age determined from articulating processes and basal recesses were larger than those from otoliths for individual fish at age increments 1-6 (Figure 4-8). After age-6, predicted back-calculated lengths were larger when calculated from otolith-annuli measurements than when determined by the other techniques (Figure 4-8). The mixed model indicated that the rate of growth estimated by the otoliths decreased at a slower rate when compared to the articulating processes and basal recesses. Until about age-6, otolith-based back-calculations were higher than those derived from both pectoral spine techniques. The difference between basal recess-derived and otolith-derived back-calculated lengths decreased by 16.4 mm TL with each one-year increase in age until about age-6 (Table 4-6). Similarly, the difference between articulating process-based growth and otolith-based growth decreased by 12.1 mm TL with each one year increase in age increment (Table 4-6). Basal recess-estimated growth decreased at a faster rate (i.e., 4.3 mm TL per year increase) than growth estimated by the articulating process technique. Length-at-age estimates were greater for the basal recess technique than the articulating process technique until age-6, and the difference between basal recess-derived mean lengths-at-age versus articulating process-derived estimates decreased by 4.3 mm TL annually until about age-7 (Figure 4-8). The articulating process mean-length at age-8 was larger than the basal recess-derived estimate.

When including the variation among the intercept and slopes, the 95% confidence limits for the mean back-calculated lengths determined by each technique occur at age increments 1−3 (Figure 4-9). Specifically, mean back-calculated lengths were significantly different among all three structures at age-1 and age-2, but differed only at age-3 between the basal recess- and otolith-derived mean back-calculated lengths (Figure 4-9). Accounting for additional variation among the intercepts (i.e., individual fish) and slopes (i.e., random effects of age increment) by incorporating random effects in the most plausible model indicated that significant differences in back-calculated lengths at ages 1−3 among all three structures compared (Figure 4-10). Additionally, the back-calculated lengths were significantly different between the basal recess and otolith means at age-4 and age-8 (Table 4-10).

DISCUSSION

We successfully compared the utility and precision of otoliths and pectoral spines to determine the ages and growth for a sample of blue catfish from an introduced population in Lake Oconee. We also used hierarchical models to evaluate precision in back-calculated growth for introduced blue catfish. Two of the traditional methods were non-lethal techniques and one was a lethal technique used to obtain age and growth information for other species of catfishes. Our findings confirm that the use of otoliths and pectoral spines can be used successfully to estimate age and growth. Our findings suggest that the use of lapillar otoliths and articulating processes would yield higher precision than the use of basal recesses for blue catfish age and growth studies. We found better precision with the otolith-based age assignments than the age assignments derived from cross-sections of pectoral spines. Reader agreement for age assignments was highest (83.5%) when assigning ages to otolith cross-sections, next highest for articulating process cross-sections (77%), and lowest for basal recess cross-sections (71.4%). Buckmeier et al. (2002) reported high (i.e., 79%) reader agreement and 97% accuracy for age assignments derived from cross-sections of lapillar otoliths from known-age channel catfish ranging 1-4 years old. Age biases (i.e., both under-estimation and over-estimation) are among the most problematic of errors in age determination studies, can lead to erroneous interpretations of data (Campana et al. 1995; Olive et al. 2011) and may have been the cause of the relatively small imprecision in age assignments observed in our study. However, our results were similar to other studies that have compared these techniques for other catfishes. Specifically, these studies found higher precision and accuracy of assigned ages for catfish when determined from otoliths than when ages were determined from pectoral spines.

The clarity, appearance of annuli, and the number of false annuli present in the cross-sections were variable among the techniques compared in our study and may have affected our interpretation of age estimates and growth. Kelley and Carver (1965) experienced similar difficulties while using pectoral spines to determine the ages of blue catfish from the Mississippi River. Taking multiple cross-sections from small blue catfish in our study often damaged otoliths and made them more difficult to read than when compared to pectoral spines. Other studies have found that annuli read from otoliths are more distinguishable than spine annuli from channel catfish (Buckmeier et al. 2002) and flathead catfish (Nash and Irwin 1999). In our study, observable annuli from cross-sections of blue catfish otoliths often appeared clearer and less variable in appearance when compared to cross-sections obtained from pectoral spine cross-sections. Blue catfish otolith cross-sections had less-noticeable false annuli than pectoral spine cross-sections made from both locations compared, and the false annuli appeared as incomplete, opaque bands that often merged with other annular marks. Cross-sections taken from the basal recess and articulating process of pectoral spines were variable in appearance. False marks within pectoral spine cross-sections appeared as light marks with blurred, incomplete margins. In some instances, false annuli appeared to converge with other circuli. In some pectoral spine cross-sections, earlier annuli appeared eroded by the central lumen, and annuli towards the outer margins of some cross-sections appeared clustered together. When annuli were counted from basal recess cross-sections cut from the spines of older fish in the sample (i.e., age-5 or older), annuli appeared crowded towards the outer margins and were difficult to distinguish The erosion of annuli by expansion of the central lumen and the crowding of annuli toward the outer margins of the pectoral spine cross-sections may have contributed to errors in our age assignments and measurements of growth.

The sample of blue catfish exhibited variable growth by each technique from ages 1−8. Our findings suggest that each technique will produce different estimates for back-calculated length-at-age for blue catfish. The confidence intervals indicated that differences in mean back-calculated lengths-at-age among the techniques compared occurred at ages 1−3. Further, back-calculated lengths derived from the basal recess technique and the otolith technique also differed among fish at age-4 and age-8. Estimates for length at ages derived from otoliths were smaller than those estimated using the pectoral spine techniques from age-1 to about age-6, and estimates after age-6 were larger when derived from otoliths. Estimates derived from the basal recess technique were also larger than those derived from the articulating to about age-7. The rate of growth among catfish determined by the basal recess also decreased at a faster rate than the rate for obtained from the other two methods. The mixed-model analysis indicated that the otolith-derived growth decreased at the slowest rate. The differences found in this study could have resulted from reader error when locating the first annulus or recent annuli on basal recess cross-sections from older fish (i.e., age-3 or older) and errors in growth measurements. The use of basal recess cross-sections for age determination has been documented to underestimate ages for older catfishes and provide erroneous growth estimates. Errors in age assignments and growth estimates occur because earliest annuli are eroded by the expansion of the central lumen as each fish grows and the most recently formed annuli crowd towards the outer margin of the structure (Muncy 1959; Mayhew 1969; Turner 1982; Nash and Irwin 1999; Buckmeier et. al 2002; Barada et al. 2011). The variation of back-calculated lengths may be attributed to differences of growth among the structures. Basal recess cross-sections from fish > age-3 had obvious partial or complete loss of the first annulus. Although we attempted to account for this error, we recognize that using reference cross-sections may not accurately reflect the true location of a missing annulus because of individual differences in growth. During our study, we attempted to examine growth by calculating the von Bertalanffy growth coefficients, but the growth distribution was not asymptotic, and L_∞ could not be calculated.

Despite the significant differences in back-calculated lengths from age-1 to age-6, estimated length was similar at the latter age increments except between the basal recess and otolith-derived estimates at age-8. The similarities in the estimates were likely a result of the size/age distribution in the sample. When collecting our sample, fish smaller than 138 mm TL and larger than 740 mm TL were not recruited to our sampling gear, and size-selectivity was evident in our sample. Thus, size classes were not equally represented in our study. In particular, we had a poor representation of the youngest and oldest year-classes. Repeating this study on a larger sample of blue catfish containing equal representation of size/age classes may reduce variability and yield more similar distributions of estimated lengths-at-age.

Future investigation of blue catfish distribution would benefit from age validation studies. Continual use of traditional age and growth determination techniques that have not been validated for blue catfish and not correcting the limitations of each technique could result in unreliable data (Campana 2001; Olive et al. 2011). Moreover, the use of such data could result in inappropriate management decisions for a given blue catfish population. Our estimates for the pectoral spine techniques were within the range of reported mean lengths at each age increment for blue catfish elsewhere (Table 4-7). Evaluating the precision and accuracy of the age determination techniques used in this study across larger samples of known-age blue catfish and across other populations would better determine their suitability for age and growth determination for the species. Validation of these methods would allow for a better evaluation of the accuracy and suitability of our model for predicting differences in back-calculated length.

The use of lapillar otoliths has gained popularity among catfish biologists as the preferred structures for age and growth determination because they tend to yield more precise and accurate age and growth estimates than pectoral spine techniques (Nash and Irwin 1999; Buckmeier et al. 2002). However, other studies have reported that pectoral spines produce data similar to otolith-based age data when ages are determined for catfishes (Michaletz et al. 2009; Colombo et al. 2010; Olive et al. 2011). Furthermore, otolith accuracy has been evaluated for only channel catfish up to age-4 (Buckmeier et al. 2002), but the use of these structures may produce accurate age estimates up to age-16 for blue catfish (Olive et. al 2011). We found that back-calculated length-at-age estimates were 31% variable among the blue catfish in our sample. However, we did achieve higher precision for age assignments with the otolith technique compared to spines. We agree with other authors that suggest the traditional, non-lethal age and growth determination techniques are suitable for populations with low abundance or those intended to produce trophy fish (Boxrucker and Kuklinski 2006; Maceina et al. 2007; Olive et. al 2011). However, lethal techniques (i.e., otoliths) may provide higher precision, better estimation accuracy, and may be more suitable than non-lethal methods when obtaining age and growth information for introduced populations.

Validation of age and growth techniques cannot be achieved when specimens from introduced populations of unknown age are used. Therefore, monitoring direct growth during a mark-recapture study would be a suitable approach to obtain accurate growth information. Age data can be obtained by employing the most precise techniques used in this study. Further, age assignments can be compared to known ages (Turner 1982; Nash and Irwin 1999; Buckmeier et. al 2002), and back-calculated growth can be compared to direct growth to evaluate accuracy. We acknowledge that mark-recapture studies can be costly and may not be an appropriate option to gather age and growth information. In such instances, biologists can consider using either the articulating processes or lapillar otoliths for age determination. Lastly, the results of this study can be used by biologists when they must decide which techniques to employ when age and growth information is needed.

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Table 4-1. Biological interpretations of predictors used in the candidate models relating to the back-calculated length-at-age of blue catfish from Lake Oconee, Georgia.

Predictor variable	Biological Interpretation (hypothesis)
Age Increment	The year in which the annulus was formed will influence back-calculated lengths.
Method	The chronometric structure being used will influence back-calculated lengths.
Age Increment × Age Increment	The quadratic effect on the rate of growth will influence back-calculated lengths.
Method × Age Increment	The quadratic effect on the rate of growth varies among the chronometric structures and will influence back-calculated lengths.

Table 4-2. Predictor variables, log-likelihood (Log*L*), Akaike's Information Criterion with the small-sample bias adjustment (AIC_c), ΔAIC_c, and Akaike weights (w_i) for the set of candidate models for predicting back-calculated length-at-age of blue catfish caught during the December 2008 and January 2009 sampling sessions in Lake Oconee, Georgia.

Candidate Model	Log*L*	AIC_c	ΔAIC_c	w_i
Method, Age Increment, Age Increment × Age Increment, Method × Age Increment	-7952	15932	0	1
Age Increment, Age Increment × Age Increment	-8235	16490	558	0
Method, Age Increment, Age Increment × Age Increment	-8045	16113	182	0

Table 4-3. Otolith-derived mean back-calculated total lengths-at-age (mm TL) and associated standard deviations for each cohort (2000-2007) of blue catfish caught during the December 2008 and January 2009 sampling sessions in Lake Oconee, Georgia. A standard deviation could not be calculated for the 2007 year-class because only one fish was captured.

		Mean Length-at-age (mm TL)							
Age	Year-class	1	2	3	4	5	6	7	8
1	2007	138							
2	2006	83.7±21.8	195±15.8						
3	2005	80.0±20.2	191±25.5	269±37.8					
4	2004	75.6±20.6	205±27.7	308±37.4	381±52.2				
5	2003	90.9±35.4	211±44.5	318±53.8	406±63.8	470±69.2			
6	2002	85.5±40.9	210±44.3	319±37.3	419±45.7	499±48.5	560±51.5		
7	2001	91.9±30.3	230±54.7	341±66.0	425±77.8	498±81.5	563±81.7	619±85.8	
8	2000	102±19.1	232±18.8	331±2.1	439±15.7	515±22.6	582±18.6	631±0.8	674±5.0
Mean		83.6±29.9	204±36.3	308±48.7	406±58.0	486±63.2	562±57.0	622±74.5	674±5.0

Table 4-4. Articulating process-derived mean back-calculated total lengths-at-age (mm TL) and associated standard deviations for each cohort (2000-2007) of blue catfish caught during the December 2008 and January 2009 sampling sessions in Lake Oconee, Georgia. A standard deviation could not be calculated for the 2007 year-class because one fish was captured.

		Mean length-at-age (mm TL)							
Age	Year-class	1	2	3	4	5	6	7	8
1	2007	138							
2	2006	132±18.0	198±20.7						
3	2005	137±30.7	209±33.2	261±42.5					
4	2004	144±28.7	243±27.6	313±41.1	367±55.6				
5	2003	143±22.0	238±30.5	329±61.1	396±80.6	439±88.7			
6	2002	154±38.9	250±48.8	346±56.8	439±64.3	500±67.2	534±63.7		
7	2001	146±40.2	223±42.2	327±56.0	432±75.1	514±78.4	559±84.7	584±89.9	
8	2000	170±22.0	240±29.9	309±51.6	389±101	455±118	523±107	591±103	619±107
Mean		144±30.4	228±40.2	319±59.5	411±73.9	479±82.7	539±70.3	586±88.5	619±107

Table 4-5. Basal recess-derived mean back-calculated total lengths-at-age (mm TL) and associated standard deviations for each cohort (2000-2007) of blue catfish caught during the December 2008 and January 2009 sampling sessions in Lake Oconee, Georgia. A standard deviation could not be calculated for the 2000 and 2007 year-classes because one fish was captured for each cohort.

		Mean length-at-age (mm TL)							
Age	Year-class	1	2	3	4	5	6	7	8
1	2007	138							
2	2006	143±20.4	198±19.6						
3	2005	161±20.0	225±22.5	275±38.1					
4	2004	160±17.7	238±21.6	301±41.0	344±51.6				
5	2003	192±35.6	280±47.8	352±63.1	419±81.7	459±89.4			
6	2002	182±39.1	277±62.7	353±68.1	433±73.2	491±81.3	521±80.7		
7	2001	196±40.5	287±46.9	388±63.6	466±85.2	529±86.0	566±88.6	587±86.7	
8	2000	171	228	313	410	506	548	575	590
Mean		172±36.1	251±54.6	339±67.1	417±67.1	486±86.8	534±83.4	586±83.1	590

Table 4-6. Estimates of fixed and random effects, standard errors (SE), and the lower and upper confidence limits (CLs) for the best-approximating model for evaluating back-calculated lengths-at-age of blue catfish (ages 1−8) in Lake Oconee, Georgia

Parameter	Estimate	SE	Lower CL	Upper CL
Fixed Effects				
Intercept	-32.44	3.99	-40.25	-24.63
Age Increment	130.06	3.22	123.75	136.37
Age Increment × Age Increment	-7.71	0.40	-8.49	-6.94
Method Articulating Process	60.03	4.01	52.17	67.89
Method Basal Recess	91.63	3.99	83.82	99.44
Age Increment × Articulating Process	-12.10	1.19	-14.43	-9.77
Age Increment × Basal Recess	-16.39	1.18	-18.71	-14.07
Age Increment × Otolith (baseline)	0.00	0.00	0.00	0.000
Random Effects				
Individual Fish	98.35	9.92	78.91	117.79
Age Increment	664.14	25.77	613.63	714.65
Age Increment × Age Increment	4.88	2.21	0.55	9.21
Residual	932.43	30.54		

Table 4-7a. Reported means for total length-at-age (mm TL) of blue catfish from various systems throughout the United States and Lake Oconee, Georgia. Mean total lengths-at-age were calculated by using articulating processes (AP) and basal recesses (BR). Means reported from sources older than 1999 were taken from Graham (1999).

		Mean Length-at-age						
Location	Number of Fish	1	2	3	4	5	6	Source
Lake Oconee, GA[AP]	122	145	229	314	404	477	539	Homer and Jennings
Lake Oconee, GA[BR]	126	168	248	330	414	496	545	Homer and Jennings
Tennessee River, TN	134	135	198	252	297	356	429	Conder and Hoffarth (1965)
Kentucky Lake, TN	369	142	229	287	343	401	447	Hale and Timmons (1990)
Kentucky Lake, TN	467	145	239	295	356	427	483	Hale and Timmons (1990)
Kentucky Lake, KY	655	132	221	274	318	363	424	Hale and Timmons (1989)
Kentucky Lake, KY	492	76	165	239	302	311	432	Freeze (1977)
Kentucky Lake, KY	756	117	213	310	391	480	559	Porter (1969)
Barkley Lake, KY	115	76	188	302	376	455	584	Freeze (1977)
Tombigbee River, AL	122	125	221	338	450	508	612	Kelley (1969)
Mississippi River Delta, LA	57	191	386	508	638	749	848	Kelley and Carver (1966)
Lake Texoma, OK	190	145	254	351	442	533	655	Jenkins (1956)
Rio Grande River, TX	103	175	262	282	373	406	465	Henderson (1972)
Santee-Cooper Lake, SC	93	168	307	427	554	696	840	White and Lamprecht (1990)
Santee-Cooper Lake, SC	Not Recorded	12	262	325	381	429	460	White (1980)
Lake of the Ozarks, MO	2389	105	178	243	309	371	426	Graham and DeiSanti (1999)
Lake Texoma, OK	328	172	253	315	370	402	439	Mauck and Boxrucker (2006)

Table 4-7b. Reported means for total length-at-age (mm TL) of blue catfish from various systems throughout the United States and Lake Oconee, Georgia. Mean total lengths-at-age were calculated by using articulating processes (AP) and basal recesses (BR). Means reported from sources older than 1999 were taken from Graham (1999).

Location	Number of Fish	Mean Length-at-age						Source
		7	8	9	10	11	12	
Lake Oconee, GA[AP]	122	588	619					Homer and Jennings
Lake Oconee, GA[BR]	126	581	590					Homer and Jennings
Tennessee River, TN	134	513	582	699	846			Conder and Hoffarth (1965)
Kentucky Lake, TN	369	500	423	551	587			Hale and Timmons (1990)
Kentucky Lake, TN	467	551	627	671				Hale and Timmons (1990)
Kentucky Lake, KY	655	485	549	584	607	693	737	Hale and Timmons (1989)
Kentucky Lake, KY	492	483	564	666				Freeze (1977)
Kentucky Lake, KY	756	627						Porter (1969)
Barkley Lake, KY	115	658						Freeze (1977)
Tombigbee River, AL	122	693	803	942	930	986	1041	Kelley (1969)
Mississippi River Delta, LA	57							Kelley and Carver (1966)
Lake Texoma, OK	190	770	871	1026	1069	1118		Jenkins (1956)
Rio Grande River, TX	103							Henderson (1972)
Santee-Cooper Lake, SC	93	958	955					White and Lamprecht (1990)
Santee-Cooper Lake, SC	Not Recorded	508	546					White (1980)
Lake of the Ozarks, MO	2389	484	542	600	657	708	762	Graham and DeiSanti (1999)
Lake Texoma, OK	328	460	497	536	584	573	677	Mauck and Boxrucker (2006)

Table 4-7c. Reported means for total length-at-age (mm TL) of blue catfish from various systems throughout the United States and Lake Oconee, Georgia. Mean total lengths-at-age were calculated by using articulating processes (AP) and basal recesses (BR). Means reported from sources older than 1999 were taken from Graham (1999).

		Mean Length-at-age						
Location	Number of Fish	13	14	15	16	17	18	Source
Lake Oconee, GA^{AP}	122							Homer and Jennings
Lake Oconee, GA^{BR}	126							Homer and Jennings
Tennessee River, TN	134							Conder and Hoffarth (1965)
Kentucky Lake, TN	369							Hale and Timmons (1990)
Kentucky Lake, TN	467							Hale and Timmons (1990)
Kentucky Lake, KY	655	813						Hale and Timmons (1989)
Kentucky Lake, KY	492							Freeze (1977)
Kentucky Lake, KY	756							Porter (1969)
Barkley Lake, KY	115							Freeze (1977)
Tombigbee River, AL	122	1067						Kelley (1969)
Mississippi River Delta, LA	57							Kelley and Carver (1966)
Lake Texoma, OK	190							Jenkins (1956)
Rio Grande River, TX	103							Henderson (1972)
Santee-Cooper Lake, SC	93							White and Lamprecht (1990)
Santee-Cooper Lake, SC	Not Recorded							White (1980)
Lake of the Ozarks, MO	2389	807	869	923	1032	956	923	Graham and DeiSanti (1999)
Lake Texoma, OK	328			804	933			Mauck and Boxrucker (2006)

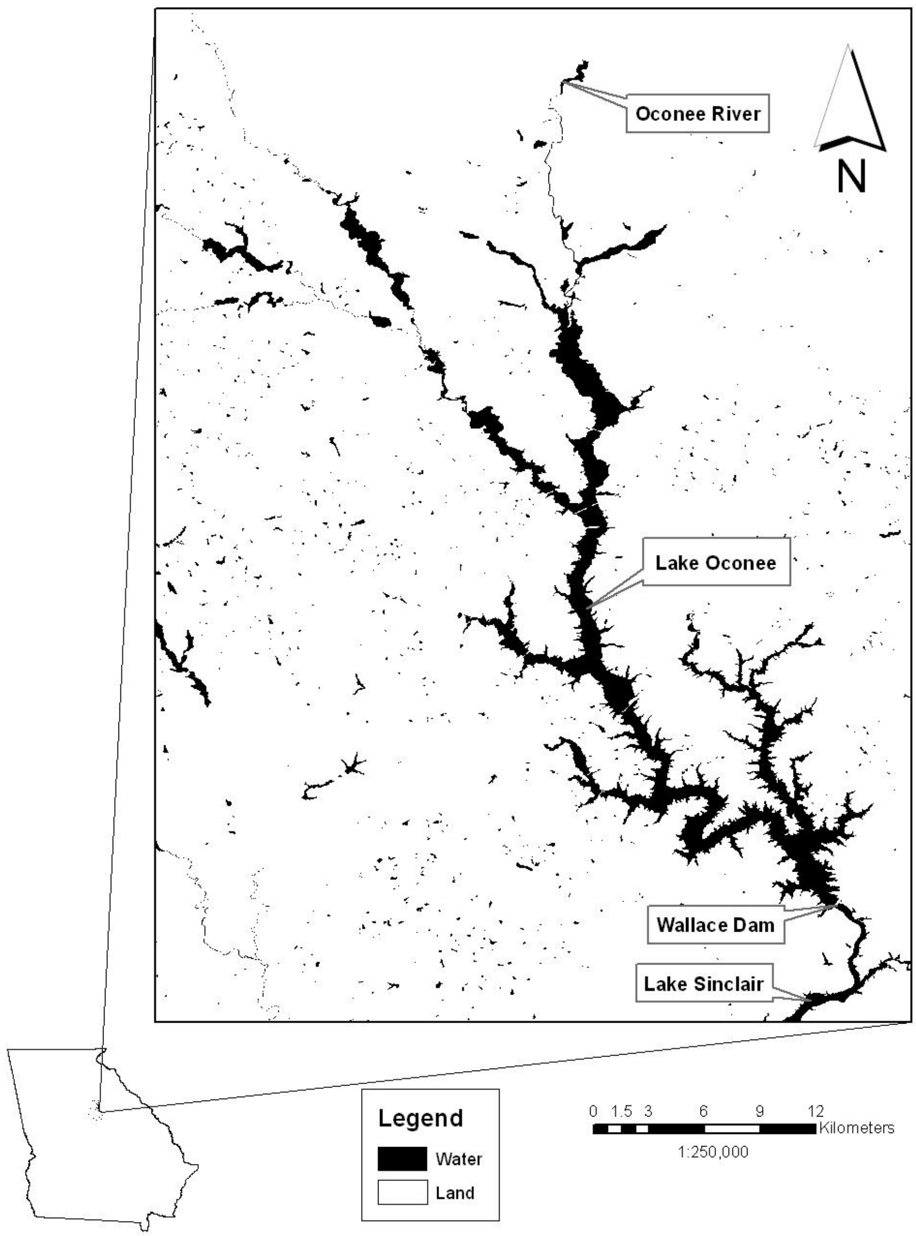

Figure 4-1. A map of the study site at Lake Oconee, Georgia enlarged (reprinted with permission from Homer and Jennings 2011).

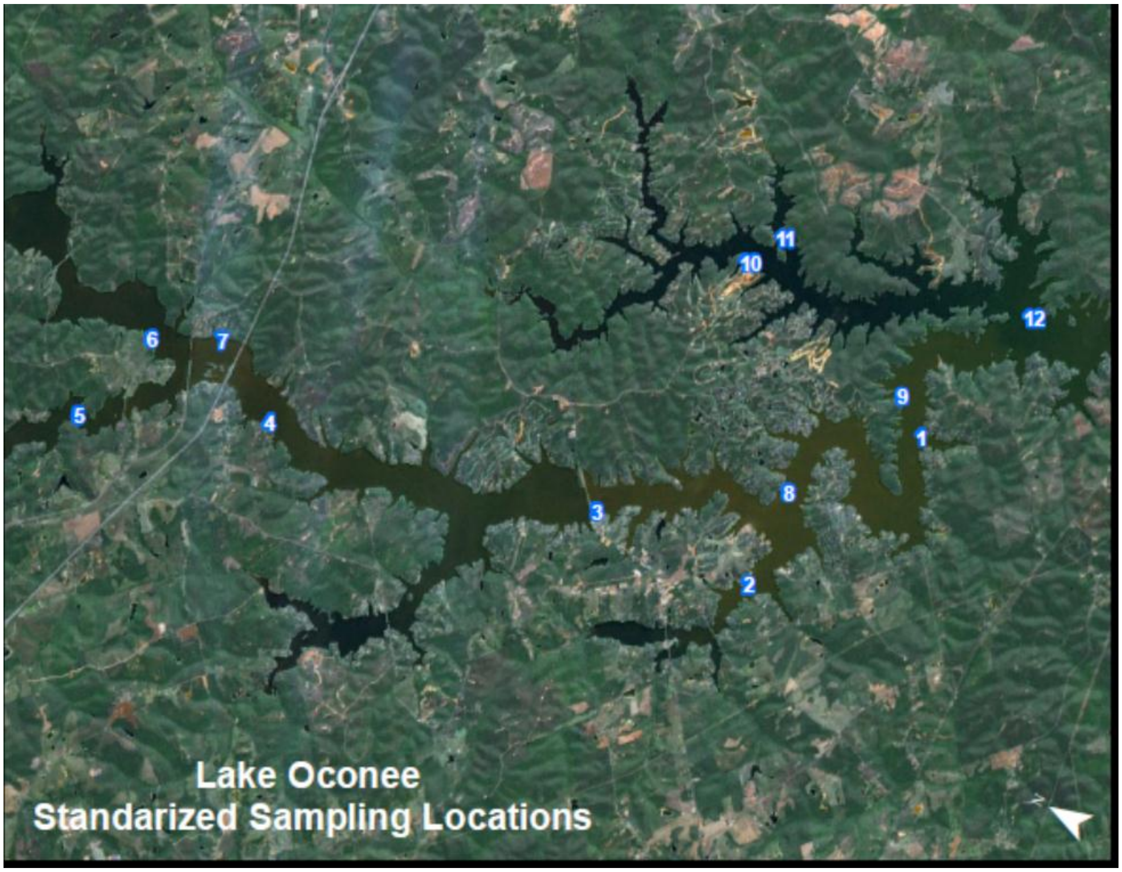

Figure 4-2. A map of the 12 gillnetting stations on Lake Oconee, Georgia established by Georgia Department of Natural Resources (reprinted with permission from Homer and Jennings 2011).

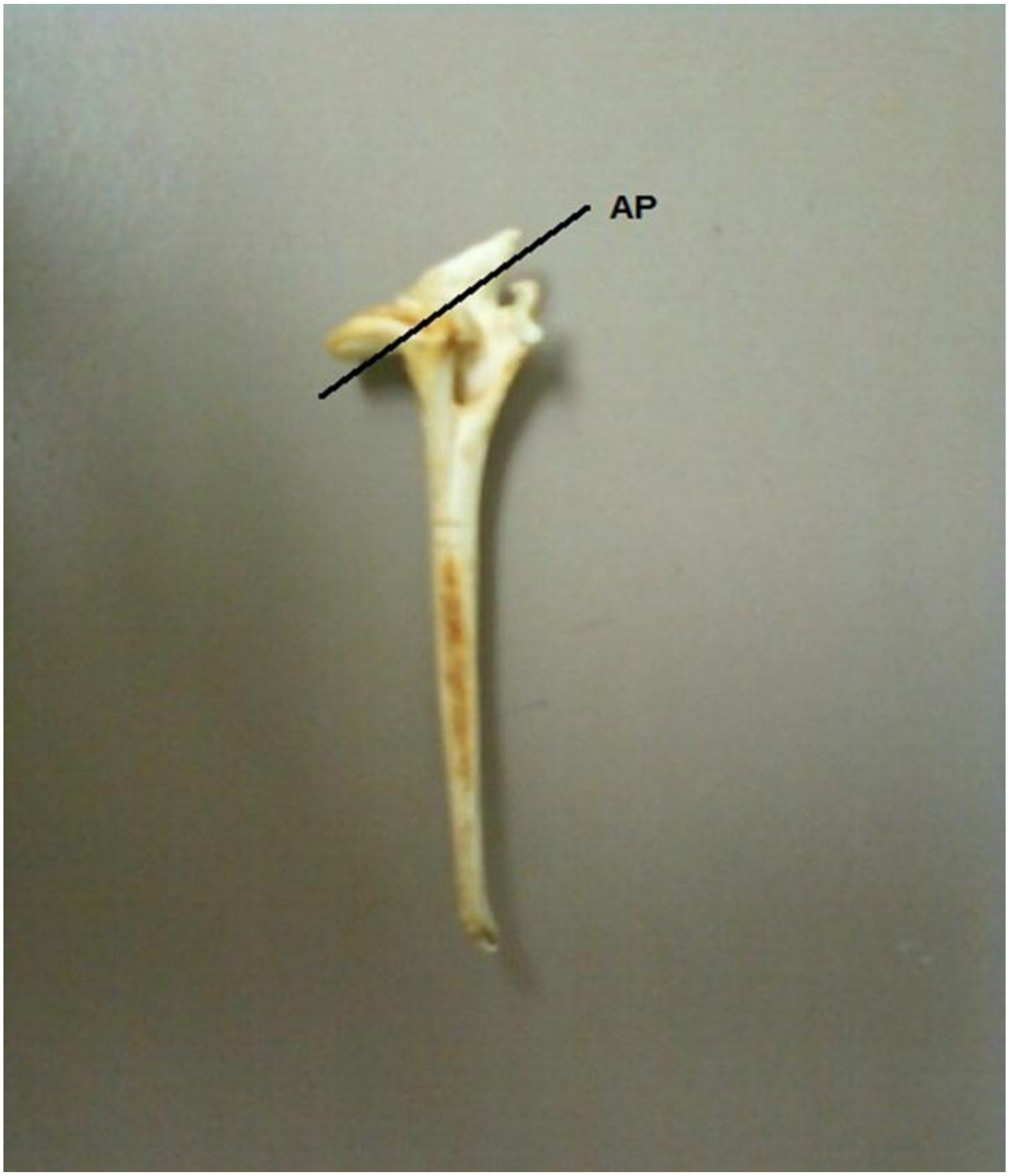

Figure 4-3. The articulating process cross-sectioning location on a blue catfish pectoral spine from a blue catfish caught from Lake Oconee, Georgia during the December 2008 and January 2009 gillnetting surveys.

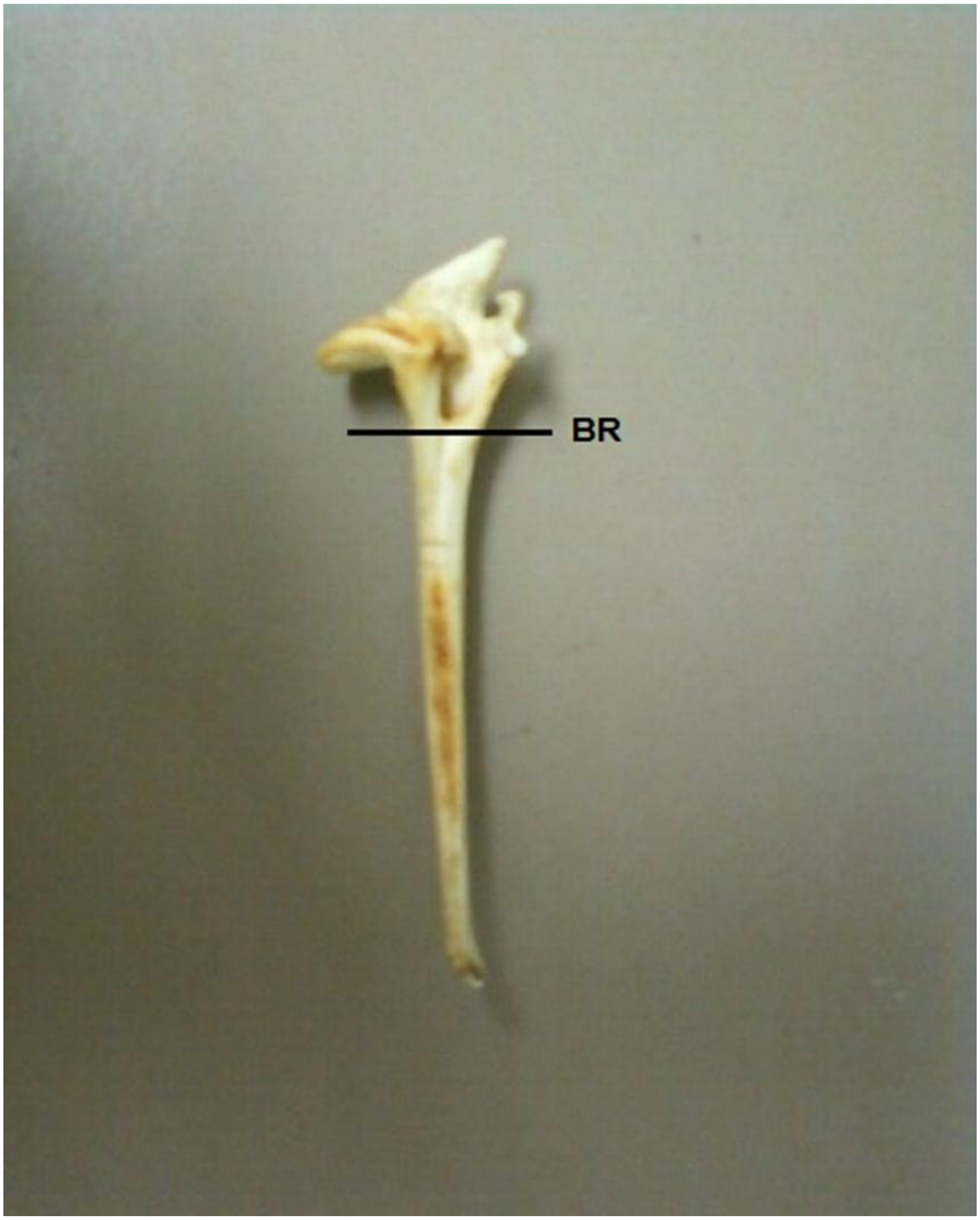

Figure 4-4. The basal recess cross-sectioning location on a pectoral spine collected from a blue catfish from Lake Oconee, Georgia caught during the December 2008 and January 2009 gillnetting surveys.

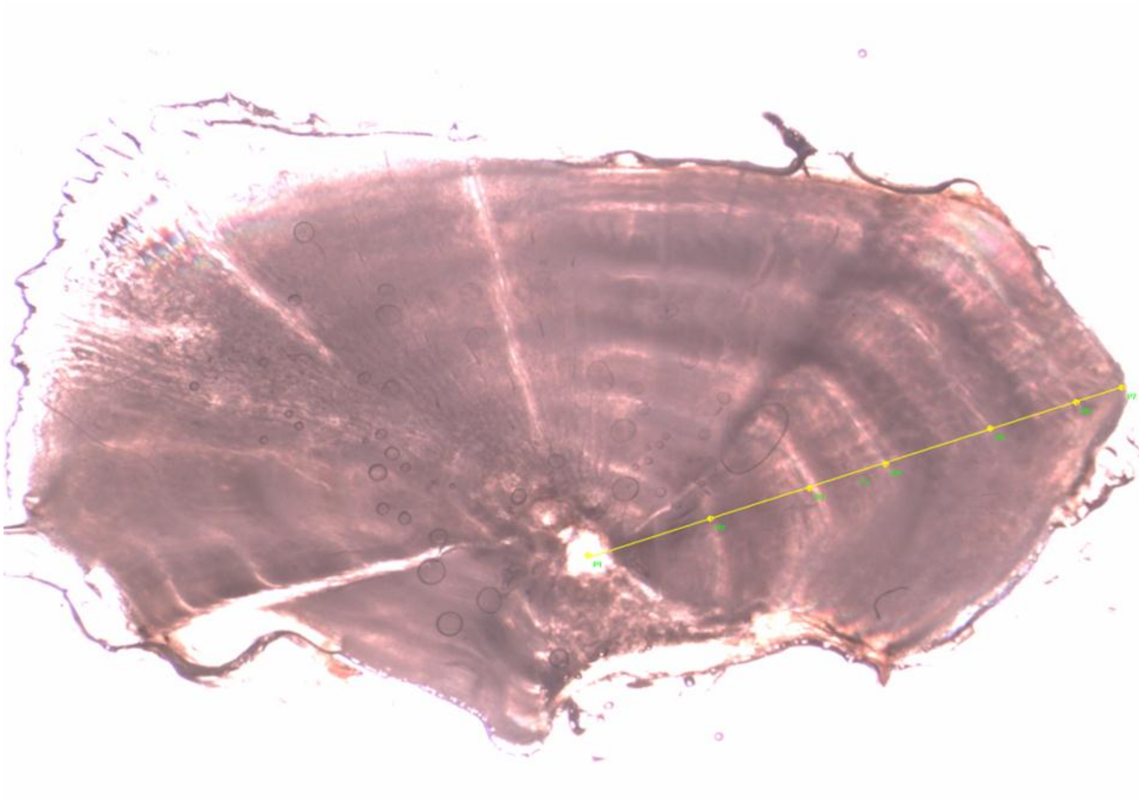

Figure 4-5. A cross-section of the articulating process of a pectoral spine from a blue catfish collected from Lake Oconee, Georgia during December 2008. This fish was estimated to be six years old (i.e., year-class 2002).

Figure 4-6. A cross-section made at the basal recess of a pectoral spine from a blue catfish captured from Lake Oconee, Georgia during December 2008. The spine was taken from a fish estimated to be approximately six years old (i.e., year-class 2002).

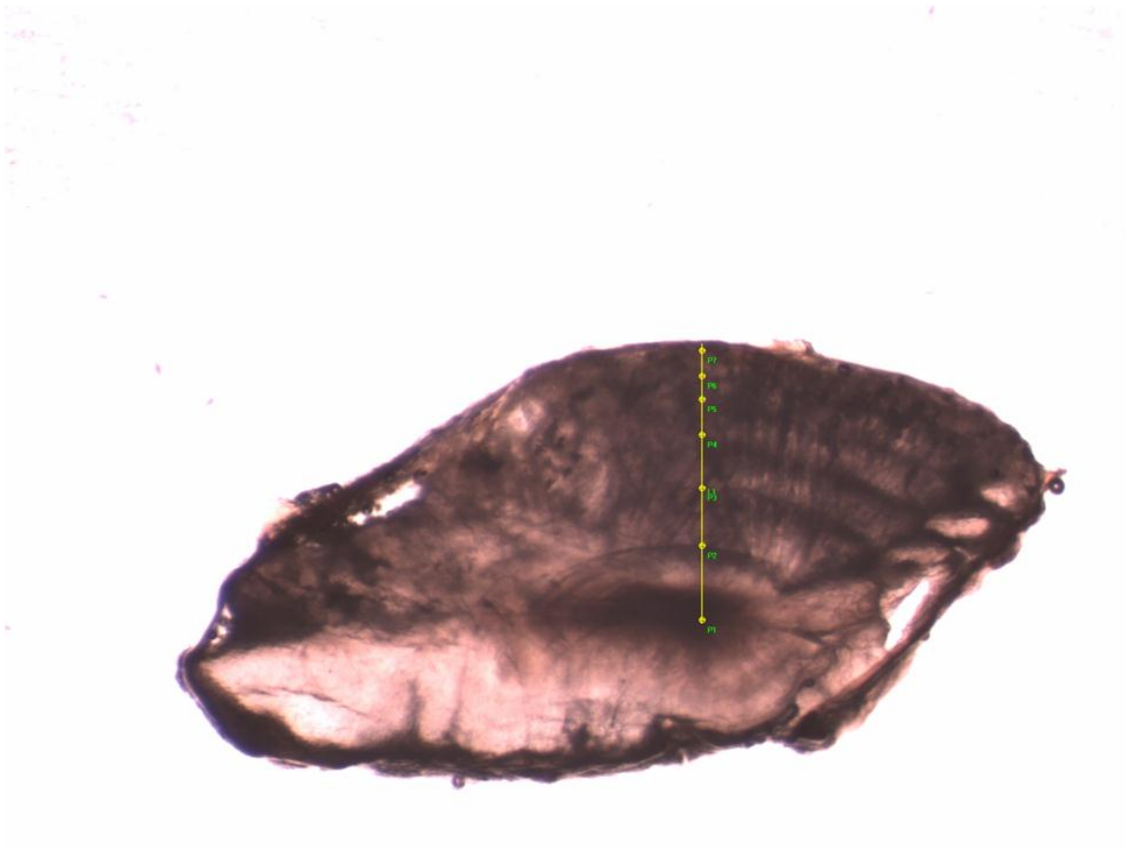

Figure 4-7. A cross-section of a lapillar otolith taken from a blue catfish captured from Lake Oconee, Georgia during December 2008. The otolith was obtained from a fish estimated to be six years old (i.e., year-class 2002).

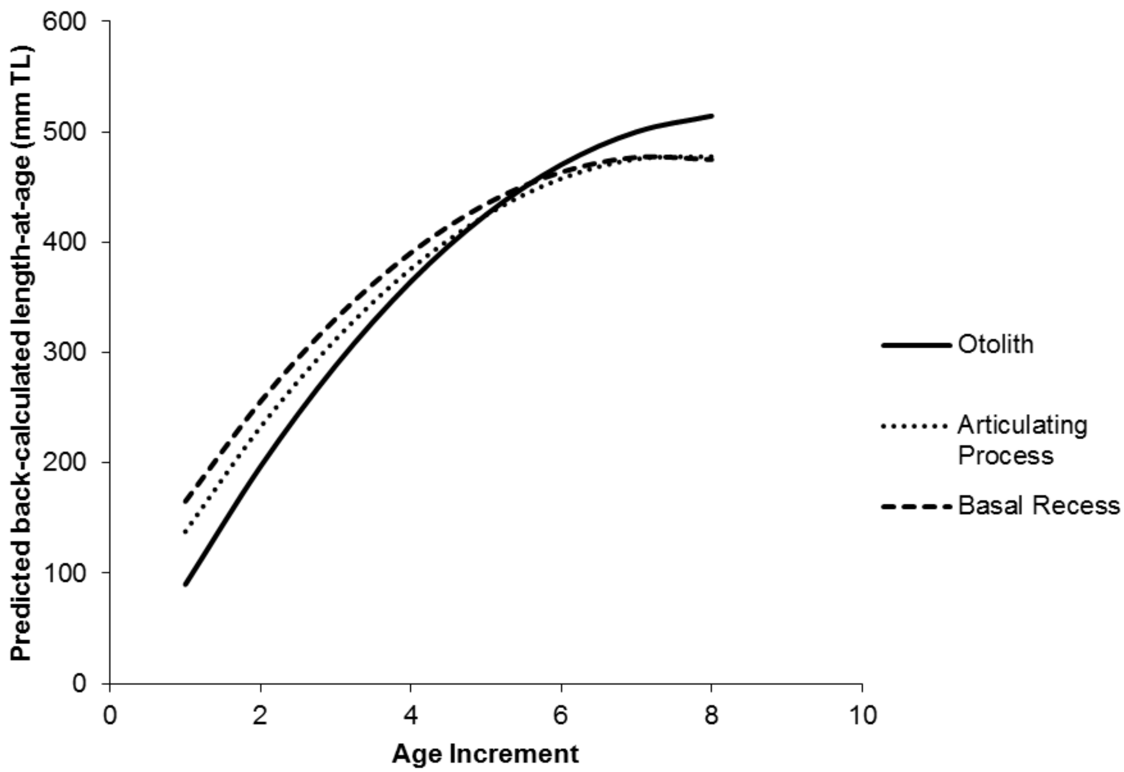

Figure 4-8. The relationships of the effect of age increments with the predicted back-calculated lengths-at-ages 1−8 derived from the articulating process, basal recess, and otolith techniques used to estimate growth of blue catfish from Lake Oconee, Georgia. The solid line illustrates growth estimates derived from otoliths; the dotted line represents growth estimates derived from articulating process technique; and the dashed line represents estimates from the basal recess technique.

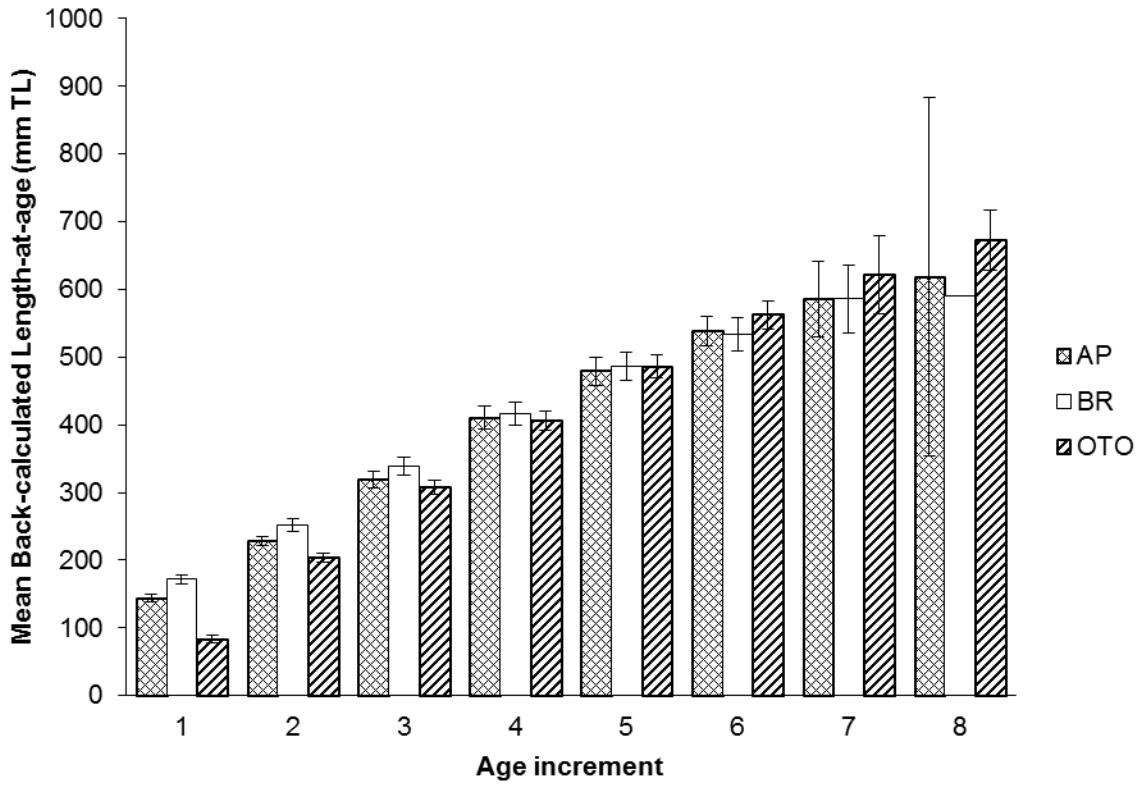

Figure 4-9. Mean back-calculated lengths-at-ages 1−8 and associated confidence intervals by the articulating process, basal recess, and otolith techniques used to estimate growth of blue catfish from Lake Oconee, Georgia. Confidence intervals were derived from the best-approximating hierarchical model and included variation in intercepts and slopes. Note, a confidence interval was not calculated for the mean length at age increment-8 for the articulating process technique because there was only one fish estimated to be age-8 by this technique.

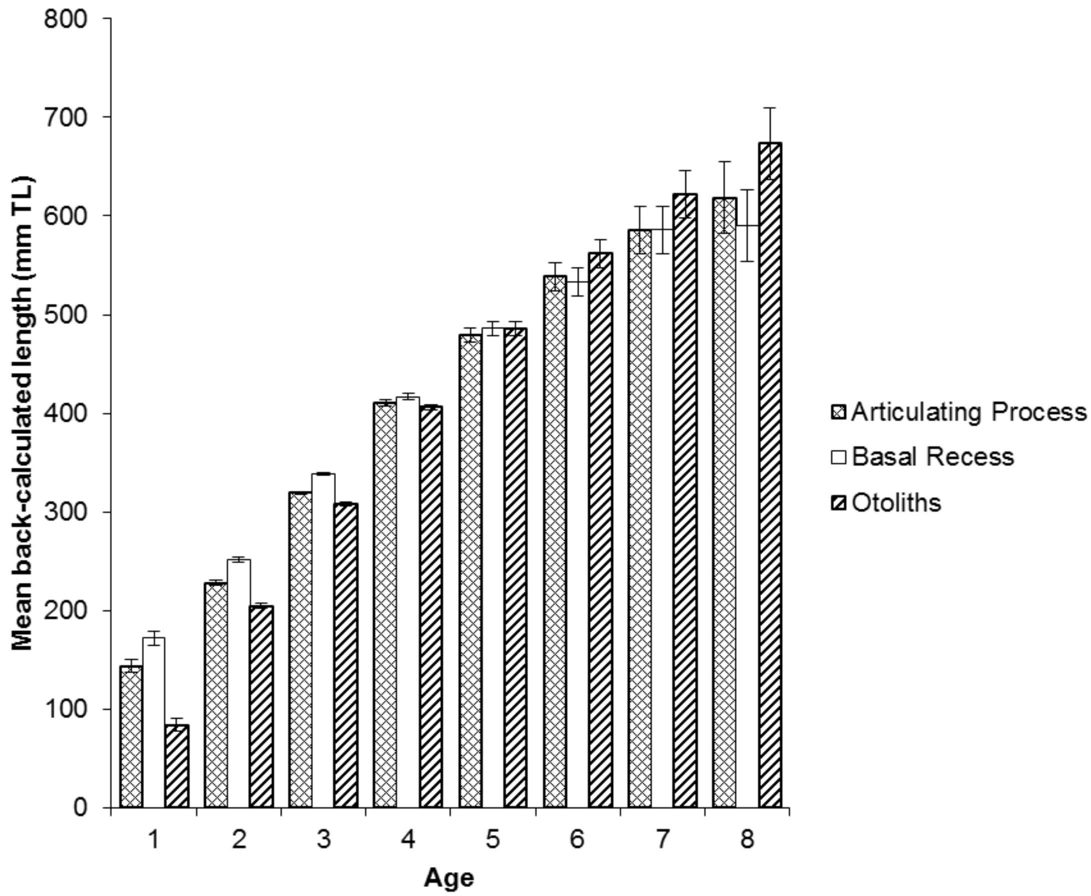

Figure 4-10. Mean back-calculated lengths at each age increment 1−8 and the associated 95% confidence intervals by the articulating process, basal recess, and otolith techniques used to estimate growth of blue catfish from Lake Oconee, Georgia. Confidence intervals were derived from the best-approximating hierarchical and do not include the variation in intercepts and slopes.

CHAPTER FIVE

MANAGEMENT IMPLICATIONS FOR THE INTRODUCED BLUE CATFISH FISHERY AT LAKE OCONEE, GEORGIA

Since the start of this project, the importance of blue catfish populations as sportfish and the effects of their introductions into various systems have gained increased research attention. Prior to our study, few papers had been published for this species in the decade since Graham (1999) stated that literature was limited, and information is still acute for populations of blue catfish in reservoirs in the southeastern United States as well as for introduced populations. Currently, our study and the findings of another concurrent study (Bonvechio et al. In Press) being conducted by Georgia Department of Natural Resources (GADNR) are the only accounts currently available for introduced blue catfish in Georgia, and both studies suggest that the species is rapidly expanding. This project provides a case study of blue catfish introductions for a region where data were non-existent, and the study contributes to the overall knowledge of the dynamics of introduced blue catfish populations.

The first component of this project consisted of identifying trends in the catch of catfishes during the annual gillnetting surveys of Lake Oconee, Georgia. Specifically, we found that annual catch of blue catfish was increasing rapidly from 1997 - 2009, and there was a simultaneous decline in the catch of native white catfish. The mechanism for the decline in the catch is unknown. Further, the decline may be a result of factors such as interspecific competition with blue catfish and/or other species within the reservoir; direct predation; a shift in the type of habitat being used by white catfish; environmental factors; or a combination of factors. Future studies should investigate this decline by monitoring changes in true population size for both the white and blue catfish populations by conducting mark-recapture studies. Such studies will also allow for fisheries biologists to develop a calibrated catch-per-unit-effort index that can be used to assess changes in true population size. Additionally, future studies should consider sampling in additional locations of Lake Oconee, and these studies should investigate the preferred habitat of both the blue and white catfishes. The findings of our first study component suggest that the blue catfish population is established in Lake Oconee, is relatively young (i.e., ages 0 – 8), growing rapidly and likely expanding its range. Additionally, individuals in the blue catfish population appear to be exhibiting rapid somatic growth.

For the second component of this project, we compared the precision of age assignments and back-calculated growth determined by using three traditional techniques that may yield high precision of estimates for blue catfish. We successfully identified two techniques that are more suitable to determine ages of blue catfish. Specifically, we found the articulating process and otolith techniques to be the preferred methods to be used for age determination for blue catfish, and we offer insight on each technique’s limitations and applicability. We achieved higher precision of age assignments for otoliths than for the two pectoral spine methods. However, back-calculated growth was variable among all three techniques compared up to age-6. Although otolith cross-sections were easier to process and interpret for age and growth estimation and yielded higher precision for age assignments than pectoral spine techniques, their use is a lethal methodology and may not be feasible for native catfishes in Lake Oconee or other populations with low abundance or high exploitation rates. If fisheries biologists choose to perform any of the age determination techniques compared in our study, we suggest the use of either lapilli or the articulating processes of pectoral spines as long as the method chosen best suits their management objective. The techniques compared in this study have not yet been validated for blue catfish, and we did not compare the accuracy of each technique. Future investigations of blue catfish populations would benefit from validating age and growth determination techniques for blue catfish to ensure the collection of reliable data. Nevertheless, the results in of our study should aid fisheries biologists when deciding how to collect age and growth information for catfishes.

The percentage of angler recruitment and retention has been decreasing nationwide over since the turn of the century, and many states have been challenged to be more aggressive with promoting their fisheries resources to potential users to increase angler recruitment and retention (USFWS 2006). Georgia and other states face problems such as less revenue returned from fishing license sales, less money returned from the Federal Aid in Sportfishing Restoration Fund, and potentially less public support for fisheries and wildlife conservation; these problems are common when angler numbers decline (Miller and Vaske 2003; Schramm Jr and Gerard 2004; American Sportfishing Association and the Association of Fish and Wildlife Agencies 2007). According to a 2006 National Survey of Hunting, Fishing, and Wildlife-Associated Recreation, angler participation between 2001 and 2006 decreased nationally by about 12%. Along with this decline has been a decline in the sale of fishing licenses in many states, including

Georgia (American Sportfishing Association and the Association of Fish and Wildlife Agencies 2007).

Angling for blue catfish is gaining popularity in the United States (Michaletz and Dillard 1999; Arterburn et al. 2002; Grist 2002). Since their discovery in Lake Oconee in 1997, blue catfish have supported increasingly popular recreational and commercial fisheries (Chris Nelson-GADNR, personal communication). Several catfish sportfishing clubs are developing and are beginning to target large fish in the system. The Georgia record size for blue catfish has been increased multiple times. In April 2011, the Lake Oconee record size of blue catfish caught by anglers increased from about 10.4 kg to 14.5 kg, and the record is likely to continue to be broken (http://southerngameandfish.com/site/new-lake-oconee-record-blue-cat-caught-and-released/). By encouraging the natural production of large blue catfish in Lake Oconee through proper management strategies, fisheries managers could promote the blue catfish population as a trophy fishery. Attracting anglers to Lake Oconee to fish for blue catfish may improve angler retention, increase fishing license sales revenue, and boost revenue to the local economy. Currently, anglers' and commercial fishermen's preferences for catfishes as game species are currently unknown and warrant research attention from fisheries biologists to improve the quality of the fisheries at Lake Oconee

The introduction of blue catfish is likely contributing to the decline of native white catfish and/or has caused a shift in use of the preferred habitat for white catfish. Changes in current management strategies may prevent the spread of the introduced population and further protect native catfishes from additional mortality caused by angling and commercial harvest. Conversely, the promotion of the fisheries may create preference of blue catfish over native species; thus, the increased popularity could lead to harvest restrictions for blue catfish and potential catch-and-release of large individuals caught by anglers. Catfish fisheries in Georgia are considered a game species, but they are not subjected to daily limits (GADNR 2011). Imposing a conservative creel limit and size restriction (i.e., maximum size restriction) for large blue catfish and an unlimited creel limit for smaller blue catfish fish could maximize the number of trophy blue catfish in Lake Oconee. Yet, allowing blue catfish to persist may lead to decreases in abundance of the native species in Lake Oconee and the Oconee River. Implementation of a maximum size or slot limit for channel catfish and white catfish and unlimited creel of blue catfish catch may encourage production of the native catfishes in the lake.

Biologists may have a better understanding of the life histories of blue catfish and species affected by their introductions by investigating blue catfish population growth, recruitment, mortality and biological interactions of blue catfish among other fishes to better understand their life histories. Further, such research may help identify needs for fisheries management wherever blue catfish have been introduced. Specifically, monitoring changes population sizes, somatic growth, and fishing mortality can be vital to understanding the population dynamics of blue catfish and other catfishes in Lake Oconee. The biological interactions of blue catfish with other species in Lake Oconee are poorly understood. However, the results of our study propose that competitive exclusion for habitat and/or food, predation, or a combination of the interactions with blue catfish could be resulting in the population decline of native white catfish. Obtaining age and growth information for the various catfishes will be a crucial component to understanding the ecological interactions among them. Mark-recapture studies are necessary for obtaining better information regarding the growth of introduced catfish populations. Simultaneously, investigation of food habits for each species would improve our understanding of the interactions among species. Lastly, such studies may be beneficial to biologists tasked with identifying preferred prey species, foraging habitat, and species imperiled by the introductions of both blue catfish and flathead catfishes in Lake Oconee.

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