REPRODUCTIVE BIOLOGY, LIFE HISTORY AND POPULATION STRUCTURE OF A BOWFIN *AMIA CALVA* POPULATION IN SOUTHEASTERN LOUISIANA

A Thesis

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In partial fulfillment of the requirements for the degree of
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by
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CERTIFICATE

This is to certify that the thesis entitled "Reproductive biology, life history, and population structure of a bowfin *Amia calva* population in southeastern Louisiana" submitted for the award of Master of Science to the Nicholls State University is a record of authentic, original research conducted by Mr. Johnathan G. Davis under our supervision and guidance and that no part of this thesis has been submitted for the award of any other degree, diploma, fellowship, or other similar titles.

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ABSTRACT

Known by names such as choupic, dogfish, and grinnel, the bowfin *Amia calva* is an ancient fish that inhabits the bayous and backwaters of Louisiana. The bowfin is the last extant species in its family Amiidae and has many distinctive characteristics and behaviors including a bony gular plate, a long dorsal fin, sexual dimorphism, parental care of offspring, and a physostomus swim bladder which functions as a lung and allows it to tolerate hypoxic waters. Bowfin are fished recreationally and commercially in Louisiana for their meat and roe. The minimum commercial and recreational size limits are 559 mm and 406 mm total length, respectively. The purpose of this study was to define the life history characteristics of a bowfin population in southeastern Louisiana, specifically age, growth, fecundity, egg size, age of maturation, and spawning period. Bowfin (N=297) were sampled from September 2005 to September 2006, from the Upper Barataria estuary using gill nets, trot lines, jug lines, and hook and line. Von Bertalanffy growth equation was used to describe growth. Females were older and heavier than males. Mean fecundity was about 23,000 eggs, and mean egg diameter was 2.0 mm from December to April. Most bowfin are mature by age 2. Only a few (N=5) female bowfin spawned during this study. The commercial minimum size limit targets the largest and oldest female bowfin in the population. If spawning success is limited, this bowfin population may become overharvested. Life history traits described in this study can be incorporated into population models to adapt current management regulations. Effective management regulations can protect the population from overharvest if fishing pressure on the population increases.

ACKNOWLEDGEMENTS

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SCIENTIFIC NAMES

Bowfin	*Amia calva*
Alligator gar	*Atractosteus spatula*
Spotted gar	*Lepisosteus oculatus*
Longnose gar	*Lepisosteus osseus*
Paddlefish	*Polyodon spathula*
Blue Catfish	*Ictalurus furcatus*
Channel Catfish	*Ictalurus punctatus*
Yellow Bullhead	*Ameirus natalis*
Bluegill	*Lepomis macrochirus*
Redear Sunfish	*Lepomis megalophus*
Green Sunfish	*Lepomis cyanellus*
Spotted Sunfish	*Lepomis punctatus*
White Crappie	*Pomoxis annularis*
Largemouth Bass	*Micropterus salmoides*
Yellow Bass	*Morone mississippiensis*
Golden shiner	*Notemigonus crysoleucas*
Gizzard shad	*Dorosoma cepedianam*
Striped Mullet	*Mugil cephalus*
Smallmouth Buffalo	*Ictiobus bubalus*
Common Carp	*Cyprinus carpio*
Crayfish	*Astacidae*
Grass shrimp	*Palaemonidae*
Wood storks	*Mycteria americana*
American alligator	*Alligator mississippiensis*

LIST OF ABBREVIATIONS

CST= Central standard time
kg= kilogram
mm= millimeter
GSI= gonadosomatic index
HSI= hepatosomatic index
SAS= Statistical Analysis Software
ANOVA= analysis of variance
FAST= Fisheries Analysis and Simulation Tools
SD= standard deviation
S= total annual survival
AM= total annual mortality
Vtg= vitellogenin

INTRODUCTION

Bowfin belong to the Holostean group of fishes and are the last extant species of Amiidae (Figure 1; Boreske 1974). Bowfin have many common names including mudfish, dogfish, marshfish, grindle, grinnel, lawyer, cottonfish, beaverfish, blackfish, speckled cat, spot tail, scaled ling, choupique, and cypress trout. In Louisiana, the bowfin is commonly called choupic, a French term (*Choupique*) derived from the Choctaw word *shupik* which means mudfish (Reed 1939). The fossil record of bowfin dates back to the Mesozoic era (Patterson 1973). Therefore, bowfin are commonly referred to as "living fossils" (Boreske 1974). Amiids and lepisosteids are the only extant representatives of Holostean fishes. The first Holostean fish appeared by the late Palaeozoic period and was similar to *Amia*. Based on fossil evidence, seven genera and twenty-three species of amiids, spanning the Cretaceous period to the present, have been described (Boreske 1974). Amiid fossils have been found on every continent except Australia (Nelson 1994). Bowfin are thought to have evolved by the beginning of the Pliocene and have been the focus of many phylogenetic studies (Patterson 1973; Schultze and Wiley 1984; Singer and Ballantyne 1991; Tufts et al. 1994). For example, bowfin are thought to be part of an intermediate stage of evolution between fishes that obtain oxygen only from water and fishes that obtain oxygen from water and air. Of the two orders of Holostean fishes, Amiiformes and Lepisosteiformes, bowfin are more closely related to teleost fishes based on shared characteristics (Suzuki and Hirata 1991; Becker 1983).

Many ancestral characters distinguish the bowfin from modern teleosts, although the two groups share many similar characters. Examples of ancestrally distinctive characteristics include a skeleton composed of both bone and cartilage, an abbreviated

1

Subclass	Infraclass	Division	Order	Suborder	Family

Teleostei

Neopterygii

Halecomorphi · · · **Amiiformes** · · · **Amiidae**

(Holostean fishes)

Ginglymodei · · · Lepisosteiformes · · · Lepisosteidae

Actinopterygii

Chondrostei · · · Acipenseriformes

Polyodontidae

Acipenseridae
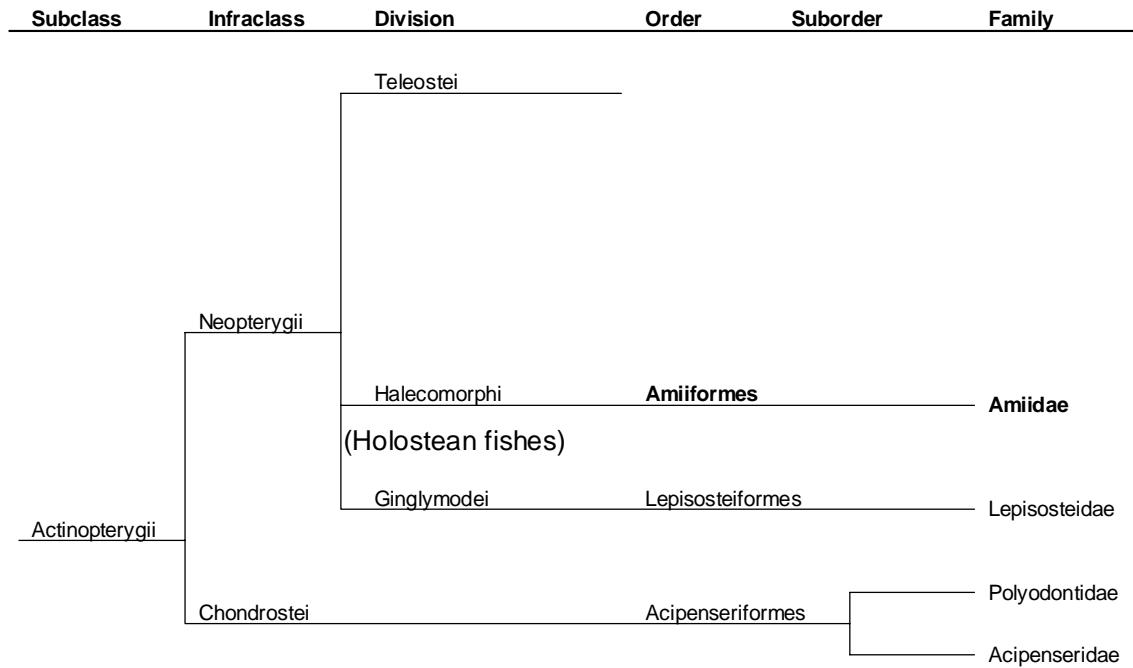
Figure 1. Phylogeny of selected fishes [adapted from Nelson (1994)].

heterocercal tail (Scott and Crossman 1973), a physostomous swim bladder that can aid

in oxygen uptake (Randall et al. 1981), an egg transport system, which is similar to

terrestrial vertebrates (Becker 1983), a spiral valve intestine (Helfman et al. 1997), and

parental care of offspring (Scott and Crossman 1973). A strong, bony jaw lined with

sharp, canine-like teeth is a trait characteristic of non-teleost fishes (Helfman et al. 1997).

Unique characteristics of bowfin include the presence of the gular plate below the jaw

and a long, undulating dorsal fin, which allows both forward and backward movement.

Characters that bowfin have in common with teleosts include amphicoelous vertebrae and

cycloid scales (Jarvik 1980).

The bowfin is found only in North America. The northern range of the bowfin

extends from the St. Lawrence River drainage of Quebec, Canada, west to the Mississippi

River drainage in Minnesota. The range extends southwest of the Appalachian

mountains to Florida and westward to parts of South Dakota, Kansas, Nebraska,

Oklahoma, Missouri and southern Texas (Scott and Crossman 1973; Figure 2). Bowfin

typically inhabit shallow, warm, vegetated waters of lakes and rivers.

Bowfin have sexually dimorphic external physical characteristics (Figure 3).

Males have a green coloration on the pelvic, pectoral, and anal fins and even the jaw,

along with a dark tail spot surrounded by an orange halo. The intensity of the coloration

increases during the spawning season. Whereas the green coloration of fins is only

distinguish during the spawning period, the dark tail spot is easily distinguishable

throughout the entire year. Mature females have no tail spot and have fins that are either

absent of color or have a reddish or orange hue. Immature females may have a faint tail

Figure 2. Distribution map of bowfin in North America. Shaded portion indicates areas in which bowfin are found [adapted from Scott and Crossman (1973)].

Figure 3. Sexually dimorphic characteristics of male (top) and female (bottom) bowfin collected from the Upper Barataria estuary in December 2005 (top) and January 2006 (bottom).

spot. Sexually dimorphic coloration such as this is not present in other ancient bony

fishes (Helfman et al. 1997).   There has been some speculation as to the purpose of this

coloration in males (Becker 1983). Reighard (1903) observed that males did not display

for females when spawning and theorized that coloration was not important for attracting

and exciting females but provides camouflage during times of exposure when guarding

nests. According to Becker (1983), the tail spot is a diversion to predators that will attack

the tail spot rather than the head of the fish. Bowfin in the northern reaches of their

geographic range spawn from late April to early May (Reighard 1903; Ballard 1986).

Spawning in Louisiana occurs from February to early March (Davidson 1991). Prior to

spawning, the male constructs a concave nest by fanning away silt with his caudal fin and

removing vegetation with his mouth. The male continuously occupies the nest. The

female arrives to spawn in the nest, moving in a circular motion with the male. Spawning

occurs when the water temperatue is 16-19°C in Michigan (Reighard 1903). The eggs

are adhesive, sticking to any vegetation or substrate at the nesting site. The female leaves

after depositing her eggs, and the male guards the nest. Bowfin nests may be used by

other species for spawning such as the golden shiner *Notemigonus crysoleucas* (Katula

and Page 1998). Bowfin eggs hatch in approximately eight days (Reighard 1903; Purkett

1965). Larvae remain attached to the vegetation until the yolk sac is absorbed. Juveniles

leave the nest at about 9-11 mm total length in a tightly associated school that is protected

by the male (Reighard 1903). Juveniles school and are protected by the male until they

are about 100 mm total length (Reighard 1903). Male bowfin may become extremely

aggressive when protecting their young, even launching onto land to frighten away

potential predators (Kelly 1924).

Bowfin are able to gulp surface air to augment oxygen uptake. The behavior begins early in development and has been observed in bowfin less than 50 mm total length (Reighard 1903). Gulped air is transferred to a modified and vascularized swim bladder in which oxygen diffuses into the blood. The rate of air breathing is dependent upon water temperature, light, and dissolved oxygen concentration (Horn and Riggs 1973; Hedrick et al. 1994). Lepisosteids have reduced gill surface area when compared to teleost fishes and must air breathe in order to uptake sufficient oxygen. Although bowfin air-breath, they have a gill surface area similar to teleost fishes (Daxboeck et al. 1981). Efficient uptake of oxygen from the water column may be necessary in northern parts of the range where ice may cover the surface of the water and limits access to the surface (Daxboeck et al 1981). However, cold waters typically have higher dissolved oxygen levels and result in decreased respiration as metabolism slows, in which case bowfin may not need to augment oxygen uptake by gulping surface air.

Air breathing allows bowfin to survive hypoxic conditions common in swamps, wetlands, and backwaters. Dissolved oxygen limits fish diversity, abundance, and survival in backwaters, resulting in fish assemblages that are dominated by adapted for aerial and surface respiration (Kilgore and Hoover 2001). Air breathing behavior increases at night when dissolved oxygen levels are low as a result of no photosynthesis (oxygen production) and constant respiration (oxygen consumption; Horn and Riggs 1973). The ability of bowfin to survive in hypoxic conditions has led to reports of bowfin surviving by burying themselves in the soil within the floodplain. Dence (1933) and Neill (1950) observed bowfin living in the substrate of dried up pools. Survival in these pools is possible because of adaptations within the gill structure. Fusion of the

7

lamellae make the gill structure rigid, preventing collapse upon air exposure and allowing air to pass over the lamellae for gas exchange (Daxboeck et al. 1981). However, McKenzie and Randall (1990) found that bowfin were incapable of aestivation because of an inability to detoxify ammonia to urea and reduce its metabolism, resulting in death.

The diet of bowfin in two North Carolina rivers primarily consisted of crustaceans such as crayfish (Astacidae) and grass shrimp (Palaemonidae; Ashley and Rachels 1999). Analysis of stomach contents of bowfin from Louisiana and Texas had similar results (Stacy 1967; Toole 1971). Dugas et al. (1976), found that bowfin collected from Henderson Lake, a backwater area within the Atchafalaya River Basin, Louisiana, feed primarily on fish during periods of low water and on crayfish during periods of high water. A study on the Kissimmee River, Florida, by Jordan and Arrington (2001) reported that bowfin feed on herpetofauna and that small backwater pools may be important feeding areas for predatory fishes that can withstand hypoxic waters.

Although bowfin are top-level predators, bowfin may be prey to other animals. According to Depkin et al. (1992), bowfin composed a portion (13% in wieght) of the diet of wood storks *Mycteria americana* in east-central Georgia. Bowfin, along with gars and shad *Dorosoma* spp., accounted for about 57 percent by volume of food for American alligators *Alligator mississippiensis* in Florida (Delany et al. 1999).

Bowfin are often regarded as a non-game species in many areas of their range and are a primary species of concern for fisheries managers. Not actively sought by anglers, bowfin have often been viewed as harmful to game fish populations and to recreational angler fishing success (Scarnecchia 1992). Because management efforts have focused on eliminating this fish, research on this species is limited. Furthermore, the ecological role

of this species is not fully understood and may be important to the structure and function of floodplain ecosystems. Although bowfin may consume some gamefish species such as *Lepomis* spp. and some catfish species (Ictaluridae), they also consume many non-game species such as gizzard shad *Dorosoma cepedianam* (Lagler and Hubbs 1940; Berry 1955; Cook 1959; Wyatt et al. 1968; Dugas et al. 1976). Other species once considered as "trash" species such as alligator gar *Atractosteus spatula* may play an important ecological role by maintaining balanced fish populations (Scott 1968; Becker 1983; Scarnecchia 1992). Bowfin may be important in controlling the numbers of smaller fishes and in preventing stunting of sportfish (Walden 1964; Purkett 1965; Scott and Crossman 1973; Mundahl et al. 1998).

Declines in sturgeon and paddlefish populations have led to an increase in the exploitation of bowfin by commercial fisherman and the caviar industry throughout southeast Louisiana. Wild sturgeon and paddlefish are primary sources of caviar. In 2003, commercial landings of bowfin in Louisiana totaled more than $128,157 from 92,355 kilograms of bowfin meat (Southwick and Allen 2005). Bowfin eggs are sold as Cajun caviar. The development of the bowfin caviar industry along with the continued harvest of bowfin meat resulted in the State of Louisiana issuing size-limits in 1991 to prevent overharvest and population decline. The minimum commercial size limit is 559 mm (22 inches) total length, and the minimum recreational size limit is 406 mm (16 inches) total length. In 1993, the use of gill nets for harvest of bowfin was prohibited from December to February. Also, the possession of bowfin eggs that are not naturally connected to the fish while on the water is illegal. Simply, fisherman are not allowed to remove eggs from bowfin until the fishing trip is completed.

Bowfin eggs ripen by February and have a dark and shiny appearance (Davidson 1991). Generally, an increase in the size of the fish oocytes leads to an increase in the yolk sequestration (LaFleur 1999). Most of the yolk (>90 percent) is derived from vitellogenin (Vtg), a yolk precursor protein. Vtg has a heterosynthetic orgin, undergoing synthesis in the liver from estrogen induction where it is then transported to the the oocyte by the blood, processed, and stored as yolk (LaFleur 1999). The caviar industry seeks to harvest individuals when vitellogenesis is completed prior to spawning, when the yolk content is the greatest.

Although bowfin are consumed throughout southern Louisiana, bowfin meat may contain high levels of mercury and other metals such as arsenic, chromium, copper, and mercury (Burger et al. 2002). Mercury bioaccumulates in the tissues of top-level predators. Mercury concentration biomagnify as it is passed from organisms on lower trophic levels to top-level predators. When compared to other piscivorous species, bowfin tend to concentrate mercury at higher levels (Francis et al. 1998).

This study took place in the Upper Barataria estuary, the headwaters for the marshes and estuaries of Barataria Bay (Figure 4). Historically, the upper Barataria esturary was flooded by the Mississippi River during spring high-water periods. However, the construction of levees and the closing of distributaries along the Mississippi River has prevented the delivery of an annual flood pulse to this system. Spoil banks along waterways also reduce the connectivity of the floodplain to the bayou. The Upper Barataria estuary no longer receives a predictable annual flood pulse; instead water levels are influenced only by unpredictable precipitation, resulting in a detachment of backwater areas from the main channel of the bayou. According to the flood pulse concept, water
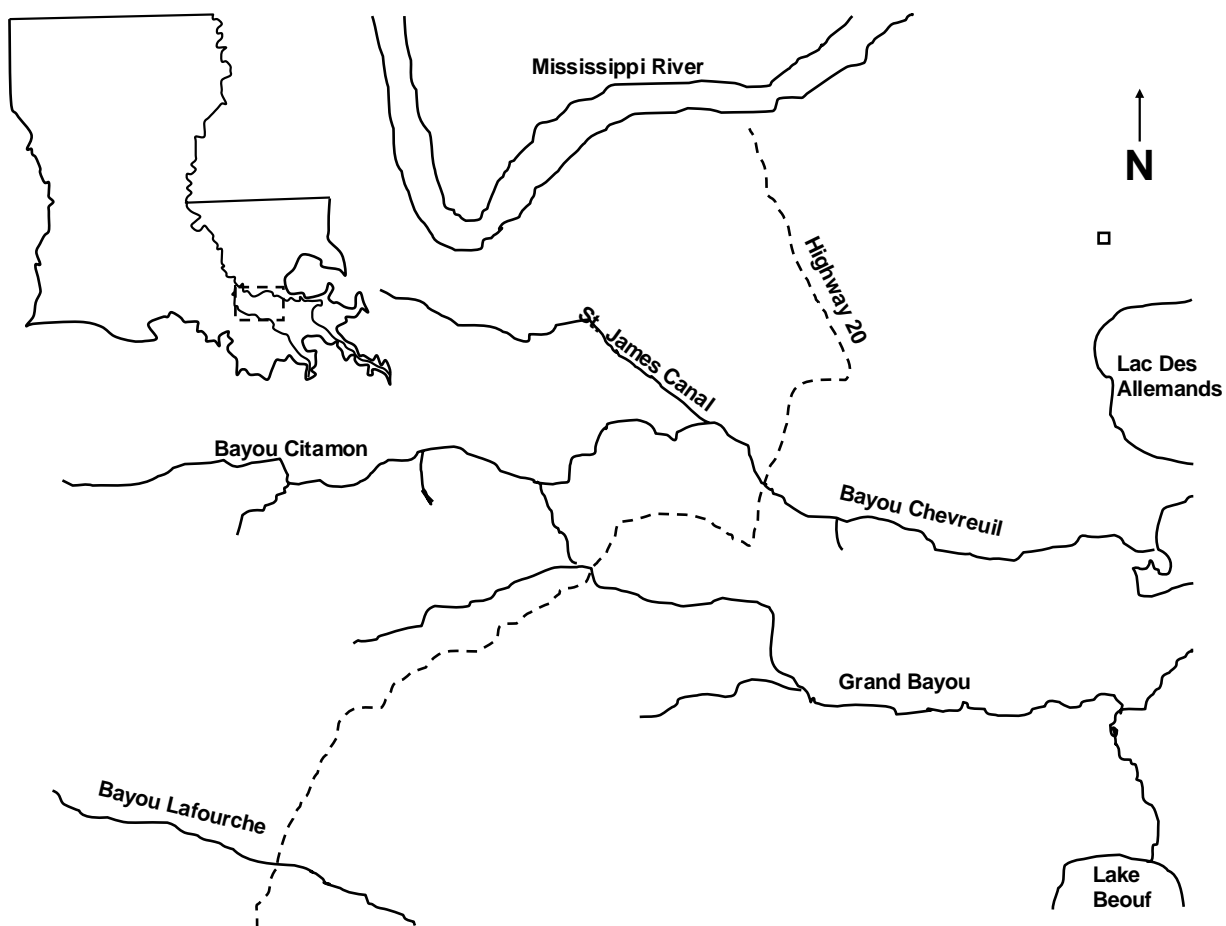
Figure 4. Map of the major waterways within the Upper Barataria estuary.

levels typically increase in the spring, inundating the floodplain, decrease during the summer, and remain low during the fall when waters are restricted to the main channel of the river (Junk et al. 1989). Backwater refuges in swamps are important for many fishes such as spotted gar and bowfin that can withstand hypoxic waters (Bonvillain 2006). Junk et al. (1989) proposed that the flood pulse is the major force that impacts the biota in a river-floodplain system and that disruption of the lateral exchange between the river or bayou and the floodplain from a flood pulse can reduce production within the system. Annual flood pulses are important to many fishes whose spawning coincides with the flood pulse, and can ultimately determine the reproductive success of a species (Hall and Lambou 1990). Connectivity of the bayou to the floodplain may be especially important for juvenile bowfin (Pezold 1998). Small floodplain pools, located near larger water bodies, are important habitat for juvenile bowfin that have been shown through swimming trials to have low dispersal capabilities (Hoover and Kilgore 2002). Juveniles use floodplain habitats during high water periods to grow and forage before the flood recedes. Overall, a reduction in the size of the floodplain can lead to a loss of habitat, resulting in decreased population size and species diversity (Junk et al. 1989).

Changes in the habitat of bowfin may affect population stability, growth, or reproduction. Potential habitat changes include hydrologic modification from the construction of levees that change annual water levels and reduce yearly flood pulses and channelization which eliminates backwater areas that are important for spawning and feeding. Nutrient distribution throughout the floodplain is greatly reduced in the absence of a flood pulse, thus reducing the amount of nutrients available to transient and resident organisms. Although the bowfin is adapted to hypoxic habitats, reduced primary and

secondary production in the absence of a flood pulse may negatively affect the population.

Basic life history information can be used to construct sustainable management scenarios for exploited species (King and McFarlane 2003). Life history information can also be used to predict the response of a fish population to environmental stress and change and modification (Partridge and Harvey 1988; Parent and Schriml 1995). The life history information described by this study can be used to assess current management strategies for bowfin in Louisiana.

For this study, a single population of bowfin was collected over an entire year to describe the macroscopic changes in egg growth and development, to define spawning period, and to collect life history information such as age, growth, fecundity, egg size, and age-at-maturation. Management strategies such as creel and harvest limits are based upon population models. Therefore, by developing population specific models, more appropriate and effective management strategies will result. A better understanding of spawning season duration will help to develop measures of protection for bowfin during spawning times, if necessary. Determining the times of the year in which egg diameter is greatest could provide commercial anglers with a guideline for the most profitable time to harvest bowfin eggs. This may reduce the harvest of individuals with underdeveloped eggs.

The goal of this study was to describe age, growth and reproductive biology of bowfin in the Upper Barataria estuary. This project defines the spawning period of bowfin and the age of maturation for a southeast Louisiana population, as well as describes population structure using age, growth, length and weight data.

METHODS

<u>Study site description</u>

The Upper Barataria estuary is the headwaters of the Barataria estuary. This area is located in southeast Louisiana and is bordered by the Mississippi River to the north and Bayou Lafourche to the south. Historically, this swamp was part of the Mississippi River floodplain. Bayou Chevreuil flows southeast through the swamp and drains into Lac Des Allemands. The northwestern reaches of the bayou are locally referred to as Bayou Citamon and the southeastern reach is referred to as Bayou Chevreuil. A man-made canal was built that connects Bayou Chevreuil to Grand Bayou which also flows south toward Barataria Bay. According to the US Environmental Protection Agency, the waters of Bayou Chevreuil, Bayou Citamon, and Grand Bayou are "impaired" due to mineralization, nuisance exotic species, organic enrichment/low dissolved oxygen, and toxic inorganics (USEPA 2005). The probable causes of the aforementioned impairments are related to drought and non-irrigated crop production (USEPA 2005). The absence of annual floodwaters from the Mississippi River is a major factor contributing to the decreased health of coastal marshes and the altered structure and function of upper estuary swamps such as the Upper Barataria estuary (Boesch et al. 1994).

<u>Field Data Collection</u>

Bowfin were collected biweekly from 20 September 2005 through 5 September 2006, from the Upper Barataria estuary. Water temperature (°C), dissolved oxygen (mg/L), and salinity (ppt) were measured with a handheld oxygen-conductivity-salinity-temperature meter at the top of the water column for each sampling trip (Yellow Springs Instruments, Yellow Springs, Ohio). Water clarity was measured with a Secchi disk

14

(cm). Water quality parameters were measured between 1000 and 1200 hours CST. Water level was measured using a calibrated water gage located at the intersection of Bayou Chevreuil, Bayou Citamon, and a man-made canal that leads to Grand Bayou.

Bowfin were collected using gill nets, trot lines, jug lines and hook and line to reduce the effect of gear size selectivity. Monofilament gill nets (1.8 m x 22.9 m) ranged in bar mesh size from 38 millimeters to 101 millimeters, bar length. Gill nets were set parallel to the bank to not impede passing boat traffic and were placed in areas in which the swamp drained into the bayou when possible to catch bowfin that were moving between the floodplain and the bayou (Figure 5). Trot lines were placed in similar locations and baited with cut gizzard shad. Jug lines, which consisted of a one liter plastic bottle with approximately 500 mm of monofilament leader, were also used (Figure 6). Jug lines were fished with 3/0 hooks, baited with cut bait and allowed to drift with the current. Hook and line sampling methods varied depending upon conditions. The top of the water column was fished with a floating rig with approximately 330 mm of monofilament leader. The bottom of the water column was fished with an egg sinker of variable size and a leader of at least 330 mm in length. On occasion, hook and line sampling without weight on a free-lining rig in which the bait was allowed to float freely downstream was also used (Figure 7). Hook and line sampling was used both in shallow, littoral waters near aquatic vegetation and in deeper waters in the main channel of the bayou.
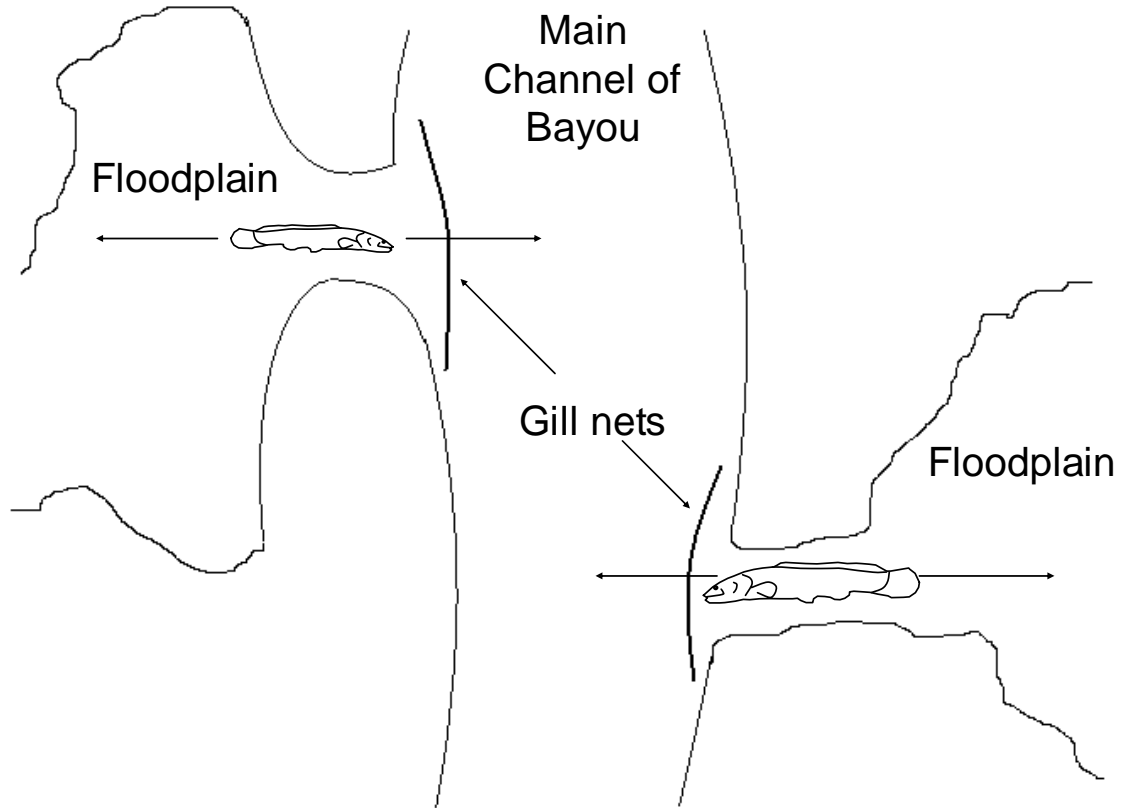
Figure 5. General location and position of gill nets in relation to the main channel and the floodplain.

Surface

Direction of flow
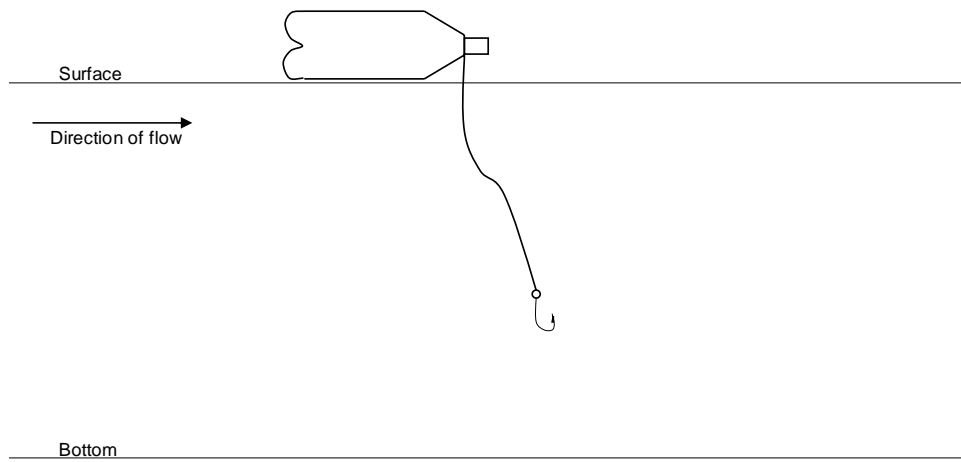
Bottom

Figure 6. Diagram of jug line gear fished at the top of the water column and drifted with the current.

Surface

(A)

Bottom

Surface

(B)

Bottom

Surface

(C)
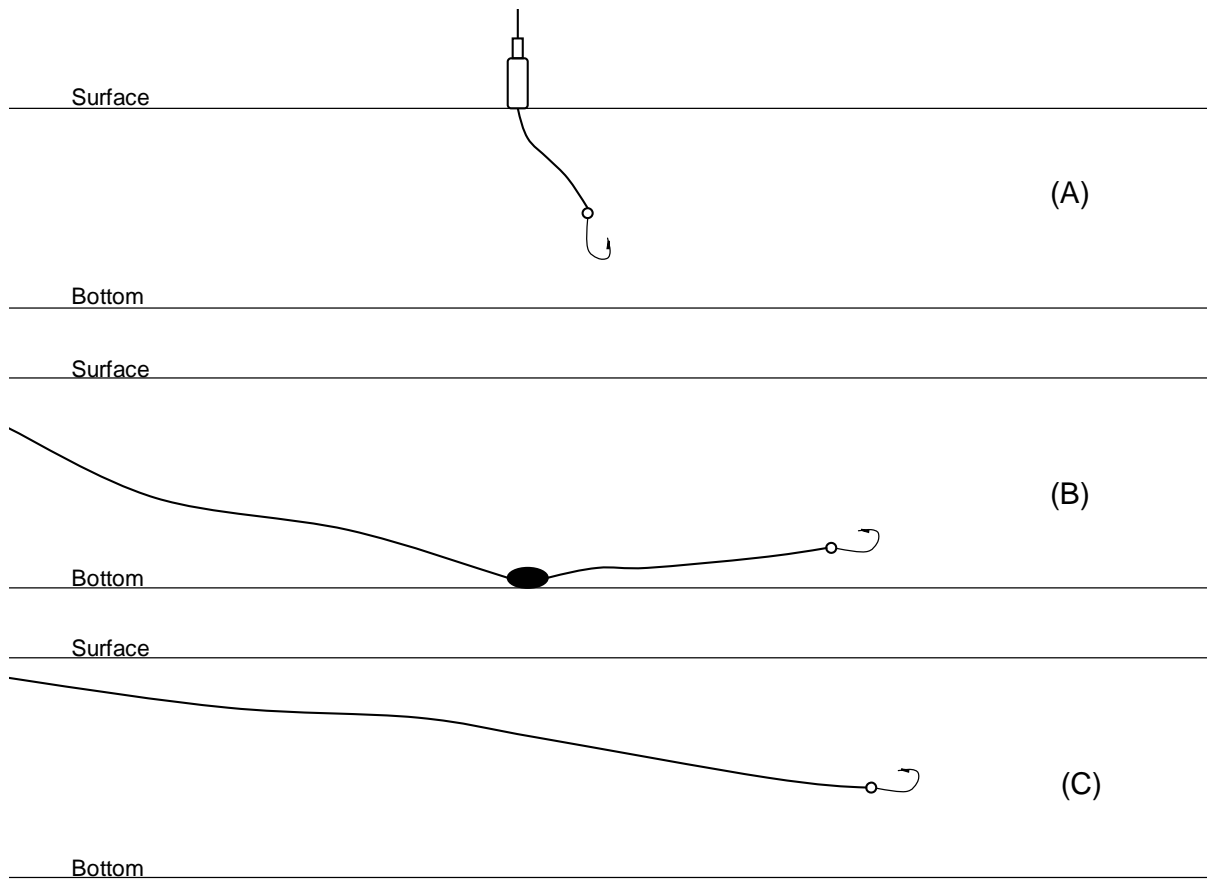
Bottom

Figure 7. Sampling methods using hook and line included floating rigs (A), bottom rigs (B), and free-line rigs (C).

Sex identifications were made using externally visible characteristics such as the presence (male) or absence (female) of a tail spot and fin coloration. Sexual identification was then confirmed by observation of the gonads. Bowfin were measured for total length to the nearest millimeter. Small bowfin (<1 kg) were weighed to the nearest gram, and large bowfin (>1 kg) were weighed to the nearest 0.01 kg. To facilitate gonad removal, bowfin were cut along the ventral side from the vent to the gills. Gonads were identified, removed, weighed to the nearest gram, and photographed. Gonads were preserved in 10% formalin. Gonad developmental state was determined according to Ladonski (1998).   Gonad descriptions included color, texture, and any other noticeable trait such as vascularization of ovarian tissue or egg size.

Gonadosomatic index (GSI) was determined separately for males and females to assist in determination of spawning period (Snyder 1983; Ferrara 2001). Gross examination of gonads was used to determine the stage of the ovarian development such as immature, developing, ovulatory, spent, and recovering (Barbieri et al. 2006). Livers were removed and weighed.   HSI was calculated following Ball et al. (1965).

Total fecundity was estimated for each female with visible immature, developing, or ovulatory stage eggs. Total fecundity is the count of ova in both ovaries that yields an estimate of reproductive potential (Crim and Glebe 1990). This differs from functional fecundity which is the production of viable oocytes. Total fecundity does not account for incomplete spawning, atresia or degeneration of eggs, and reabsorption of oocytes.   A subsample of eggs weighing 10% of the total ovarian weight was removed from each ovary, and the total number of eggs in the subsample was counted (Ladonski and Burr, *in*

press). The accuracy of this method was compared with whole ovary egg counts (N=11).

Ovaries were labeled and stored in 10% formalin for reference. A random subsample of

twenty eggs was removed prior to gonad preservation, and individual egg diameters were

measured to the nearest millimeter using digital calipers and imaging software from

December through March (Ferrara 2001). The total number of eggs per individual was

divided by body weight to determine the number of eggs per gram.

Otoliths were removed by displacing the gill arches and removing the sagittal

otoliths from the otic capsules at the base of the skull (DeVries and Frie 1996). Otoliths

were washed and dried, and placed in labeled vials for aging. Whole otoliths were

viewed under a dissecting microscope for age determination. Otoliths were examined in

whole view and in section, but annuli were not observed. Therefore, gular plates, not

otoliths, were used to age bowfin. Gular plates were removed from the lower jaw and

boiled to remove skin and tissue. Gular plates were then dried and stored in labeled coin

envelopes.

Multiple readers (N=3) aged gular plates without knowledge of total length, and

any discrepancies in age were discussed until an age was agreed upon (Campana et al.

1995). Gular plates were read using a light table in which light emanated from behind

the gular plate, allowing for visualization of annuli. After age was determined by the

readers, each annulus was marked with a pencil. Digital calipers were used to measure

the total length of the gular plate and the distance from the base of the gular plate to each

annulus (i.e. growth increment). Growth increments were used to used to backcalculate

total lengths for each age (Maceina and Betsill 1987).

<u>Statistical Analysis</u>

Total length and weight were compared between the sexes with analysis of variance (ANOVA). Regression analysis was used to compare total length and weight. Length-frequency distributions and age-frequency distributions between males and females were compared with a Kolmogrov-Smirnov two sample test. Seasons of the year were designated as winter (December-February), spring (March-May), summer (June-August), and fall (September-November). ANOVA followed by Tukey's *post hoc* comparison was used to determine monthly and seasonal differences in mean egg diameter and GSI. The timing of spawning was determined using GSI values and macroscopic inspection of the gonads. Fecundity was $\log_{10}$ transformed to achieve normality. Regression analysis was used to determine the relationship between age and fecundity and total length and fecundity. ANOVA was used to compare age-specific size differences between males and females. The von Bertalanffy growth function was used to describe sex-specific growth. Mean length-at-age was used to calculate growth coefficient (k), the maximum theoretical length (L_∞), and the time when initial length was zero (t_0). The von Bertalanffy growth curve was used to determine age at which bowfin recruit to the commercial and recreational minimum length limits. Catch-curve regression was used to provide survival and mortality rates and maximum age for females and males. The age-at-maturity was defined as the age at which at least 50 percent of females were mature. All inferences were based on $\alpha=0.05$.

RESULTS

Field Data

A total of 292 bowfin were collected from 20 September 2005 to 5 September 2006. In addition to bowfin, 17 other fish species were collected (Table 1). The majority of bowfin were collected from the northwestern portion of the Upper Barataria estuary in Bayou Citamon (Figure 8). Water temperature ranged from 12.2-32.0°C and averaged 21.2(±6.2)°C. Dissolved oxygen ranged from 1.61-3.93 mg/L with an average of 2.71(±0.67) mg/L. Salinity ranged from 0.1-0.2 ppt. Water clarity ranged from 18.0-83.8 cm and averaged 45.3 cm. Water level ranged from 0-64 cm and averaged 56(±12.2) cm. A zero reading was the lowest reading on the gage and was at sea level.

Data collection

More females (N=204) were collected than males (N=87; Figure 9). The sex ratio of females to males was 2.3:1. Sex was accurately identified for all fish using external characters. Immature females (N=5) had a faint tail spot present but lacked the orange halo. Females were longer, heavier, and older than males (Table 2). Weight increased exponentially with increased total length for females and males (Figures 10 and 11). Based on length-frequency analysis, lengths of females were significantly different (d=0.33; $P<0.05$) than males.

Based on monthly GSI values for females and males, spawning occurred in late February and early March (Figures 12 and 13). The first spent ovaries were observed on 21 March 2006. GSI of females increased in November and peaked in early March before decreasing to low levels in the summer and fall. GSI values were greater for older bowfin in females ($P<0.0001$) and males ($P=0.0066$). Individuals less than four years of
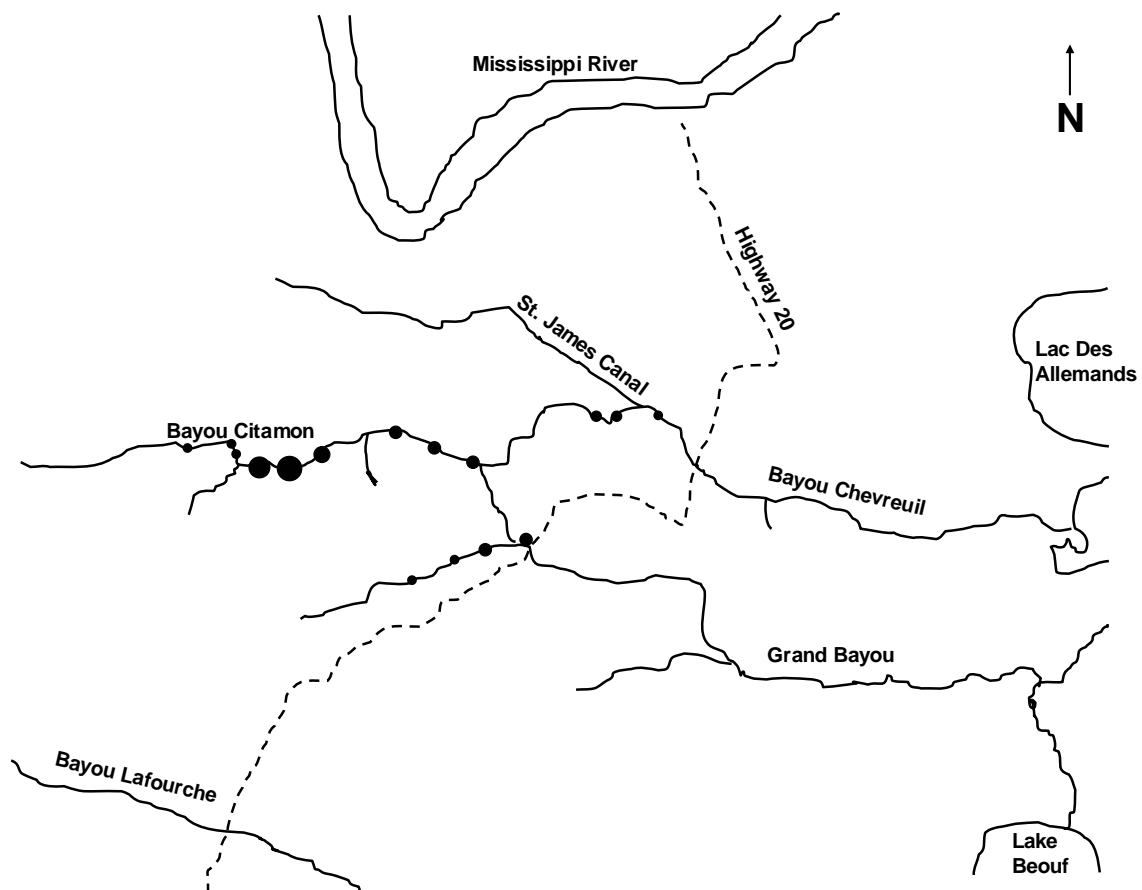
Figure 8. Locations from which bowfin were collected September 2005 to September 2006, from the Upper Barataria estuary. Size of the black dot reflects the number of bowfin collected at each site.

Table 1. Total number of each fish species collected September 2005 to September 2006, from the Upper Barataria estuary with gill nets, hook-and-line, and jug lines.

Species	Common Name	Number
Lepisosteus oculatus	Spotted Gar	351
Amia calva	Bowfin	292
Dorosoma cepedianum	Gizzard Shad	122
Ictalurus punctatus	Channel Catfish	40
Ictalurus furcatus	Blue Catfish	26
Pomoxis annularis	White Crappie	25
Ameiurus natalis	Yellow Bullhead	19
Morone mississippiensis	Yellow Bass	12
Cyprinus carpio	Common Carp	11
Mugil cephalus	Striped Mullet	9
Micropterus salmoides	Largemouth Bass	7
Lepomis macrochirus	Bluegill	7
Lepomis microlophus	Redear Sunfish	4
Atractosteus spatula	Alligator Gar	3
Lepomis punctatus	Spotted Sunfish	2
Ictiobus bubalus	Smallmouth Buffalo	2
Notemigonus crysoleucas	Golden shiner	1
Lepomis cyanellus	Green Sunfish	1
Total		**924**
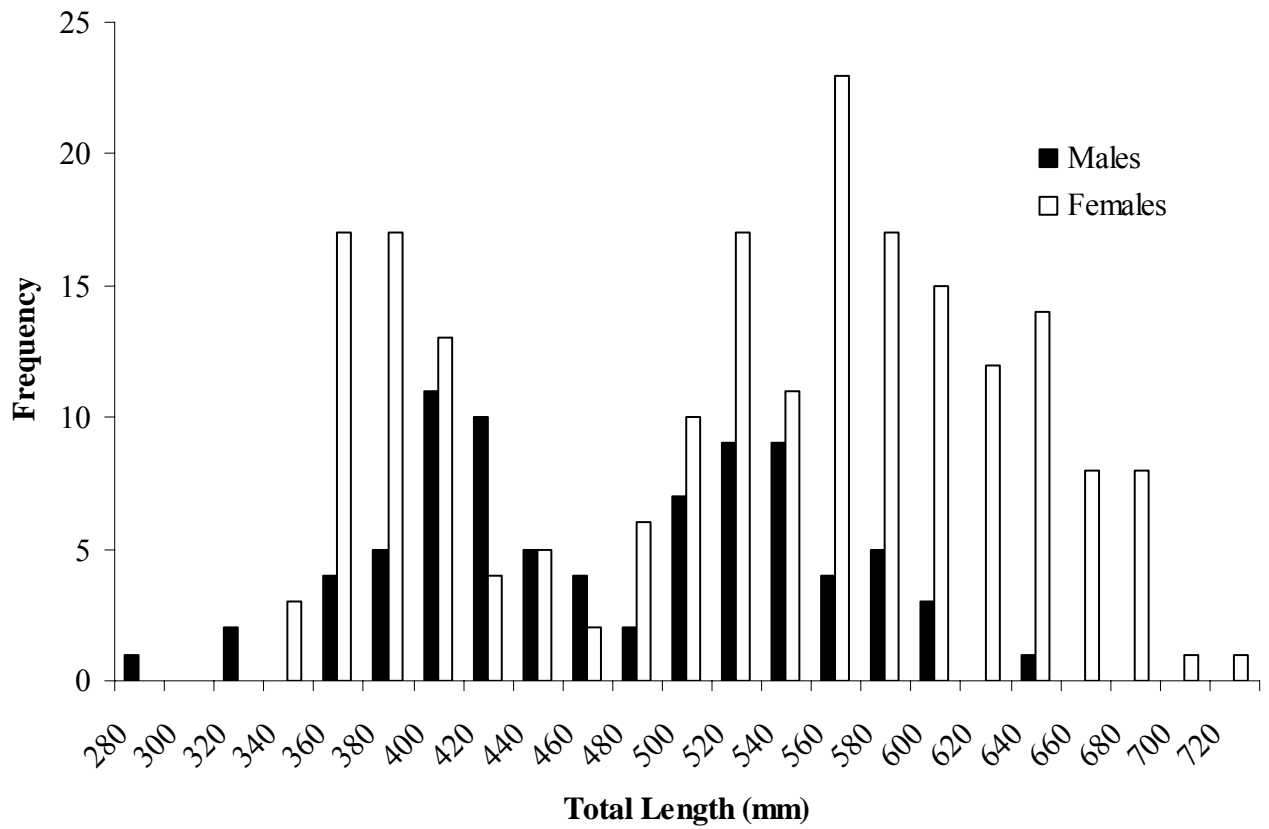
Figure 9. Length-frequency distribution of male (N=82) and female (N=204) bowfin collected September 2005, to September 2006, from the Upper Barataria estuary. Length-frequency of female bowfin was different from the length-frequency of male bowfin (d=0.33, *P*<0.05).

Table 2. Mean (±SD), number (N), and range for total length (mm), weight (g), and age (year) of female and male collected September 2005 to September 2006, from the Upper Barataria estuary. Total length, weight, and age were greater (α=0.05) for females than males.

Variable	N	Mean±SD	Range
Females			
Total Length (mm)	204	532±101.9	344-736
Weight (g)	197	1,544±903.3	300-4,610
Age (years)	201	4.7±1.79	1-10
Males			
Total Length (mm)	87	463±73.2	316-657
Weight (g)	82	865±451.8	271-2,600
Age (years)	87	3.5±1.29	1-6
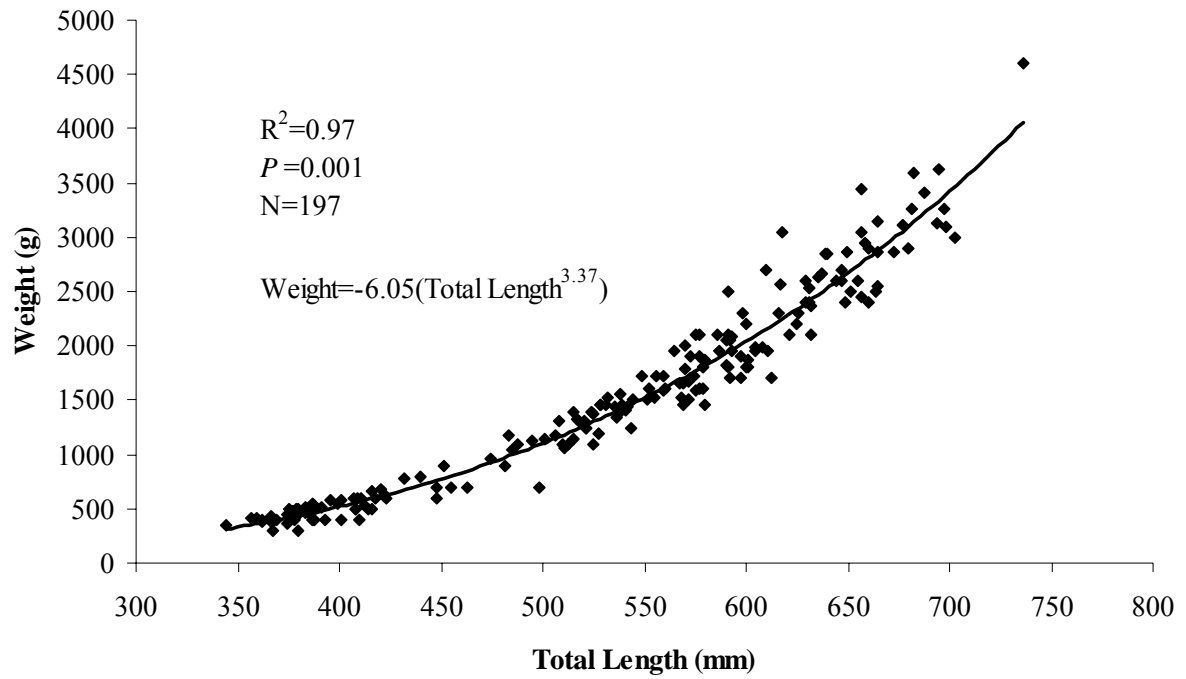
Figure 10. Weight-length relationship for female bowfin collected September 2005 to September 2006, from the Upper Barataria estuary.
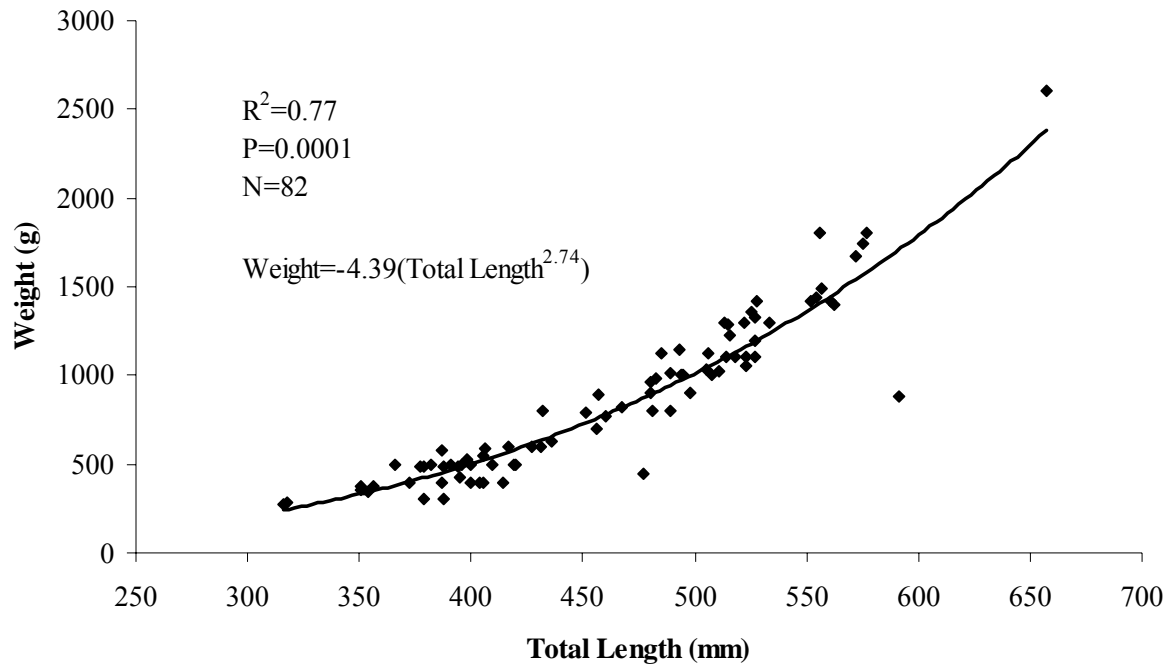
Figure 11. Weight-length relationship for male bowfin collected September 2005 to September 2006, from the Upper Barataria estuary.
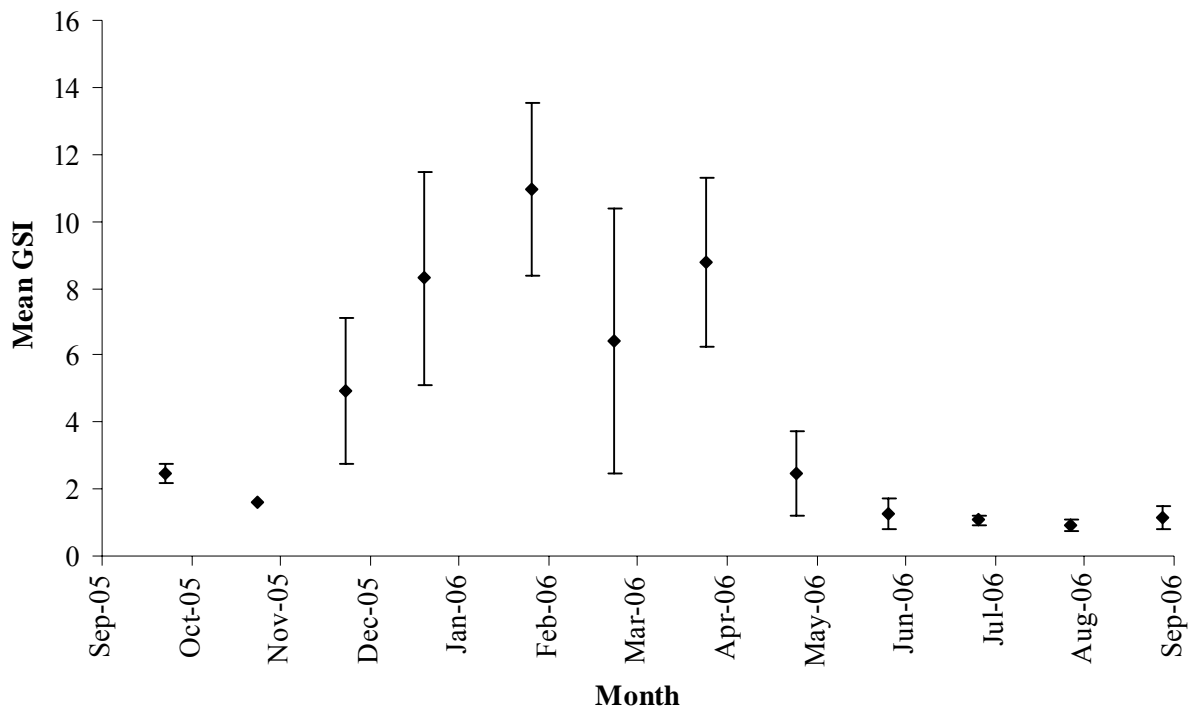
Figure 12. Mean (±SD) monthly gonadosomatic index for female bowfin (N=194) collected from September 2005 to September 2006, in the Upper Barataria estuary.
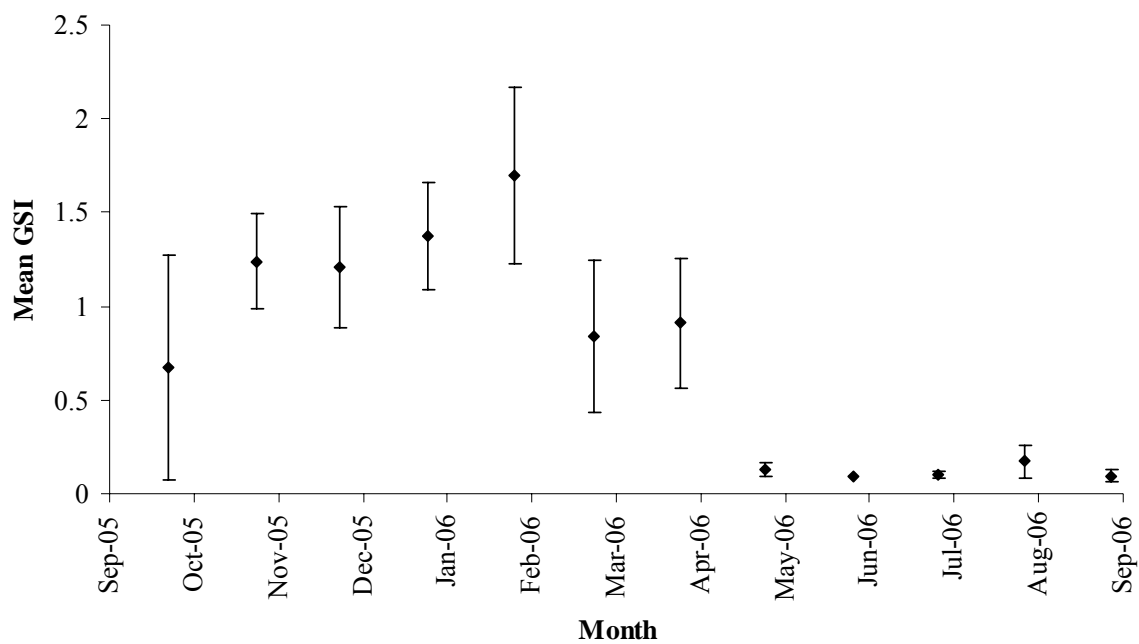
Figure 13. Mean (±SD) monthly gonadosomatic index for male bowfin (N=81) collected from September 2005 to September 2006, in the Upper Barataria estuary.

age were excluded from analysis to reduce the influence of age on monthly GSI values (Figure 14). GSI did not decline after the assumed spawning period. Only five individuals sampled after February were thought to have spawned. Bowfin that did not spawn retained and reabsorbed the eggs.

Mean female HSI (0.95) was greater than mean male HSI (0.78; P=0.0129). No differences (P>0.1) were detected among monthly HSI values for females and males.

Mean fecundity was 22,923±16,561 eggs with a range of 1,900 to 72,500 eggs. Fecundity was positively related (P=0.0001; R^2=0.86) to total length of bowfin (Figure 15) and with age of bowfin (Figure 16). The accuracy of all total egg counts in comparison with the estimated total number were not more than 1.49 percent different (Table 3). A paired t-test resulted in no difference (P=0.68) between estimated and total egg count. The mean number of eggs per gram of body weight was 15 eggs/gram of body weight.

Mean egg diameter (N=83; 2.0±0.3 mm) was greatest during the winter, reaching maximum sizes in January and February, and was correlated (P<0.0001; R^2=0.42) to month (Figure 17). Total length was positively correlated to egg diameter (P<0.0001; R^2=0.59).

Age frequencies were different (d=0.33; P<0.05) between males and females (Figure 18). Maximum age of bowfin was 10 years. The mean age of female bowfin (N=201) was 4.65 years and was greater than (P<0.0001) the mean age of male bowfin (N=87), which was 3.48 years (Table 2).
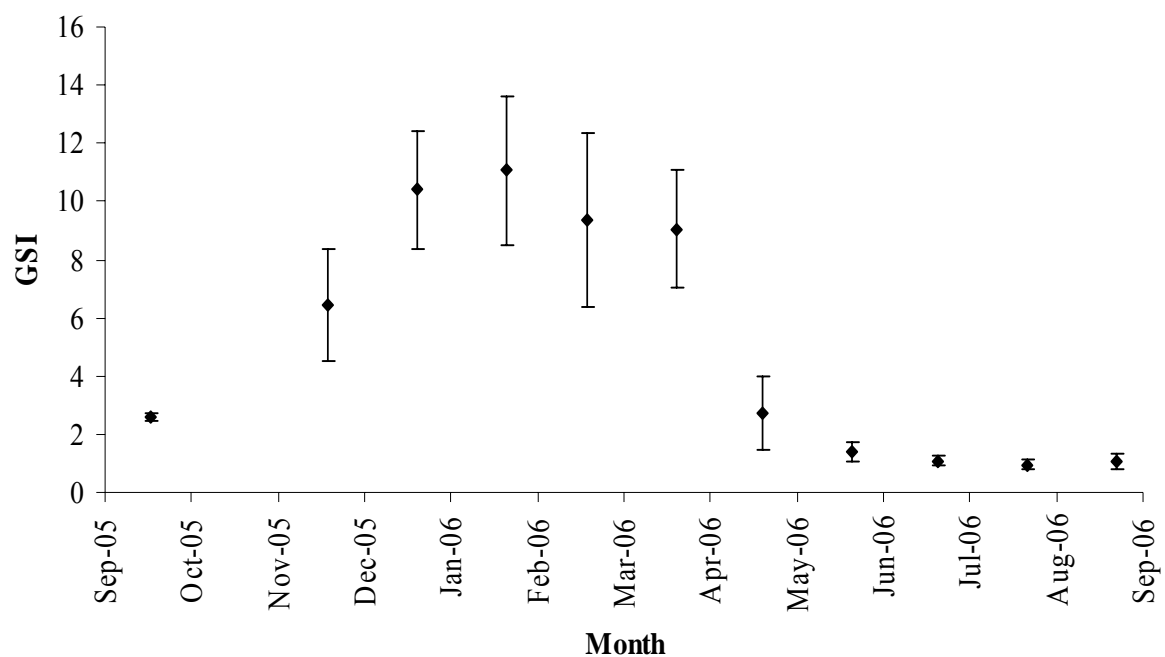
Figure 14. Mean (±SD) monthly gonadosomatic index for female bowfin (N=144) ages 4 and older from September 2005 to September 2006 in the Upper Barataria estuary.

$R^2=0.86$
$P=0.0001$
$N=115$

$Log_{10}Fecundity=3.87(Log_{10}Total\ Length)-6.28$
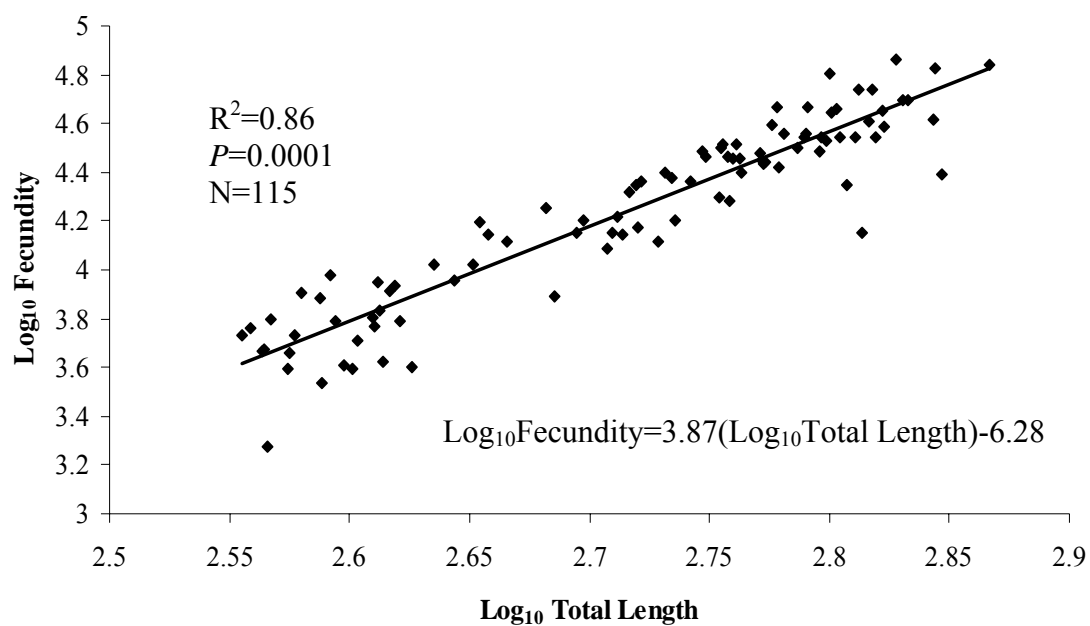
Figure 15. Relationship between Log_{10}fecundity and log_{10}total length for female bowfin collected from the Upper Barataria estuary.
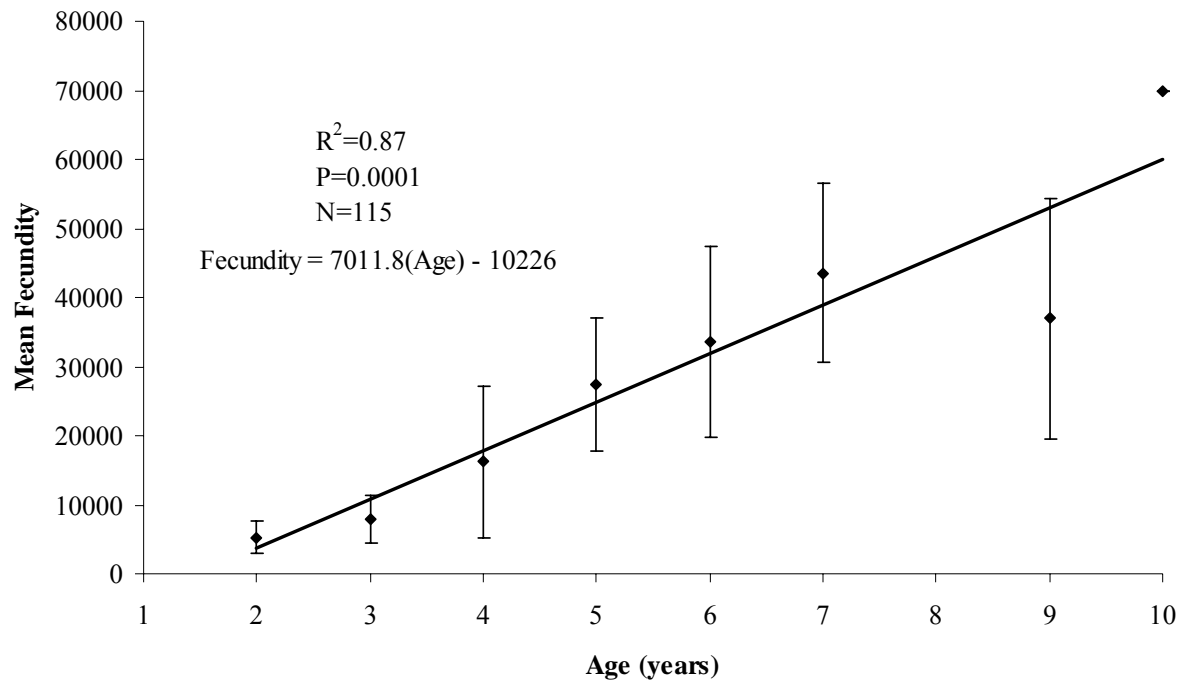
Figure 16. Mean fecundity at age for female bowfin collected from September 2005 to September 2006 in the Upper Barataria estuary.

Table 3. Comparison of fecundity estimation techniques (total egg counts and 10% sample extrapolation) of ovaries of bowfin. Ten percent egg count is the egg count of approximately ten percent of overall gonad weight. Percent difference is the total egg number from the total egg counts minus the estimated total egg number, divided by the sum of the two egg count estimation techniques multiplied by 100. There was no difference (Paired t-test; *P*=0.68) between estimated and total egg count.

Fish ID	Collection Date	Gonad Location	Gonad Weight	10% Egg Count	Estimated Egg Number	Total Egg Number	% Difference
1424	6 Apr 06	Left	41	593	5930	6595	1.49
1424	6 Apr 06	Right	41.5	704	7040	7253	0.48
1036	1 Dec 05	Right	3.39	104	1040	1199	0.36
1036	1 Dec 05	Left	5.17	298	2980	2548	-0.97
1460	21 Mar 06	Left	98.43	1257	12570	12876	0.69
1454	21 Mar 06	Left	4.63	101	1010	1034	0.05
1454	21 Mar 06	Right	4.22	89	890	943	0.12
1487	23 Feb 06	Right	50	684	6840	6480	-0.81
1093	11 Jan 06	Right	6.2	266	2660	2368	-0.65
1060	14 Dec 05	Right	5.2	160	1600	1585	-0.03
1060	14 Dec 05	Left	6.8	203	2030	2158	0.29
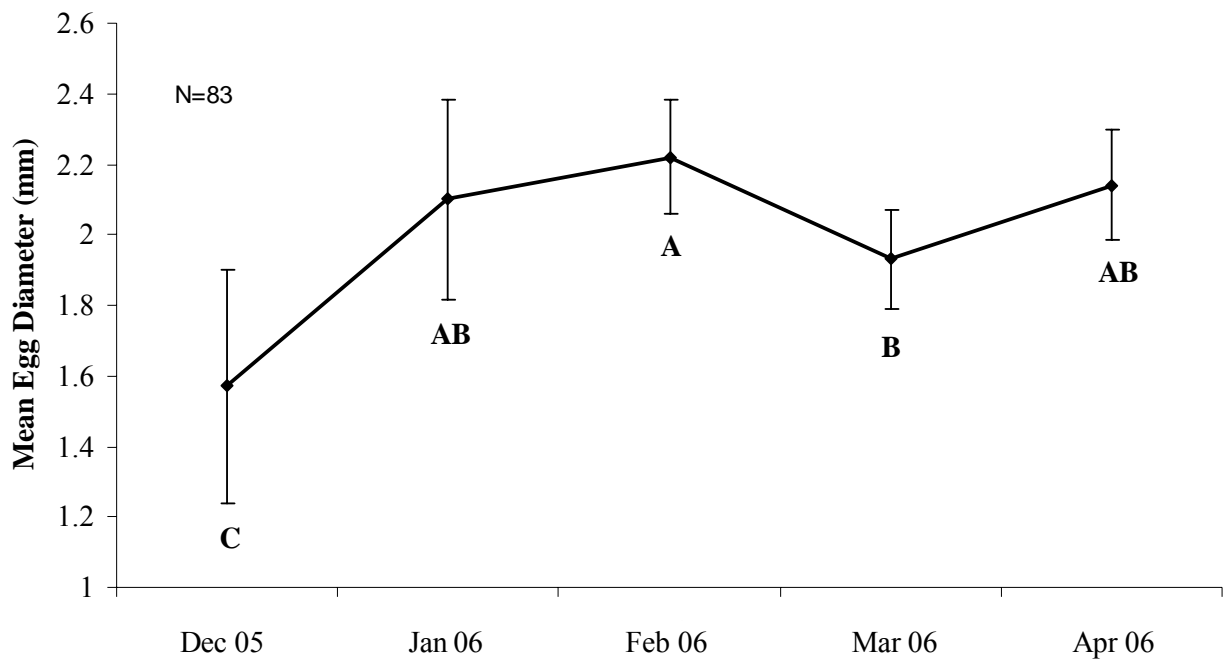
Figure 17. Mean (±SD) diameter (mm) of bowfin collected from December 2005 to April 2006, in the Upper Barataria estuary. Twenty eggs were randomly selected from each fish. Means with the same letter indicate no difference.
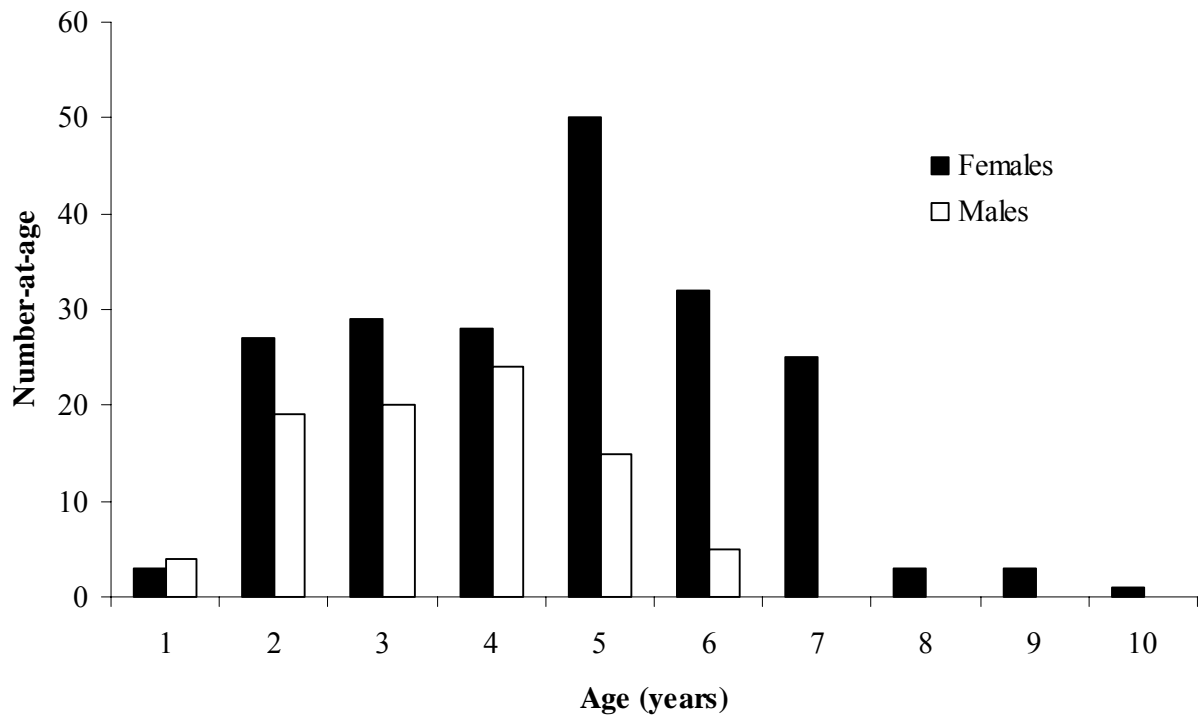
Figure 18. Age-frequency distributions for female (N=197) and male (N=87) bowfin collected from September 2005 to September 2006, in the Upper Barataria estuary. Ages of females were different (d=0.33; *P*<0.05) than males.

The von Bertalanffy growth coefficient (k), theoretical maximum size (L_∞) and the time where length theoretically equals zero (t_0) were 0.075, 1154 mm, and -3.58, respectively (Figure 19). Using this equation, the time that it takes a bowfin to reach the recreational minimum length of 406 mm is 2.21 years. Additionally, the time it takes for a bowfin to reach the commericial minimum length of 559 mm is 5.25 years.

Total annual survival (S) calculated from a weighted catch curve for bowfin was 42.4 percent (Figure 20). The calculated maximum age was 10.1 years for bowfin. Age of maturation was 2 years for both females and males.

The figure shows a scatter plot with a fitted curve. The y-axis is labeled "Total Length (mm)" ranging from 0 to 800. The x-axis is labeled "Age (years)" ranging from 0 to 10.

Text within the plot:
R^2=0.99
P =0.0001
N=276

$L_t=1154(1-e^{-0.075(t-(-3.58))})$

where:

L_∞=1154
k=0.075
t_0=-3.58
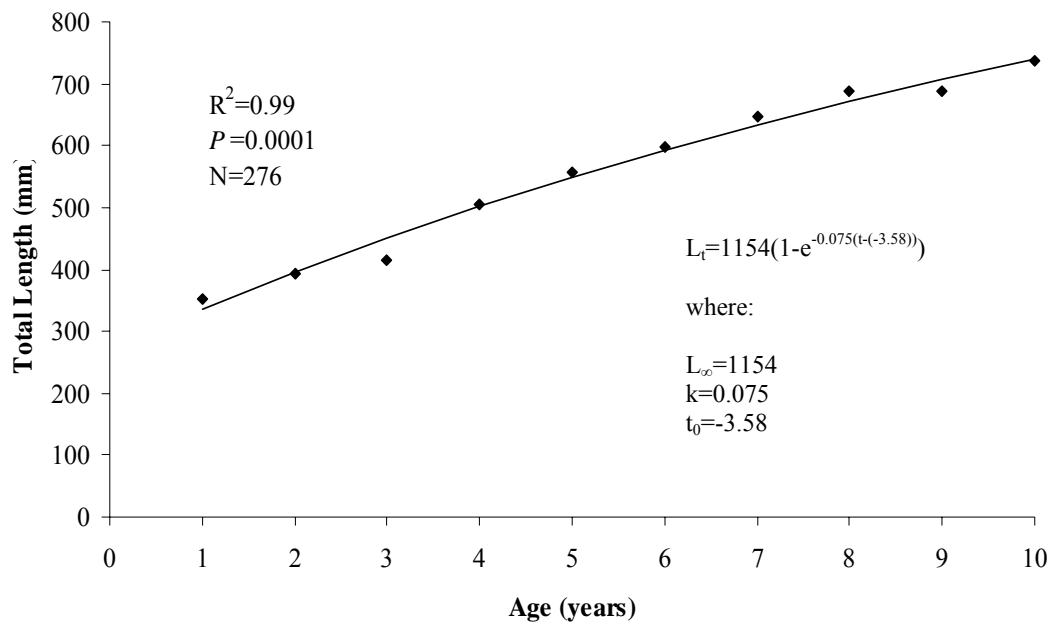
Figure 19. Von Bertalanffy growth curve for bowfin *Amia calva* collected from September 2005 to September 2006, in the Upper Barataria estuary.
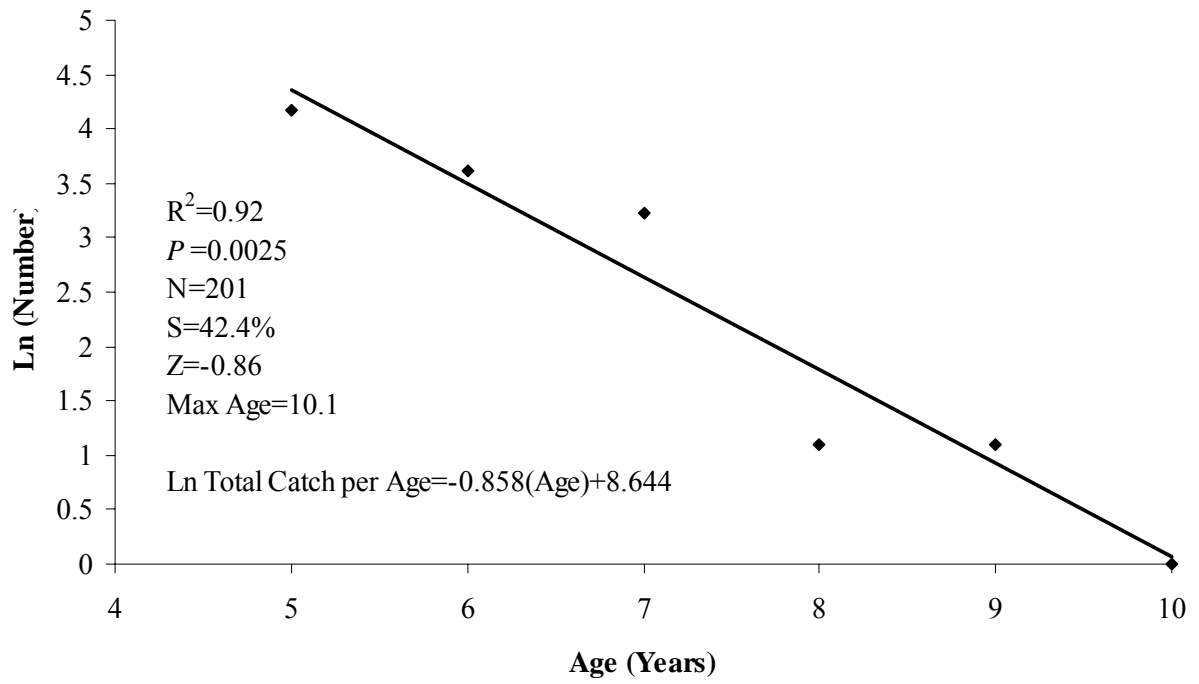
Figure 20. Catch-curve regression, instantaneous total mortality rate (Z), and total annual survival rate (S) of bowfin collected from September 2005 to September 2006, in the Upper Barataria estuary.

DISCUSSION

Field Data

The majority of fish collected were spotted gar (40%), bowfin (32%), and gizzard

shad (13%). Dissolved oxygen was low (Mean=2.7 mg/L), and may become hypoxic

(<2.0 mg/L) in some areas. By breathing atmospheric oxygen, gars and bowfin can

survive hypoxic conditions. In areas downstream of the Highway 20 bridge, no bowfin

were collected. Although bowfin may be present in the downstream area of Bayou

Chevreuil, more bowfin were collected in the upstream reaches. Based upon field

observation, the northernmost parts of the Upper Barataria estuary has increased shallow

water habitat and accessibility to the floodplain than the downstream reach.

Sex Identification

Identification of sexes using external characteristics (i.e. presence or absence of

an upper caudal peduncle spot) was an accurate field technique. Sex was correctly

identified using external characters for all males and females although young, immature

females had a faint tail spot that lacked an orange halo. Zahl and Davis (1932) also found

that immature females have a caudal peduncle spot. On average females were longer and

heavier than males. Selection for sexual size dimorphism in which males are smaller

may be dependent upon a number of factors including environmental stress (i.e. food,

temperature), weak male-male competition, or the ratio of growth rate to mortality rate

(Parker 1992).

Post-fertilization parental care can positively influence reproductive success for

fish (Johnston 1999). Differences in longevity between sexes may be the result of

parental care by males. Parental care by males, of which the main benefit is increased

41

survivorship of young, and the mating behavior of building and protecting a nest uses energy and can affect survival (Gross and Sargent 1985). This may explain why female bowfin are longer-lived than males. Parental care by males can also result in the evolution of larger egg sizes for females because energy is not spent on nest-building or post-spawning care but is instead invested in egg development (Gross and Sargent 1985).

Spawning

Bowfin are a total spawner species, releasing their eggs over a short period of time. During this study, only five out of 123 female bowfin had spent ovaries, potentially resulting in a weak year-class for 2006. Unspawned eggs became atretic as early as March, at the end of the assumed spawning period. Atretic eggs are orange to yellow in color and are smaller in size than ripe eggs (Barbieri et al. 2006). Reasons for the lack of spent ovaries are not readily apparent. Little historical data is available on the frequency of non-annual spawning across all fish species because of the difficulty of identifying non-reproductive individuals in some species (Rideout et al. 2005). However, non-spawning individuals were easily identified for bowfin.

For many fish spawning is strongly influenced by environmental variables such as temperature and photoperiod (Crim and Glebe 1990). In some fish species, the largest individuals within a species may skip an annual spawning event when environmental and nutritional conditions are below a certain threshold (Rideout et al. 2005). Spawning success of bowfin may have been affected by water levels within the swamp. Spawning behavior of some fishes can be triggered by the onset of a flood pulse (Welcomme 1985), but can also be disrupted by the timing or absence of a floodpulse, thus affecting recruitment success and community structure (Agostinho et al. 2001). Although the

42

majority of bowfin did not spawn, gizzard shad, which can use vegetated, littoral habitat along the main channel, did spawn (Fontenot 2006). During high water conditions, more area of the floodplain is flooded, increasing the availability of nesting sites. Water levels remained low during the spawning period and were restricted to the main channel of the bayou in most areas. As a result, males may have experienced intraspecific competition when searching for suitable nesting sites.

Spawning coincides with the spring flood pulse of the Mississippi River, but because levees prevent seasonal inundation of the floodplain, water levels remained low. The floodplain was solely dependent on rainfall for water supply during the spawning season, but the amount of rainfall was low during the spawning period of February and March. If high water levels, created from precipitation, increase the amount and quality of spawning habitat and thus spawning success, then year-classes from high water years should be stronger than those from low-water years.

The floodpulse concept (FPC) describes the lateral exchange of water, nutrients, and organisms between the river channel and the floodplain (Junk et al. 1989). Inundation of the floodplain can increase primary and secondary production and decomposition making nutrients available for uptake by organisms (Junk and Wantzen 2004). During the flood pulse, fish move onto the floodplain to forage. Nutrients from the floodplain stimulate primary production that can increase zooplankton and lead to larval fish growth (Wantzen et al. 2002). Therefore, the floodplain provides habitat for spawners and food for their larvae. An increase in energy and nutrients from the flood pulse can be transported through the food web to larger fishes such as bowfin, but in years of no or reduced flood pulse less energy and nutrients are available. Another

source of nutrients in the Upper Barataria estuary may be from agriculture runoff. Approximately 38% of land usage in the Upper Barataria basin is for agriculture (Braud et al. 2006)

Species of sturgeon such as the atlantic sturgeon *Acipenser oxyrhyncus* do not spawn every year (Smith 1985). Sturgeon are a primary source of caviar, and exploitation by the caviar industry is the primary cause for decline of sturgeon stocks. Bowfin may not spawn annually in this population, which decreases the reproductive potential of the population and increases the chance for overexploitation.

The timing and duration of inundation of the floodplain may be another critical factor affecting spawning success (Fontenot et al. 2001). In large temperate rivers, inundation may last for weeks or months as waters slowly rise in the winter and spring (Wantzen et al. 2002). However, the Upper Barataria estuary has daily fluctuations in water level in which the flood plain is not inundated for long periods (Figures 21 and 22). Bowfin require 1 to 6 days to build a nest and deposit eggs (Reighard 1900), 8 to 10 days for larvae to hatch (Reighard 1903), and 7 to 9 days for larvae to absorb the yolk sac while attached to vegetation (Scott and Crossman 1973). Based on these time frames, the time required to complete spawning behavior would be 16 to 25 days. The optimal temperature for spawning activity is 16-19°C (Reighard 1903). Because of variation in water level in the Upper Barataria estuary, the most successful spawning sites during low water periods may be the permanently inundated littoral habitat in the main channel of the bayou.

Competition among females may also occur. More females were collected than males. The sex-ratio, in which females outnumbered males, was unexpected because the

commercial roe fishery targets large females, which can reduce the number of females in the population. Fisheries that target females typically see a decline in the ratio of females to males over time (Hoenig and Hewitt 2005). The actual sex ratio is most likely close to 1:1. The observed sex ratio may be unbalanced because of seasonally dependent behavior differences. Fifty-six percent of bowfin collected from December through early February were female. From late February to the end of March, 76% of bowfin collected were females. Bowfin collected from June through August were predominately (84%) female. Therefore, our collection techniques were potentially biased and may have selected females over males. Collection techniques such as using baited hooks (i.e. hook-and-line and jug lines may have selected for more aggressive feeding females. Habitat partitioning between males and females could occur as well. Difficulty arose in sampling shallow, vegetated areas which may have higher densities of males.

Fewer males in the population results in fewer nests and, therefore, increases the competition among females which may discourage spawning. Typically, there is more than three times the number of males to females at the spawning sites (Scott and Crossman 1973). This is because males stay on the nest whereas females the spawning grounds for only a short period of time to spawn.

Variation in spawning leads to variation in egg production which may result in variable survival from one year to the next. Trippel (1995) defines year class size as the number of young fish produced by a population each year, which can vary based on biological and environmental factors such as egg production, predation, starvation, water temperature, and other hydrological elements. A weak year class in this population in the size range of 420 to 480 mm may exist. Many gears were used to eliminate sampling

bias, and, furthermore, the large number of bowfin collected at smaller and larger size ranges reduces the probability of sampling gear bias. Year class strength can result from poor recruitment. Whereas limitation of spawning and spawning habitat can affect recruitment, additional factors that can effect recruitment to larger sizes include competition for space, food availability, predation, reduced fertilization success, cannibalism, and environmental factors such as floods, droughts, or temperature (Royce 1972; Hilborn and Walters 1992).

For 118 out of 123 female bowfin eggs were fully developed but were never released. Possible causes for non-spawning of mature eggs for fish include overcrowding, shortage of males, pollution, lack of spawning sites, low dissolved oxygen, and insufficient water movement (Rideout et al. 2005). Of these causes, shortage of males, lack of spawning sites, and low dissolved oxygen could be possible causes of non-annual spawning in bowfin. Furthermore, because eggs were fully ripened, conditions were conducive for development and vitellogenesis to occur. But because eggs were never released, non-annual spawning was a result of conditions during the spawning season (Rideout et al. 2005). Non-annual spawning can also be related to survival. A high energetic cost is associated with reproduction and can impact post-spawning survival, and therefore, a trade-off exists with respect to survival and spawning (Rideout et al. 2005). By choosing to spawn when conditions are optimal, fish can increase survival, lifespan, and eventual egg production. Successive years of sampling are needed to determine if non-annual spawning is rare or occurs frequently in this population.

Another explanation of impaired spawning success in bowfin may be related to the presence of environmental pollutants. Reproductive disorders such as infertility, modified reproductive structures, or impaired hormone secretion can result from the introduction of xenobiotic contaminants into the environment. Endocrine disruption from various environmental contaminants can have an effect on the development and maturation of individuals, altering future reproductive function (Guillette et al. 2000). Studies using American alligators as a sentinel species in Florida have found a relationship between pesticide exposure and reproductive abnormalities (Guillette et al. 2000). Agricultural runoff is prominent in the Upper Barataria estuary and may lead to exposure of pollutants to bowfin.

Fecundity

Fecundity estimation is fundamental to understanding the biology and population dynamics of fish. When combined with other reproductive information such as age and size at maturity, spawning fraction, and spawning season, fecundity can be used to estimate spawning stock biomass and eventually recruitment (Murua et al. 2003). Fecundity is influenced by total length, age and weight in many fish species (Healey 1971; Coates 1988; Lobon-Cervia et al. 1997; Love and Johnson 1998; Ferrara 2001). The production of a greater number of eggs by larger and older females increases the chances of reproductive success. Eddy and Surber (1943) reported total fecundity for 533 mm bowfin as 64,000, which is much higher than estimated from this population. The fecundity estimate of a fish of similar size from this population would be less than 20,000 eggs. Davidson (1991) calculated mean fecundity as 36,179 eggs from 29 bowfin from across Louisiana with a mean total length of 599 mm. For this study, mean fecundity was

22,924 eggs from 115 bowfin with a mean total length of 532 mm. Scott and Crossman (1973) report that a 2,268 g female contained 23,600 eggs. A fish of similar weight from this population is calculated to produce approximately 35,000 eggs. Differences in fecundity may be explained by the effect of latitude. When compared to other non-teleost fish, the mean number of eggs per gram of body weight for bowfin (15.2 eggs/g body weight) is higher than those of the alligator gar (4.1 eggs/g body weight) and longnose gar (0.8 eggs/g body weight) but more than the spotted gar (0.1 eggs/g body weight; Ferrara 2001). Thus, bowfin have smaller eggs than gar. Whereas gar produce larger eggs to increase survival, the bowfin have adapted a different strategy, parental care, to increase survival of eggs.

Some studies suggest that fecundity is lower at higher latitudes (Paulson and Smith 1977). Factors in addition to latitude may influence fecundity. Poor condition can reduce the number or size of oocytes and lead to non-annual spawning (Bell et al. 1992). Also, environmental pollutants can lead to reduced fecundity or atresia (Johnson et al. 1998).

Fecundity was estimated by direct enumeration of eggs, but fecundity is also measured using gravimetric methods (Hunter and Goldberg 1980), stereometric methods (Emerson et al. 1990), volumetric methods (Simpson 1951), and automated particle counter methods (Witthames and Walker 1987). Of these methods the gravimetric is probably the most common method, and the automated particle counter method is the least time consuming, allowing for processing of larger sample (Murua et al. 2003).

<u>Egg Diameter</u>

According to Sargent et al. (1987), larger eggs typically have larger yolk sacs which provide more nutrients to the larvae, increasing growth and initial larvae size but may require a longer period for yolk absorption. This can result in lower mortality, faster growth rate, and shorter time to become an adult. As a result, large eggs have an increased likelihood of survival (Knutsen and Tilseth 1985; Buckley et al. 1991; Hutchings 1993). For cod and haddock, larger (total length) fish produce larger eggs (Kjesbu 1989; Hislop 1988). In some cases such as with largemouth bass, larger individuals spawn first, providing the progeny with a longer growing period that can affect over-winter survival (Miranda and Muncy 1987).

Bowfin produce eggs that are slightly elliptical in shape with a size of 2.8 x 2.2 mm (Dean 1916). Mean egg diameter of bowfin from the Upper Barataria estuary was 2.0 mm and included egg measurements from bowfin ranging in size from 362 to 697 mm in total length, collected from December to April. For the caviar industry, the most profitable harvest would be of larger, older bowfin just before spawning in January and February, maximizing egg number, weight, and size.

<u>Age and Growth</u>

Sexual maturity for this population is reached at age 2 for females and males. Age-at-maturity for this study was younger than age-at-maturity reported in Cooper and Schafer (1954) and Cartier and Magnin (1967), whose studies were in Michigan and Canada, respectively, in the northern extent of the range of bowfin. An indicator of an overexploited population can be a decrease in the age of maturity. Lowering of the age of maturity can indicate a response to a decrease in stock size (Trippel 1995; Reed et al.

49

1992). Scott and Crossman (1973) report that sexual maturity occurs between 3 and 5

years at a size of 610 mm total length for female bowfin in Wisconsin. All fish sampled

in the study were mature by age three and a size of 400 mm total length, and the age of

maturity of most fish was two years. A younger age of maturity in this population in

response to a decrease in stock size is unlikely. Bowfin in this population have a longer

growing season than populations in the northern extent of the species' range because of

warmer water temperatures, and therefore, may reach maturity at a younger age

(McDowell 1994).   Growth rates are independent of latitude for some species such as

striped bass *Morone saxatilis*, American shad *Alosa sapidissima*, and mummichog

Fundulus heteroclitus (Connor 1990). A paddlefish *Polyodon spathula* population in

Louisiana that was closed to harvest after overharvest by commercial anglers resulted in a

decrease in fecundity, an increase in egg size, and a reduction in age at maturity (Reed et

al. 1992).

The increase of energy and nutrients on the floodplain from a flood pulse may be

closely tied to increased growth rates fo fish for that year (Bayley 1988; Cone et al. 1986;

Sommer et al. 2001). Gutreuter et al. (1999) observed an increased growth rate in littoral

fishes such as largemouth bass *Micropterus salmoides* and bluegill *Lepomis microchirrus*

when comparing size of otolith growth increments to the magnitude of flood pulses in the

upper Mississippi River. Conversely, in the lower Mississippi River, which has a greatly

reduced floodplain from the construction of levees that are closer to the main channel of

the river, Rutherford et al. (1995) showed that growth of species such as blue catfish

Ictalurus furcatus, channel catfish *Ictalurus punctatus*, freshwater drum *Aplodinotus

grunniens*, and gizzard shad *Dorosoma cepedianum* was the result of main channel

primary and secondary production rather than from inputs from the floodplain. DeAngilis et al. (1997) observed greater fish production with increased flood duration in the freshwater marshes of southern Florida. For catfishes, floodplain inundation may not provide an energetic benefit if water temperatures are not optimal for active feeding (Schramm et al. 2000).

Assigning ages to fish using hard structures such as gular plates or otolith requires age validation. Acceptable techniques for validating ages include mark-recapture or use of known age fish (Beamish and MacFarlane 1983). In this study fish ages were not validated. Multiple readings of gular plates by three individuals detected any discrepancies in the assignment of ages. Percent agreement between agers is a traditional measurement of precision, but its effectiveness can vary based upon the number of year-classes in the fishery (Campana et al. 1995; Beamish and Fournier 1981).

Life History Classification

Life history information is essential for constructing population models that include fish ages and fecundity, but this information is usually lacking in newly exploited species (King and McFarlane 2003). Bowfin are not newly exploited, but rather are not of primary management concern. In general, biologists have most commonly associated the life history of fishes with two main strategies or endpoints on the r-K continuum (MacArthur and Wilson 1967). The r-strategists are usually short-lived, small in size, mature early, produce many offspring with low survival, have minimal parental care, and increase rapidly until reaching carrying capacity at which point they decrease rapidly. K-strategists are long-lived, large in size, grow slowly, mature later, produce few offspring with higher survival, exhibit parental care, and are usually at densities near or around

51

carrying capacity (Smith and Smith 2001). Fish do not conform well to this model, and it has been suggested that a third stage exists that is characterized by fish that are long-lived, large in size, and mature early (Kawasaki 1983). Winemiller and Rose (1992) defined three similar life history strategies with similar endpoints using a triangular continuum. These endpoints are (1) small, rapidly maturing, short lived fishes (opportunistic), (2) highly fecund fishes with long life spans (periodic), and (3) fishes of intermediate size that usually exhibit parental care and produce fewer but larger offspring (equilibrium). Particular life history strategies are thought to have evolved in response to environmental conditions resulting in life history strategies that maximize reproductive success under environmental constraints (Stearns 1976).

The life history strategy of bowfin does not conform to one specific strategy of the trilateral gradient but instead is intermediate between two strategies. The life history strategy of bowfin lies between periodic and equilibrium strategists and is similar to the life history strategy of other non-teleost species such as gar, paddlefish, and sturgeon. Ferrara (2001) defined gars as intermediate-periodic life-history strategists. This is the strategy that most closely reflects the life history strategy of bowfin. Bowfin spawning behavior is similar to that of other medium-sized fishes that have seasonal spawning, large batches of eggs, and male nest guarding such as *Ameirus* spp. and *Lepomis* spp. Although bowfin life history strategy lies between the periodic and equilibrium strategies, the extended period of parental care exhibited by the males place bowfin closer to the equilibrium life history strategy. Therefore, survival of larval and juvenile bowfin is not only tied to habitat condition but also to the condition of the adult male (Winemiller and Rose 1992).

Summary of Life History Characteristics of Bowfin

This study quantified many life history traits for a single population of bowfin. Female bowfin are longer-lived than are male bowfin. Females spawn in the spring when water temperatures exceed 14°C, from mid-February to early March, but spawning may not occur annually. Bowfin fecundity increases with the size and age of the female with a mean of about 23,000 eggs. Egg size during the spawning season is approximately 2.0 mm. For this population the growth coefficient (k) is 0.075 and is considered to be a slow growth rate. The maximum theoretical length (L_∞) is 1154 mm; and the time in which the length is zero (t_0) is 3.58. Bowfin mature by age 2, and maximum age for bowfin is 10 years.

Management Considerations

Bowfin grow quickly and mature early, producing many large eggs, spawning during late February and early March when the water temperatures exceed 14°C. The life history characteristics are consistent with a species that can support a fishery. However, current harvest strategies target larger and older females which are the most fecund and probably the most productive spawners. Harvest of large bowfin may eventually result in fewer and smaller bowfin if exploitation is high. Harvesting of larger fish, which produce many eggs, puts the burden of future production on smaller, less fecund individuals which may be incapable of maintaining stock size (Trippel 1995). Rates of harvest or exploitation for this population are unknown. Quantification of exploitation is necessary to determine if overharvest is occurring.

An additional concern is that bowfin in this population may not spawn on an annual basis if conditions are not conducive to spawning. Non-annual spawning can

increase the risk for overexploitation by anglers and has occurred in sturgeon. Sturgeon

stocks worldwide have decreased due to both overexploitation and environmental

degradation. For example, the reported catch for world sturgeon stocks for 1982 was

about 28,000 tons but decreased to less than 2,000 tons by 1999 (Billard and Lecointre

2001). The assumption that fish above a certain age or size spawn annually may be

incorrect and can be problematic because spawning biomass is frequently used in

developing management strategies (Rideout et al. 2005). Non-annual spawning changes

the reproductive potential for spawners, and, as a result, spawning biomass becomes a

poor predictor of the potential reproduction of the population (Marshall et al. 2003).

Current management strategies for bowfin in southeast Louisiana provide

individuals the opportunity to spawn at least once before they are subjected to harvest.

However, if non-annual spawning is occurring and environmental conditions are not

acceptable for spawning for multiple years, large bowfin that are harvested from the

population may have never successfully spawned. Therefore, no new individuals are

added to the population whereas the largest spawners are removed. Populations of

bowfin would decline, and populations would require time to rebuild since smaller, less

fecund spawners would rebuild the population. Adapting management strategies to

account for non-annual spawning would be conducive to maintaining population size and

to provide for a sustainable fishery.

The absence of historical data on this bowfin population makes it difficult to

determine if it is healthy or "stressed". A "stressed" population is defined as one that has

undergone a substantial decline in size (Shuter 1990). The population of bowfin in

southeast Louisiana is still rebuilding from low levels prior to regulation in 1991.

Continued monitoring is necessary to determine if the fishery can be sustained at current levels of exploitation.

Further Research

Additional bowfin research is needed in many areas. Estimating the level of exploitation allows managers to determine the effects of fishing on recruitment and to determine at what levels of exploitation a sustainable fishery can exist. Fishing effort is considered excessive when it results in the depletion of commercial stocks and threatens sustainability (Bailey 1987).

Successive years of sampling can evaluate the periodicity of non-annual spawning. Estimates of the periodicity of non-annual spawning can be useful for development and adjustment of population dynamic models. Estimates of the frequency of non-annual spawning can be combined with data on water quality, water stage, and rainfall to predict future population sizes.
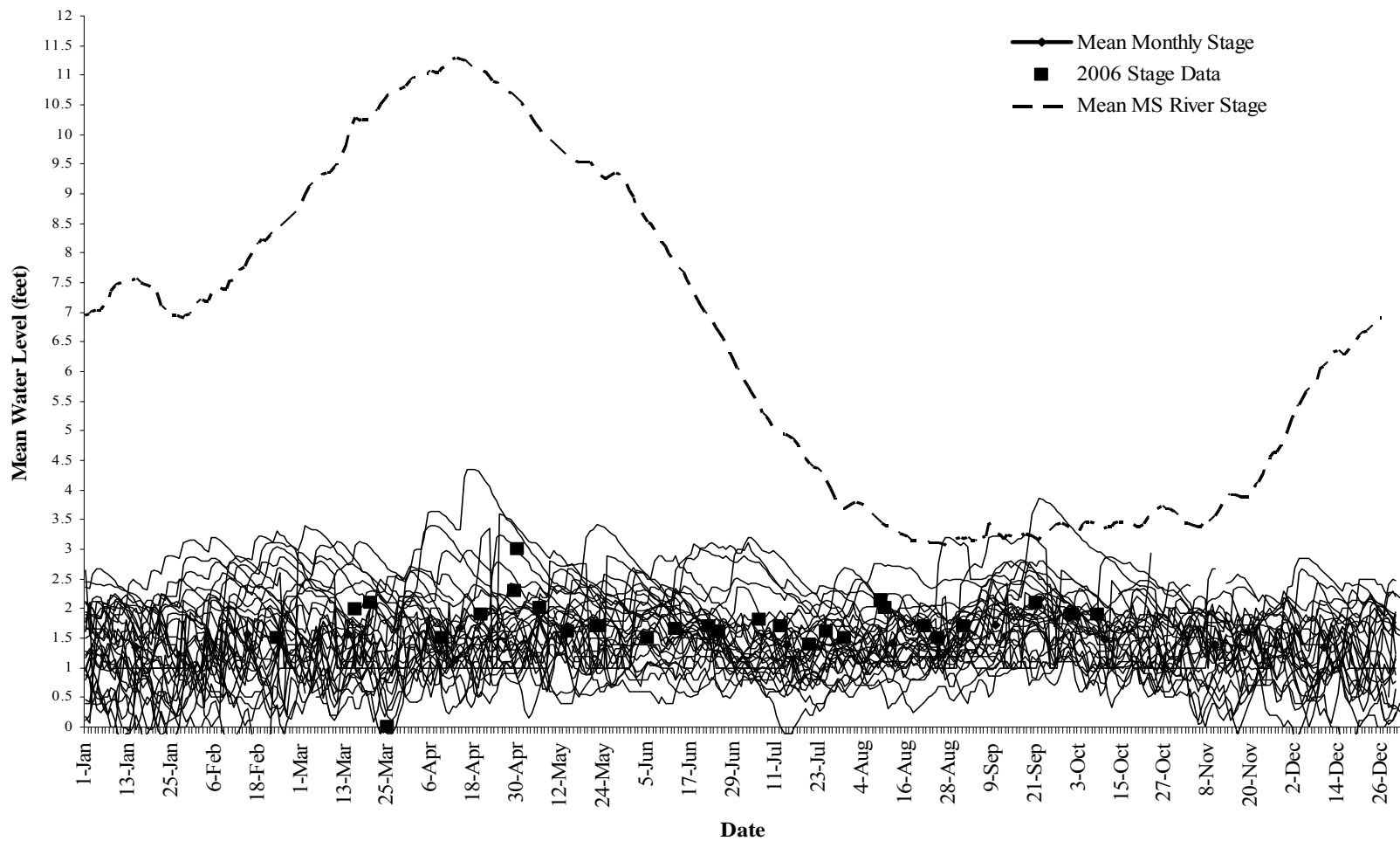
Figure 21. Mean daily water stage level for Upper Barataria estuary relative to the mean daily Mississippi River stage from 1959 to 1992 (USEPA 2005).
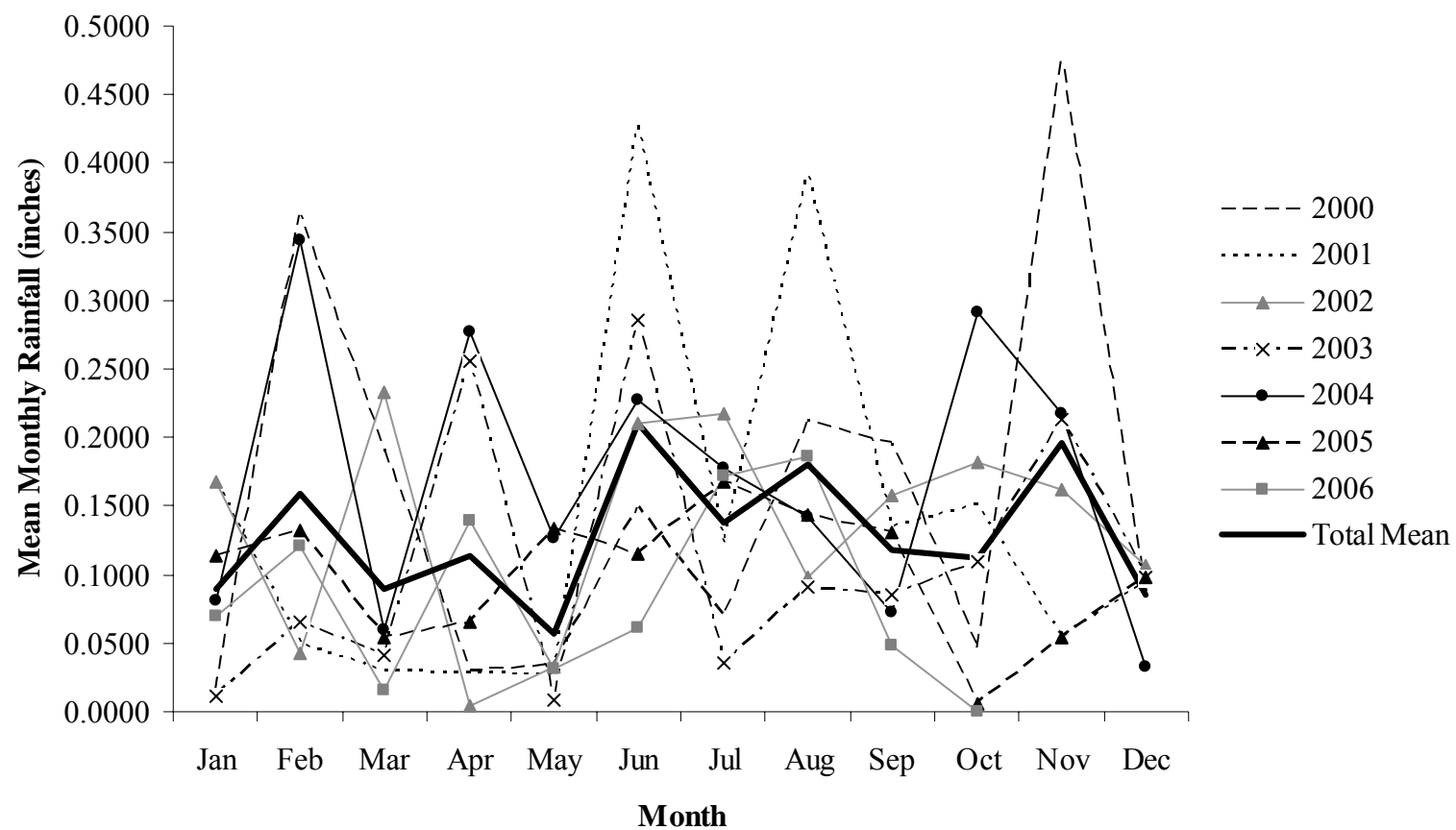
Figure 22. Mean monthly rainfall data from 2000-2006 from Donaldsonville, LA, west of Upper Barataria estuary (USGS 2006).

RECOMMENDATIONS

Reestablishment of the historical connection of the Upper Barataria estuary to the Mississippi River would provide an annual flood pulse to this system and restore the historic structure and function of this swamp. Restoration of natural swamp conditions can aid populations of fish such as bowfin that can use floodplain habitat for spawning and foraging. Restoration strategies such as freshwater diversions can provide Mississippi River water to the Upper Barataria estuary. Diversions should be flowed in accordance with Mississippi River stage. For example, pumping one percent of river water when the Mississippi River reaches flood stage but not pumping water when the river is low would simulate a natural flood pulse. Restoration of this type will allow for natural variation to occur in the flood pulse, preserving species diversity within the area.

Development of population models using the life history traits quantified in this study, in combination with exploitation rates, can be used to prevent overharvesting of bowfin and can be used to evaluate the current management strategies. Additionally, population modeling should account for non-annual spawning. Continual monitoring of the population can determine the periodicity of non-annual spawning. Management strategies and harvest regulations should be flexible to account for the numbers of spawners in the population. The numbers of spawners will vary based upon the level of harvest of females and the periodicity of non-annual spawning.

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Appendix I. Raw data for bowfin collected from 20 September 2005 to 5 September 2006 with collection date, total length (mm), weight (g), left and right gonad weight (g), sex, fecundity (total number of eggs), mean egg diameter (mm), GSI from the Upper Barataria estuary. TL=Total length, Wt=Weight

Fish ID	Collection Date (year month day)	Age	TL	Wt	Left Gonad Wt	Right Gonad Wt	Sex	Egg #	Mean Egg Diameter	GSI
38	20050920	6	600	.	12.2	12.3	F	.	.	.
39	20050920	6	580	.	1	1	M	.	.	.
40	20050920	4	521	.	4.6	4.1	F	.	.	.
41	20050920	5	580	.	1.2	1.2	M	.	.	.
42	20050920	5	595	.	11.1	12.3	F	.	.	.
43	20050920	4	575	2100	16.8	12.7	F	.	.	1.4
44	20050928	4	618	.	15.3	16	F	.	.	.
45	20050922	4	513	1300	0.6	0.6	M	.	.	0.1
46	20050928	3	474	.	1.8	2.1	M	.	.	.
47	20050929	3	398	.	1.5	1.5	M	.	.	.
48	20050928	5	646	.	10.6	11.8	F	.	.	.
49	20050922	5	621	2100	11.6	11.9	F	.	.	1.1
50	20051003	3	458	.	0.5	0.3	M	.	.	.
1001	20051212	3	418	600	7.4	6.6	F	6200	.	2.3
1002	20051212	3	400	500	3.9	3.6	M	.	.	1.5
1003	20051212	5	551	1500	54	80	F	.	.	8.9
1004	20051212	3	387	400	2.1	2.7	M	.	.	1.2
1005	20051206	4	527	1100	4	4.1	M	.	.	0.7
1006	20051206	5	592	1700	45	44.4	F	27150	.	5.3
1007	20051206	6	562	1400	4	4.3	M	.	.	0.6
1008	20051206	6	579	1800	33.4	32.3	F	30360	.	3.7
1009	20051206	7	698	3100	100.9	90.2	F	66700	.	6.2
1010	20051206	4	597	1900	62.2	61.9	F	47110	.	6.5
1011	20051206	5	601	1800	32.7	34.1	F	20750	.	3.7
1012	20051206	5	523	1100	3.9	3.6	M	.	.	0.7
1013	20051206	5	600	1800	45.6	49.2	F	36510	.	5.3
1014	20051206	6	600	2200	87.2	76.4	F	55730	.	7.4
1015	20051206	6	591	1800	47	37.9	F	28270	.	4.7
1026	20051212	3	448	700	18.1	16.3	F	13520	.	4.9
1027	20051212	4	489	800	6.1	5.4	M	.	.	1.4
1028	20051212	6	597	1700	52.6	50	F	31131	.	6.0
1029	20051212	5	527	1200	8.2	7.2	M	.	.	1.3
1030	20051212	2	372	400	3.7	2.6	M	.	.	1.6
1031	20051212	2	382	500	3.2	2.6	M	.	.	1.2
1032	20051212	2	391	500	3.4	3.1	M	.	.	1.3
1033	20051212	5	522	1300	7.5	10.3	M	.	.	1.4

Fish ID	Collection Date (year month day)	Age	TL	Wt	Left Gonad Wt	Right Gonad Wt	Sex	Egg #	Mean Egg Diameter	GSI
1034	20051212	2	388	500	7	4.2	F	3229	.	2.2
1035	20051212	4	514	1100	9.4	8.2	M	.	.	1.6
1036	20051212	3	423	600	5	2.9	F	4020	.	1.3
1037	20051111	2	379	500	4.2	3.8	F	.	.	1.6
1038	20051111	3	432	800	4.5	4	M	.	.	1.1
1039	20051111	3	431	600	4.7	3.8	M	.	.	1.4
1040	20051028	2	362	400	4.6	3.5	F	9390	.	2.0
1041	20051017	.	598	2300	31.2	31	F	.	.	2.7
1042	20051017	.	626	2300	27.7	27.8	F	34780	.	2.4
1043	20051017	5	632	2100	28.2	28	F	44140	.	2.7
1044	20051014	1	366	500	0.1	0.1	M	.	.	0.0
1045	20051014	5	660	2900	22.5	53	F	.	.	2.6
1046	20051014	4	577	1800	5.2	17	M	.	.	1.2
1047	20051014	6	657	2600	11.8	7.5	M	.	.	0.7
1048	20050922	4	556	1800	1.9	1.2	M	.	.	0.2
1051	20051215	4	498	700	30.4	25.9	F	16060	1.78	8.0
1052	20051215	3	369	400	7.9	7.8	F	6220	1.76	3.9
1053	20051215	3	414	500	8.7	6.7	F	8150	1.44	3.1
1054	20051214	2	387	400	9.7	7.6	F	7110	1.46	4.3
1055	20051214	2	393	400	9.7	6.5	F	6160	1.49	4.1
1056	20051214	2	408	500	6	5.9	F	5090	1.26	2.4
1057	20051214	4	533	1300	8.4	7.9	M	.	.	1.3
1058	20051214	2	367	400	9.4	3.2	F	4960	1.38	3.2
1059	20051214	2	409	500	2.4	2.7	M	.	.	1.0
1060	20051214	2	388	400	6.8	5.2	F	3630	1.46	3.0
1061	20051214	2	367	300	5.3	4.6	F	4460	1.37	3.3
1062	20051214	2	400	400	3.1	3.1	M	.	.	1.6
1063	20051214	4	508	1000	6.8	5.8	M	.	.	1.3
1064	20051214	5	649	2400	113.7	120.8	F	55020	2.13	9.8
1065	20051214	4	419	500	1.8	1.8	M	.	.	0.7
1066	20051214	3	448	600	13.9	10.1	F	7590	1.48	4.0
1067	20051214	3	387	400	13	9.5	F	8280	1.57	5.6
1068	20051214	4	481	900	41.3	30.8	F	17820	1.99	8.0
1069	20051214	1	379	300	2.5	2.1	M	.	.	1.5
1070	20051214	5	481	800	4.9	4.8	M	.	.	1.2
1076	20051215	3	380	300	11.1	10.5	F	11330	1.46	7.2
1077	20060111	2	404	400	2	3.1	M	.	.	1.3
1078	20060111	5	495	1000	6.6	5.6	M	.	.	1.2
1079	20060111	4	518	1100	8.3	7.1	M	.	.	1.4
1080	20060111	2	410	400	10.6	8.1	F	6820	1.69	4.7
1081	20060111	2	405	400	3.4	3.3	M	.	.	1.7
1082	20060111	6	579	1600	62.9	62.1	F	22140	2.23	7.8
1083	20060111	3	455	700	39.1	28.7	F	14070	2.09	9.7
1084	20060111	4	414	400	1.7	1.7	M	.	.	0.9
1085	20060111	2	420	500	2.4	2.8	M	.	.	1.0
1086	20060111	3	388	300	3.1	2.9	M	.	.	2.0
1087	20060111	3	416	500	24.9	21.1	F	13160	1.82	9.2

Fish ID	Collection Date (year month day)	Age	TL	Wt	Left Gonad Wt	Right Gonad Wt	Sex	Egg #	Mean Egg Diameter	GSI
1089	20060111	4	456	700	3.8	3.6	M	.	.	1.1
1090	20060111	3	427	600	3.4	3.2	M	.	.	1.1
1091	20060111	3	463	700	29	19.5	F	13000	1.82	6.9
1092	20060111	2	408	500	11.4	11.3	F	6620	1.96	4.5
1093	20060111	3	401	400	6.2	5.5	F	5090	1.61	2.9
1094	20060120	4	505	1038	6.9	6.9	M	.	.	1.3
1095	20060120	5	577	1600	97	97.5	F	32790	2.24	12.2
1097	20060124	7	673	2870	176.6	168.6	F	72500	2.61	12.0
1098	20060124	6	631	2540	165.1	148.5	F	63340	2.46	12.3
1099	20060124	6	570	2000	93.6	83.1	F	35550	2.42	8.8
1100	20060124	5	527	1330	7.9	8.6	M	.	.	1.2
1101	20060124	4	409	600	20.8	21.1	F	8960	2.2	7.0
1102	20060124	5	575	1590	93.8	91.3	F	28570	2.33	11.6
1103	20060124	4	516	1230	12	9.3	M	.	.	1.7
1104	20060124	6	557	1490	9.6	11.3	M	.	.	1.4
1105	20060124	5	506	1130	8.1	9.5	M	.	.	1.6
1106	20060124	4	493	1150	8.7	7.3	M	.	.	1.4
1107	20060124	5	561	1420	11.8	10.9	M	.	.	1.6
1108	20060124	5	569	1450	81.1	82.5	F	31710	2.28	11.3
1109	20060124	5	542	1440	79.4	71.4	F	23990	2.42	10.5
1110	20060124	3	405	550	4.5	3.8	M	.	.	1.5
1111	20060124	3	376	420	9	7	F	4570	1.72	3.8
1120	20060221	4	494	1000	9	10.5	M	.	.	2.0
1121	20060221	5	510	1100	43	47.5	F	12250	.	8.2
1122	20060221	6	651	2500	43	41.5	F	14250	.	3.4
1123	20060210	6	612	1700	87.7	105.9	F	31480	2.46	11.4
1124	20060210	5	525	1100	68.7	66.6	F	16670	2.43	12.3
1125	20060207	3	396	497	4.3	3.9	M	.	.	1.6
1126	20060207	3	394	483	2.9	2.5	M	.	.	1.1
1127	20060207	5	572	1500	104.1	98.6	F	30000	2.47	13.5
1128	20060207	3	391	518.5	19.2	24	F	9530	2.04	8.3
1129	20060207	3	406	592.5	3.7	3.2	M	.	.	1.2
1130	20060207	6	539	1400	92.2	90.1	F	27110	2.52	13.0
1131	20060207	7	664	2500	167.5	163.8	F	44600	2.5	13.3
1132	20060207	4	498	900	9.6	9.6	M	.	.	2.1
1133	20060207	5	527	1200	70.9	64.6	F	22860	2.47	11.3
1357	20060501	7	640	2850	49.17	64.87	F	.	.	4.0
1358	20060501	7	657	3050	95.91	86.74	F	.	.	6.0
1359	20060501	5	611	1950	20.57	21.93	F	.	.	2.2
1360	20060501	5	556	1720	23.57	22.39	F	.	.	2.7
1361	20060501	5	531	1450	24.54	20.2	F	.	.	3.1
1362	20060501	4	528	1450	17.89	11.64	F	.	.	2.0
1363	20060501	1	316	271	0.13	0.12	M	.	.	0.1
1364	20060501	9	682	3600	80	77	F	.	.	4.4
1365	20060509	5	573	1900	21.57	18.59	F	.	.	2.1
1366	20060509	3	420	684	6.02	6	F	.	.	1.8
1367	20060509	5	565	1950	26.09	24.94	F	.	.	2.6

Fish ID	Collection Date (year month day)	Age	TL	Wt	Left Gonad Wt	Right Gonad Wt	Sex	Egg #	Mean Egg Diameter	GSI
1369	20060509	4	451	785.5	0.65	0.62	M	.	.	0.2
1370	20060509	4	508	1300	11.63	11.7	F	.	.	1.8
1371	20060509	5	577	1900	24.84	18.14	F	.	.	2.3
1372	20060509	1	318	284	0.17	0.23	M	.	.	0.1
1373	20060509	2	376	462.5	1.71	1.87	F	.	.	0.8
1374	20060509	4	488	1100	12.56	12.18	F	.	.	2.2
1375	20060509	2	380	441	2.56	2.45	F	.	.	1.1
1376	20060509	3	422	635	6.18	6.08	F	.	.	1.9
1377	20060524	7	639	2850	20.37	17.14	F	.	.	1.3
1378	20060524	7	629	2600	27.74	24.06	F	.	.	2.0
1379	20060524	6	610	2700	32.07	28.89	F	.	.	2.3
1380	20060524	5	541	1400	16.57	13	F	.	.	2.1
1381	20060524	6	658	2950	17.87	16.78	F	.	.	1.2
1382	20060614	4	518	1300	10.43	9.69	F	.	.	1.5
1383	20060614	4	501	1150	8.1	4.79	F	.	.	1.1
1384	20060614	5	579	1800	12.89	14.21	F	.	.	1.5
1385	20060614	2	366	382	2	1.68	F	.	.	1.0
1386	20060614	7	665	3150	25.12	26.43	F	.	.	1.6
1387	20060614	7	657	3450	35.13	32.35	F	.	.	2.0
1388	20060614	2	401	579.5	4.26	2.96	F	.	.	1.2
1389	20060614	7	591	2100	13.92	16.62	F	.	.	1.5
1390	20060626	6	591	2500	7.09	9.19	F	.	.	0.7
1391	20060626	3	379	486	0.22	0.25	M	.	.	0.1
1392	20060626	6	577	2110	14.08	15.37	F	.	.	1.4
1393	20060626	6	590	1820	11.54	12.31	F	.	.	1.3
1394	20060626	2	384	485	2.84	2.37	F	.	.	1.1
1395	20060626	5	483	1170	9.11	8.56	F	.	.	1.5
1396	20060626	2	377	481.5	0.27	0.09	F	.	.	0.1
1397	20060707	8	688	3410	24.5	25	F	.	.	.
1398	20060713	2	398	527	0.22	0.21	M	.	.	.
1399	20060713	7	694	3125	14.03	14.9	F	.	.	.
1400	20060713	4	521	1245	7.53	7.04	F	.	.	.
1405	20060406	6	635	2640	144.32	118.49	F	46010	2.25	10.0
1406	20060406	5	517	1320	45.89	25.22	F	13890	2.08	5.4
1407	20060406	7	625	2200	99.76	114.63	F	30550	2.33	9.7
1408	20060406	5	535	1440	49.22	26.94	F	13040	2.01	5.3
1409	20060406	5	539	1450	70.39	73.26	F	22820	2.29	9.9
1410	20060406	7	697	3260	139.41	147.41	F	41620	2.09	8.8
1411	20060406	5	579	1870	120.78	117.9	F	34040	2.1	12.8
1412	20060406	5	572	1670	87.85	85.38	F	27720	.	10.4
1413	20060406	5	568	1520	76.83	66.58	F	19970	2.18	9.4
1414	20060406	4	552	1600	87.77	64.09	F	22950	1.97	9.5
1415	20060406	5	559	1730	92.34	93.4	F	36620	2.03	10.7
1416	20060406	.	637	2660	134.29	117.09	F	35200	2.23	9.5
1417	20060406	6	572	1670	9.74	9.53	M	.	.	1.2
1418	20060406	5	601	1870	108.91	88.77	F	31640	2.09	10.6
1419	20060406	5	604	1990	107.87	98.29	F	.	2.16	10.4

Fish ID	Collection Date (year month day)	Age	TL	Wt	Left Gonad Wt	Right Gonad Wt	Sex	Egg #	Mean Egg Diameter	GSI
1421	20060406	4	515	1390	37.86	35.72	F	16390	1.92	5.3
1422	20060406	5	560	1610	80.98	68.41	F	29280	2.17	9.3
1423	20060406	5	580	1870	72.48	65.18	F	25220	2.33	7.4
1424	20060406	4	525	1380	41	41.5	F	12970	.	6.0
1434	20060326	2	377	490	1.51	0.9	M	.	.	0.5
1435	20060326	3	387	580	1.48	1.73	M	.	.	0.6
1436	20060326	3	383	520	1.64	1.36	F	.	.	0.6
1437	20060326	4	525	1360	5.08	4.18	M	.	.	0.7
1438	20060326	4	528	1460	76.94	58.13	F	.	.	9.3
1439	20060326	4	549	1730	84.24	72.78	F	.	.	9.1
1440	20060326	4	396	580	11.4	7.14	F	4050	.	3.2
1441	20060326	5	593	2080	73.89	114.47	F	.	.	9.1
1442	20060326	4	489	1010	3.54	3.19	M	.	.	0.7
1443	20060326	3	374	450	5.13	5.23	F	.	.	2.3
1444	20060326	3	536	1340	60.1	51.42	F	.	.	8.3
1445	20060326	2	356	380	1.03	0.95	M	.	.	0.5
1446	20060326	6	608	1980	110.52	93.74	F	.	.	10.3
1447	20060326	6	574	1720	48.1	76.42	F	.	.	7.2
1448	20060326	6	586	2110	110.81	68.98	F	.	.	8.5
1449	20060326	3	485	1130	1.5	1.5	M	.	.	0.3
1450	20060326	3	457	890	5.64	4.66	M	.	.	1.2
1451	20060324	4	485	1040	13.98	13.04	F	7770	.	2.6
1452	20060321	3	397	.	.	.	.	.	.	.
1453	20060321	8	695	3620	228.11	198.26	F	.	2.17	11.8
1454	20060321	2	368	400	4.63	4.22	F	1900	1.65	2.2
1455	20060321	2	383	460	1.9	1.71	F	.	.	0.8
1456	20060321	3	375	490	12.26	8.5	F	3950	1.94	4.2
1457	20060321	2	380	500	13.16	9.57	F	4800	1.89	4.5
1458	20060321	4	521	1250	76.2	78.06	F	20860	1.98	12.3
1459	20060321	2	474	960	2	2.06	F	.	.	0.4
1460	20060321	5	559	1590	98.43	91.01	F	24600	2.05	11.9
1461	20060321	3	440	790	21.37	20.83	F	9000	2.1	5.3
1462	20060321	3	407	590	23.5	21	F	6420	1.65	7.5
1463	20060321	2	387	540	1.57	1.7	F	.	.	0.6
1464	20060321	3	399	540	10.99	7.68	F	3930	1.82	3.5
1465	20060321	2	378	420	7.41	8.19	F	3550	1.81	3.7
1466	20060321	5	515	1290	9.24	7.8	M	.	.	1.3
1467	20060321	6	544	1500	70.09	70.5	F	16000	1.95	9.4
1468	20060321	4	495	1120	72.34	62.06	F	14100	1.96	12.0
1469	20060321	5	483	980	7.33	7.96	M	.	.	1.6
1470	20060321	4	554	1440	9.89	9.5	M	.	.	1.3
1471	20060317	2	351	370	1.5	0.5	M	.	.	0.5
1472	20060317	3	417	600	3	3	M	.	.	1.0
1473	20060317	2	388	490	1	0.5	M	.	.	0.3
1474	20060317	4	416	660	30	23	F	4120	1.88	8.0
1475	20060317	3	366	430	11.5	8	F	4670	2.15	4.5
1476	20060317	5	552	1420	8	7.5	M	.	.	1.1

Fish ID	Collection Date (year month day)	Age	TL	Wt	Left Gonad Wt	Right Gonad Wt	Sex	Egg #	Mean Egg Diameter	GSI
1478	20060317	2	362	380	4	3.5	F	2120	1.46	2.0
1479	20060317	3	359	410	13	12.5	F	5350	1.71	6.2
1480	20060317	7	665	2870	170	168.5	F	39700	2.75	11.8
1481	20060317	2	432	770	28	26.5	F	10500	.	7.1
1482	20060317	2	411	590	7	7	F	4210	1.99	2.4
1483	20060317	1	388	530	10	9.5	F	.	1.88	3.7
1484	20060317	7	629	2400	125	133	F	34040	1.63	10.8
1485	20060317	8	681	3260	224.5	221	F	.	2.06	13.7
1486	20060223	5	480	899.5	9.5	10	M	.	.	2.2
1487	20060223	5	512	1100	49.5	50	F	14130	.	9.0
1488	20060223	6	657	2450	178	180	F	54960	2.09	14.6
1489	20060223	7	655	2600	148.5	175	F	40400	2.3	12.4
1490	20060223	5	593	1950	93	95.5	F	27490	.	9.7
1491	20060223	7	587	1950	147	126	F	.	1.58	14.0
1492	20060223	7	647	2700	136.5	121.5	F	34960	.	9.6
1493	20060223	9	703	3000	139	69	F	24710	.	6.9
1494	20060223	7	660	2400	148.5	140.5	F	35140	.	12.0
1495	20060223	5	590	2050	106	98.5	F	29840	.	10.0
1496	20060223	6	616	2300	138	143.5	F	34880	.	12.2
1497	20060223	5	604	1950	128	112.5	F	36260	.	12.3
1498	20060223	6	665	2550	148	130	F	37540	1.71	10.9
1499	20060223	9	680	2900	179.5	169.5	F	49250	2.13	12.0
1500	20060223	7	631	2400	144.5	131.5	F	.	2.19	11.5
1501	20060410	10	736	4610	241.5	244	F	69770	.	10.5
1502	20060410	6	570	1790	78.97	102.08	F	30140	.	10.1
1503	20060314	6	642	.	.	.	F	22280	.	.
1504	20060314	5	572	.	.	.	F	.	.	.
1505	20060410	6	650	2860	122.82	130.86	F	.	.	8.9
1506	20060410	7	617	2570	30.41	216	F	35980	.	9.6
1507	20060410	7	618	3050	186.5	160	F	46650	.	11.4
1508	20060410	1	357	420	1.53	1.43	F	.	.	0.7
1509	20060410	4	451	890	20.18	18.07	F	15820	.	4.3
1510	20060410	6	524	1390	68.79	66.44	F	22250	.	9.7
1511	20060410	4	528	1420	5.09	4.37	M	.	.	0.7
1701	20060713	3	520	1310	7.89	7.06	F	.	.	1.1
1702	20060726	6	580	1450	9.69	7.98	F	.	.	1.2
1703	20060726	4	543	1250	6.08	5.34	F	.	.	0.9
1704	20060726	5	555	1525	7.85	7.77	F	.	.	1.0
1705	20060726	1	344	339.5	1.48	1.39	F	.	.	0.8
1706	20060726	2	351	351	0.2	0.2	M	.	.	0.1
1707	20060726	4	515	1150	6.41	7.67	F	.	.	1.2
1708	20060726	4	480	967	0.65	0.47	M	.	.	0.1
1709	20060726	2	354	343	0.15	0.12	M	.	.	0.1
1710	20060810	7	632	2360	12.78	14.3	F	.	.	1.1
1711	20060810	5	592	2055	8.77	10.08	F	.	.	0.9
1712	20060810	7	644	2600	12.93	14.46	F	.	.	1.1
1713	20060810	3	467	819	0.42	0.5	M	.	.	0.1

Fish ID	Collection Date (year month day)	Age	TL	Wt	Left Gonad Wt	Right Gonad Wt	Sex	Egg #	Mean Egg Diameter	GSI
1715	20060810	3	385	469	1.85	1.64	F	.	.	0.7
1716	20060810	2	374	369	1.52	1.65	F	.	.	0.9
1717	20060810	3	477	450	0.53	0.52	M	.	.	0.2
1719	20060905	2	436	625.5	0.17	0.24	M	.	.	0.1
1720	20060905	2	460	773.5	0.27	0.33	M	.	.	0.1
1721	20060905	6	532	1520	7.97	5.9	F	.	.	0.9
1722	20060905	4	511	1052	3.95	3.17	F	.	.	0.7
1723	20060905	5	523	1050	0.56	0.46	M	.	.	0.1
1724	20060905	5	506	1175	6.28	6.1	F	.	.	1.1
1725	20060905	5	567	1650	10.58	9.4	F	.	.	1.2
1726	20060905	3	412	535	5.17	4.28	F	.	.	1.8
1727	20060905	4	511	1025	0.38	0.36	M	.	.	0.1
1728	20060905	2	591	880	0.49	0.51	M	.	.	0.1
1729	20060905	2	395	428	0.19	0.17	M	.	.	0.1
1503a	20060410	4	569	1660	84.77	78.38	F	.	.	9.8
1504a	20060410	6	573	1700	73.86	77.73	F	19180	.	8.9

Appendix II. Number of each fish species caught and catch per unit of effort (CPUE) from all collection trip from 20 September 2005 to 5 September 2006 from the Upper Barataria estuary.

Species	# Caught	Gear	CPUE(#/hr)
Bowfin	104	Gill Net	0.246
Bowfin	75	Hook and Line	1.316
Bowfin	2	Jugline	
Alligator Gar	2	Gill Net	0.060
Spotted Gar	335	Gill Net	0.803
Blue catfish	6	Gill Net	0.063
Channel Catfish	19	Gill Net	0.069
Common Carp	11	Gill Net	0.068
Gizzard Shad	126	Gill Net	0.396
Striped Mullet	2	Gill Net	
Largemouth Bass	4	Gill Net	0.045
Bluegill	6	Gill Net	0.034
Redear Sunfish	2	Gill Net	
White Crappie	22	Gill Net	0.080
Yellow Bass	9	Gill Net	0.083
Yellow Bullhead	11	Gill Net	0.098

APPENDIX III

Appendix III. Rainfall data from the USGS precipitation gage near Donaldsonville, Louisiana from 2000-2006.

Month	2000	2001	2002	2003	2004	2005	2006	Total Mean
Jan	0.02	0.17	0.17	0.01	0.08	0.11	0.07	0.09
Feb	0.36	0.05	0.04	0.06	0.34	0.13	0.12	0.16
Mar	0.19	0.03	0.23	0.04	0.06	0.05	0.02	0.09
Apr	0.03	0.03	0.00	0.26	0.28	0.07	0.14	0.11
May	0.03	0.03	0.03	0.01	0.13	0.13	0.03	0.06
Jun	0.15	0.43	0.21	0.28	0.23	0.12	0.06	0.21
Jul	0.07	0.12	0.22	0.04	0.18	0.17	0.17	0.14
Aug	0.21	0.39	0.10	0.09	0.14	0.14	0.19	0.18
Sep	0.20	0.13	0.16	0.08	0.07	0.13	0.05	0.12
Oct	0.04	0.15	0.18	0.11	0.29	0.01	0.00	0.11
Nov	0.47	0.05	0.16	0.21	0.22	0.05		0.20
Dec	0.08	0.10	0.11	0.10	0.03	0.10		0.09
Average	0.16	0.14	0.13	0.11	0.17	0.10	0.08	

BIOGRAPHICAL SKETCH

Johnathan Davis was born on July 15, 1980, in Memphis, Tennessee. After graduating from Houston High School in Germantown, Tennessee in 1998, Johnathan attended Mississippi State University. Johnathan graduated from Mississippi State University in May of 2003 with a B.S. in Wildlife and Fisheries Science with an emphasis in Fisheries Science. After graduating, Johnathan worked for the Mississippi State University Department of Wildlife and Fisheries where he conducted research on largemouth bass under Dr. Harold Schramm, Jr. Johnathan then moved to the Mississippi Gulf Coast to work for the Mississippi State University Science and Technology Research Center at the Stennis Space Center, conducting research on alligator gar and artificial reefs under Dr. Wendell Lorio. Johnathan then continued his education by enrolling in the graduate program in Marine and Environmental Biology at Nicholls State University. Johnathan conducted research on the life history of bowfin. While at Nicholls State, Johnathan served as the vice-president and president of the Biology Society, a student organization, and was inducted into the Phi Kappa Phi Honor Society. After graduation in the Fall of 2006, Johnathan will enroll in the Ph.D. program in the Department of Biology at Tennessee Technological University.

CURRICULUM VITAE

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EDUCATION

M.S. Marine and Environmental Biology, Fall 2006, Nicholls State University, Thibodaux, Louisiana, 70310. Thesis title: Reproductive biology, life history, and population dynamics of bowfin *Amia calva* population in southeastern Louisiana.

B.S. Wildlife and Fisheries Science with a concentration in Fisheries Science, May 2003, Mississippi State University, Mississippi State, MS.

TEACHING EXPERIENCE

Spring 2005-Fall 2006: Taught introductory freshman biology labs that surveyed the plant and animal kingdoms.

RESEARCH EXPERIENCE

1. Reproductive biology, life history, and population dynamics of bowfin *Amia calva* in southeast Louisiana.
2. Age and growth of alligator gar *Atractosteus spatula* from Theriot, Louisiana.
3. Laboratory spawning techniques for spotted gar and laboratory care of juvenile spotted gar.
4. Fish assemblages of concrete rubble artificial reefs in coastal Mississippi.
5. Status of alligator gar populations in coastal Mississippi counties.
6. Post-release mortality of largemouth bass *Micropterus salmoides* from simulated tournaments.

SKILLS

Boat and trailer operation and light maintenance, pirogue operation, ATV operation, PVC and copper plumbing, field techniques including gill nets, electrofishing, seining, funnel traps, larval fish traps, fish identification, water quality monitoring, external fish tagging, live fish transport, fish otolith removal, and data management.

Oyster lease bottom profiling, potting and planting coastal plants. Microsoft Word, Excel, and Power Point, and FAST, some experience with ARC GIS and SAS.

LABORATORY EXPERIENCE

Care and maintenance of live fish, induced spawning of spotted gar, larvae rearing, water quality monitoring and maintenance.

MEMBERSHIP AND SERVICES:

> Louisiana Chapter of the American Fisheries Society
> Mississippi Chapter of the American Fisheries Society
> World Aquaculture Society
> American Society of Ichthyologists and Herpetologists
> Phi Kappa Phi
> Nicholls State University Biology Society-Vice President; President

HONORS AND AWARDS

2006 3rd Place Student Presentation. Joint Meeting of the Mississippi and Louisiana Chapters of the American Fisheries Society.
2006 Phi Kappa Phi Honor Society Inductee. Nicholls State University Chapter.
2006 Nicholls State University Research Council Student Research Competition. 1st Place Abstract.
2006 Nicholls State University Research Council Student Research Competition. 2nd Place Poster presentation.
2005 2nd Place Student Presentation. 31st Annual Meeting of Mississippi Chapter of the American Fisheries Society.

PUBLICATIONS

Schramm, H.L. and **J.G. Davis**. 2006. Survival of largemouth bass from populations infected with largemouth bass virus subjected to simulated tournament condition. North American Journal of Fisheries Management. 26:826–832.

Davis, J.G., Q.C. Fontenot, and A.M. Ferrara. (*In Prep*) Reproductive biology of bowfin *Amia calva* in southeastern Louisiana.

Davis, J.G., Q.C. Fontenot, and A.M. Ferrara. (*In Prep*) Age and growth of bowfin *Amia calva* in southeastern Louisiana.

SCIENTIFIC PRESENTATIONS

2006 **Davis, J.G.**, Q.C. Fontenot, and A.M. Ferrara. Life history characterisics of a bowfin (*Amia calva*) population in southeastern Louisiana. 14 July 2006. Annual Meeting of the American Society of Ichthyologists and Herpetologists, New Orleans, Louisiana.

2006 **Davis, J.G.**, Q.C. Fontenot, and A.M. Ferrara. Prelminary Assessment of Life History Characteristics of Bowfin in Southeast Louisiana. 1 Febuary 2006. Joint Meeting of the Mississippi and Louisiana Chapters of the American Fisheries Society.

2006 **Davis, J.G.**, Q.C. Fontenot, and A.M. Ferrara. Prelminary Assessment of Life History Characteristics of Bowfin in Southeast Louisiana. Nicholls State University Research Week Competition, Thibodaux, Louisiana (poster presentation).

2005 **Davis, J.G.** and W. Lorio. Assessment of Concrete Rubble as Artificial Reef Material in the Mississippi Sound. Febuary. 31st Annual Meeting of Mississippi Chapter of the American Fisheries Society. Philadelphia, Mississippi.

EMPLOYMENT

January 2005-Present. Graduate Teaching Assistant, Nicholls State University, Department of Biological Sciences. Assisted in teaching introductory biology courses. Assisted in laboratory work including measuring water quality and monitoring tanks. Cleaned fish tanks. Worked with species such as spotted gar, alligator gar, bowfin, gizzard shad, and paddlefish. Used collection gear such as gill nets. Developed thesis on life history characteristics of bowfin in southeast Louisiana.

May 2005-August 2005. Project Technician, T. Baker Smith, Inc. Assisted in performing wetland delineations including site assessments of vegetation, hydrology, and soil, and developing final reports. Collected contaminated soil samples for laboratory testing. Developed Spill Prevention Countermeasures and Control plans. Collected information using GPS units. Other duties included operation of trailers, vehicles, and ATVs.

January 2004-January 2005. Research Associate I. Mississippi State University, Science and Technology Research Center. Assisted on a project analyzing the status of alligator gar populations in coastal Mississippi counties. Also worked on a project focusing on fish assemblages associated with artificial reefs near Deer Island and Cat Island in the Gulf of Mexico south of Biloxi, MS. Duties included operation of boats and trailers, operation of collection gear, and data collection and management. Set

out gill nets for fish collection on both projects. Also, used fish traps and electrofishing gear as a means of capture.

June 2003-September 2003. Research Assistant I. Mississippi State University, Department of Wildlife and Fisheries. Worked under Dr. Harold L. Schramm Jr. as a research assistant. Conducted a lab study focusing on tournament mortality of largemouth bass. Assisted in other projects, including a project analyzing the effect of summer bass tournaments on largemouth bass survival and methods of livewell controls to ensure better survival. Assisted in assessment of techniques for collection of black carp. Used electrofishing gear and sienes in fish collecting. Operated vehicles and towed boats and trailers. Utilized hauling tanks to transport fish such as largemouth bass and bluegill.