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The life history of longnose gar, *Lepisosteus osseus*, an apex predator in the tidal waters of Virginia

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THE LIFE HISTORY OF LONGNOSE GAR, *LEPISOSTEUS OSSEUS*, AN
APEX PREDATOR IN THE TIDAL WATERS OF VIRGINIA

A Dissertation
Presented to

The Faculty of the School of Marine Science
The College of William and Mary

In Partial Fulfillment
Of the Requirements for the Degree of
Doctor of Philosophy

by
Patrick E. McGrath
2010

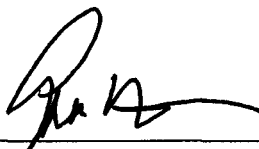
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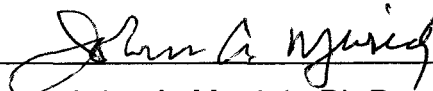
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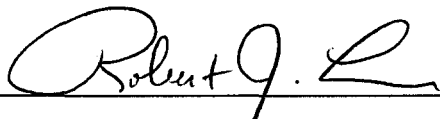


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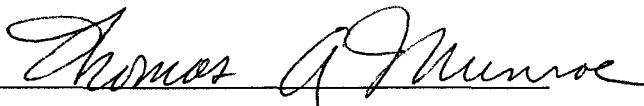
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DEDICATION

This work is dedicated to Dr. John E. Olney, Sr., a great man with a great laugh. His input greatly improved this dissertation and his legacy lives on in the many lives he touched.

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ABSTRACT

Longnose gar (*Lepisosteus osseus*) inhabit all of the major tributaries of Chesapeake Bay in Virginia, extending from fresh to estuarine waters. Literature concerning longnose gar from tidal environments is limited and this study concerns important aspects of the life history (e.g., growth, reproduction, dimorphism, movements, and diet).

Age, growth, and reproduction are important life history aspects for understanding the biology of fishes and may be affected by the environment in which an individual lives. This study found no differences in the age, growth, and fecundity parameters between longnose gar from tidal portions of Chesapeake Bay tributaries and previous studies in non-tidal environments. Fecundity averaged 30,000 eggs and a von Bertalanffy growth model described growth of longnose gar to be sexually dimorphic, rapid in the first year of life, and leveling off after maturity.

Sexual dimorphism has been documented previously in two species of the family Lepisosteidae, *L. osseus* and *L. oculatus*. The present study expands upon previous work on this species by examining a broader array of morphometric characters, while removing the bias associated with overall body length. A stepwise discriminant function analyses found that five characters best distinguish the sexes: head width, mid-snout width, anal-fin height, anal-fin width, and prepectoral-fin length. Discriminant function analyses with the five characters and standard length yielded misclassification rates of 8.8% and 6.2% for females and males, respectively.

Another goal of this project was to characterize the movements of longnose gar by using both acoustic and conventional tagging methods and by examining historical catch records from a trawl survey. Two individuals moved 69 and 74 km, which is greater than the distance observed in the only other report on long-distance movement by longnose gar individuals. Spawning data were collected from two acoustically tagged longnose gar and spawning residency time was approximately one month. Winter distributions of longnose gar, previously unknown, occurred both inshore and mid-channel and were similar to the summer and fall.

Finally, this study characterized the diet of longnose gar inhabiting tidal rivers in Virginia. The top five prey types recovered from stomachs were white perch, menhaden, killifishes (*Fundulus* spp.), Atlantic croaker, and spot. Marine and anadromous fishes (%W = 59.4%) and resident fishes (%W = 40.6%) were equally important in the diet of longnose gar. The diet varied with the seasonal prey fish assemblages, longnose gar length, and salinity, reinforcing the categorization of the species as an opportunistic predator. The relative abundance, rapid growth, and high fecundity of this apex predator warrant further study and inclusion into ecosystem models.

AUTHOR'S NOTE

The primary research chapters of this dissertation were written in the format of the journal in which each is published, in review, or to be submitted. Said chapters are written in the third person to represent my co-authors. The citations for the chapters are as follows:

Chapter 2

McGrath, P. E., E. J. Hilton, and J. A. Musick. (In prep). Age, Growth, and Reproduction in a Tidally Influenced Population of Longnose Gar, *Lepisosteus osseus*. *Journal of Freshwater Fish Ecology*.

Chapter 3

McGrath, P. E. and E. J. Hilton. (In review). Sexual Dimorphism in Longnose Gar (*Lepisosteus osseus*) from Tidal Rivers of Virginia. *Journal of Fish Biology*.

Chapter 4

McGrath, P. E., E. J. Hilton, and J. A. Musick. (In prep). A first examination of the seasonal distribution and movements of longnose gar (*Lepisosteus osseus*) with the York River System, Virginia. *Southeastern Naturalist*.

Chapter 5

McGrath, P. E., E. J. Hilton, and J. A. Musick. (In prep). Trophic interactions of longnose gar, *Lepisosteus osseus*, an apex predator in the tidal tributaries of Chesapeake Bay. *Environmental Biology of Fishes*.

Life history of longnose gar, *Lepisosteus osseus*, an apex
predator in the tidal waters of Virginia

CHAPTER 1:

Introduction to the Biology of the Longnose Gar, *Lepisosteus osseus*

The longnose gar is one of seven extant species within the family Lepisosteidae. Fossil lepisosteids are known from most continents, including North America, South America, Africa, Europe, and Asia (Wiley 1976; Wiley and Schultze 1984), although extant species occur in North America, Central America, Cuba, and Isles of Pines. Gars have been present in these regions for approximately 100 million years (Wiley 1976; Wiley and Schultze 1984), during which this family has experienced numerous climatic and habitat changes. As a group, gars retain many plesiomorphic features, such the ability to breathe air, ganoid scales, an abbreviated heterocercal tail, and remnants of a spiral valve, earning the title "living fossils" (Balfour and Parker 1882; Suttkus 1963; Wiley 1976). However, lepisosteids also have some derived characters such as an attenuated snout produced by elongation of the ethmoid region, opisthocoelous vertebrae, and plicidentine teeth (Balfour and Parker 1882; Suttkus 1963; Wiley 1976). Gars are very similar in shape and coloration, however maximum body size can range from the 2 feet (Florida gar) to 12 feet (alligator gar) and the size and the shape of the jaws is species specific (Suttkus 1963). Longnose gar can be easily distinguished from other lepisosteids by the length of its snout, which is significantly longer than all extant congeners (Suttkus 1963).

Longnose gar occur throughout much of the eastern half of the United States. They are more common in freshwater, but have been caught in salinities up to 31 ppt (Uhler and Lugger 1876; Hildebrand and Schroeder 1928; Jean 1946; Goodyear 1967; Schwartz 2003). Longnose gar have been

caught or observed in the deep areas in the middle of lakes and rivers and in the shallows along the waters edge. They can utilize areas of low or high water flow and can often be located around structure such as vegetation, stone outcrops, or downed trees (Suttkus 1963). Longnose gars were also a historical food source, consumed by Native Americans, early colonists (Pearson 1942), and was one of the species eaten by the first settlers at Jamestown, Virginia helping them survive their harsh, early years (Straube and Lucchetti 1996). Although they are not presently the focus of a commercial fishery, longnose gars do support a limited recreational fishery and are consumed for food at a small scale.

State of Knowledge

Several studies have been completed concerning the life history of longnose gar; however, the bulk of knowledge resulted from work performed in non-tidal freshwater locations. In this section, I review previous studies on the biology and ecology of longnose gar. Specifically, I discuss those aspects of gar biology that I will expand the current state of knowledge through my studies of longnose gars in tidal rivers of Virginia.

Age and Growth

Longnose gar grow quickly in the first two (male) or four (female) years of life (Netsch and Witt 1962; Klassen and Morgan 1974; Johnson and Noltie 1997; Ferrara 2001; Sutton et al. 2009). Hatching occurs 7-9 days after

spawning (Haase 1969), and the newly hatched larvae are 8.8-10.0 mm (Yeager and Bryant 1983; Simon and Wallus 1989). Longnose gar attain approximately 400 mm by the end of the first year of growth (Netsch and Witt 1962; Klassen and Morgan 1974; Johnson and Noltie 1997; Ferrara 2001; Sutton et al. 2009). Growth slows significantly after maturity, which generally occurs at 6-7 years and 2-3 years of age for females and males, respectively (Netsch and Witt 1962; Haase 1969; Ferrara 2001). The maximum ages for longnose gar in Wisconsin were found to be 32 for females and 29 for males (Haase 1969).

Females are larger than males at each age except for the first year of life (Netsch and Witt 1962; Haase 1969; Klassen and Morgan 1974; Johnson and Noltie 1997). The growth rate of females has been shown to be greater than that of males between ages two and five; the males matured during this time whereas the females did not (Netsch and Witt 1962; Haase 1969; Klassen and Morgan 1974; Johnson and Noltie 1997). Two studies examined the growth of longnose gar and calculated von Bertalanffy growth parameters of 0.17 and 0.21 and maximum lengths of 1306 and 1009 mm (Ferrara 2001; Sutton et al. 2009).

A few studies have examined the length-weight relationship of longnose gar. Longnose gar caught in Missouri had a length-weight relationship of $\log W = -7.0 + 3.5 \log SL$ (Netsch and Witt 1962; Johnson and Noltie 1997), while in Kansas the length-weight relationship was $\log W = -6.43 + 3.27 \log SL$ (Klassen and Morgan 1974). Longnose gar caught in Cape

Fear Estuary in North Carolina (where salinities ranged from 0-30) had a length-weight relationship best described by $\log W = -6.25 + 3.3 \log SL$ (Schwartz 2003).

Sexual Dimorphism

Longnose gar were found to be sexually dimorphic, with females attaining larger weights, pelvic girths, anal girths, anal fin lengths, and total lengths (Johnson 1994). Spotted gar were also found to be sexually dimorphic in southeastern Louisiana (Love 2002), with females significantly longer and with longer snouts than males when effects of variation in mass and age were taken into account. Love (2002) hypothesized that females were longer due to the larger gonad size. However, the reason for snout length dimorphism was not apparent. It is unknown if sexual dimorphism occurs in the snout length of longnose gar.

Reproduction

The age of 50% maturity for female longnose gar in Alabama and Missouri was 6 years and in Wisconsin it was 7 years (Netsch and Witt 1962; Haase 1969; Ferrara 2001). The age of 50% maturity for male longnose gar was 2 years (Netsch and Witt 1962; Haase 1969). In Missouri, Johnson and Noltie (1996) assessed a spawning population and found the males outnumbered the females, 1.67:1. This uneven sex ratio might be the result of males maturing at least four years earlier than females.

In Oklahoma, spawning occurred in water temperatures of 20 to 30°C (Beard 1889) and in Wisconsin, spawning peaked between 19.5 and 21.0°C (Haase 1969). Throughout the range of longnose gar (e.g., Alabama, New York, Florida, Missouri, Oklahoma, Wisconsin), spawning has been found to occur between late April and early July (Beard 1889; Holloway 1954; Netsch and Witt 1962; Haase 1969; Eschelle and Riggs 1972; Johnson and Noltie 1996; Ferrara 2001).

Based on observations of spawning by Haase (1969) in Wisconsin, longnose gar generally remained on the spawning beds during the day and dispersed at night; however, spawning was occasionally witnessed at night. The typical ratio of fish on the spawning ground was one female to five males. Prior to spawning, a female would lead 5-6 males around for 15 minutes, and then the spawning gar would angle their head down at the substrate and remain with the snouts almost touching the substrate. Finally, a rapid, violent quivering occurred as the eggs and sperm were released (Haase 1969). Longnose gar eggs have been deposited on small stones in shallow water, large stones in deep pools, rocky shelves, attached to vegetation, and in smallmouth bass nests (Beard 1889; Haase 1969; Goff 1984; Johnson and Noltie 1996). Eggs range from 2.5-3.2 mm in width (Beard 1889; Simon and Wallus 1989; Ferrara 2001; Long and Ballard 2001) and are greenish to slate gray in color with an adhesive coating for sticking to the substrate.

In Missouri, pre-spawning gonadosomatic indices (GSI) were recorded between 8.00 and 9.65 for males and 14.49 and 16.38 for females. Fecundity

averages around 30,000 eggs, but can be as low as 4,273 eggs and as high as 77,156. Fecundity and GSI were shown to be positively related to body weight (Holloway 1954; Netsch and Witt 1962; Johnson and Noltie 1997; Ferrara 2001). Ferrara (2001) found longnose gar to average 0.8 eggs/g body weight.

Reproductive seasonality has not been measured in longnose gar, but it was characterized for female and male Florida gar, *L. platyrhincus*. Histological examinations of females revealed the presence of oogonia, primary oocytes, previtellogenic oocytes, and vitellogenic oocytes present throughout the year, although the relative percentages of each varied seasonally. Florida gar were group-synchronous spawners and began oocyte development in the fall following a quiescent period during the summer. Sex steroid concentrations peaked in the fall along with the onset of gametogenesis and vitellogenesis in females and active spermatogenesis in males. Sex steroids and vitellogenin plasma (in females) concentrations decreased during the winter and then increased to a second peak prior to spawning in February and March (Orlando et al. 2003; Orlando et al. 2007).

Movements and Habitat

Literature on seasonal movements of longnose gar is scarce, and primarily concerns movements related to spawning. There has yet to be a study completed utilizing radio or acoustic tags to monitor longnose gar movements and habitat preferences. The movements and habitat use of the

spotted gar, *L. oculatus*, and the alligator gar, *A. spatula* have been examined. Spotted gar were tagged with radio transmitters in the Lower Atchafalaya River Basin, Louisiana and were monitored throughout the year (Snedden et al. 1999). Areas of relocation were found to be the largest during the spring (265.1 ha) followed by the summer (10.5 ha) and the fall-winter (6.2 ha). Spotted gar movements increased as the water temperature and river stage rose in the spring and included the inundated floodplain, which provided spawning habitat. Spotted gar were also found to be shoreline orientated, preferred submerged branches as cover, and avoided areas of exposed bank (Snedden et al. 1999). Alligator gar have been tracked in the Mobile-Tensaw Delta, Alabama and found to have linear ranges between 2.73 and 12.25 km. The maximum distance moved was 23.10 km (Sakaris et al. 2003).

Spawning movements of longnose gar have been characterized as broad and extensive. Lacustrine longnose gar have been found to migrate into lake tributaries to spawn. Johnson and Noltie (1996) found the spawning migration to be positively correlated with stream flow and water level and negatively correlated with temperature. Residence times on the spawning grounds ranged from 15 to 94 days, with males staying on the spawning grounds longer than females. Longnose gar also displayed yearly site fidelity (12.5%) to the spawning ground. After the spawning season, fish were recaptured a maximum of 48 km away. Larvae remain in the general area of egg deposition, but begin to disperse when feeding begins. Young of the year

remain amongst vegetation during the first summer of life (Haase 1969; Eschelle and Riggs 1972).

Prey Composition

Longnose gar are almost exclusively piscivorous and the prominent prey are forage fishes, with clupeids comprising the most common prey, followed by cyprinids, fundulids, and atherinids. Game fishes are also consumed, but to a lesser extent, and include ictalurid catfishes, *Perca flavescens*, *Esox* spp. and centrarchids (Cahn 1927; Rimsky-Korsakoff 1930; Scott 1938; Lagler and Hubbs 1940; Bonham 1941; Frisby 1942; Lagler et al. 1942; Holloway 1954; Goodyear 1967; Suttkus 1963; Haase 1969; Crumpton 1970; Toole 1971; Seidensticker 1987). Haase (1969) measured the prey items and found larger individuals consumed larger prey, although the larger fish did not abandon smaller prey but rather consumed a wider range of prey sizes.

Almost all of the existing prey composition data were gathered from studies of populations from freshwater rivers and lakes, and estuarine feeding habits for the species have been largely unreported. Goodyear (1967) conducted the only study to complete a diet analysis for estuarine longnose gar. He studied longnose gar in the Mississippi Gulf Coast and concluded that individuals moved downstream into 3-10 ppt at night to feed upon gulf menhaden (*Brevoortia patronus*) and then returned to tidal freshwater in the morning. Nearly all of the longnose gar contained gulf menhaden (frequency

of occurrence = 89%). The fish fed on a range of sizes from 3.2 – 21.0 cm, with juveniles comprising the bulk of the prey. It was not uncommon to find a longnose gar stomach containing as many as 17 gulf menhaden juveniles (Goodyear 1967).

Eschelle and Riggs (1972) raised fertilized eggs of longnose gar in aquaria and found that the larvae absorb their yolk-sac by day nine and at a size of approximately 18 mm. Food items were not found in longnose gar smaller than 20 mm (Pearson et al. 1979). Post-larval juvenile longnose gar were collected during the early summer for two straight years from the Ohio River, Kentucky to examine diet preferences (Eschelle and Riggs 1972). The first year the dominant prey item was cladocerans, with fishes comprising only 13.3% of the food items. The results from the second year were completely different, with larval fishes (*Notropis* sp. was the dominant piscine prey) comprising 84.1% of the diet and cladocerans being the second most important. In Lake Texoma (Oklahoma), post-larval longnose gar were found to be primarily piscivorous and often consumed *Menidia audens* (Eschelle and Riggs 1972). In Wisconsin, YOY longnose gar mainly preyed upon cyprinid larvae or cladocerans, but also insects, atherinids, lepomis, fundulids, and other longnose gar (Haase 1969).

All previous diet studies of longnose gar have found that greater than 50% of stomachs are empty (Scott 1938; Bonham 1941; Lagler et al. 1942; Goodyear 1967; Haase 1969; Crumpton 1970; Seidensticker 1987). Digestion has been shown to be slow in the family Lepisosteidae. Hunt (1960)

experimentally found the digestion rate for Florida gar (*L. platyrhincus*) was 0.025 percent of the body weight per hour and it took at least 24 hours for complete digestion. Netsch and Witt (1962) observed the rate of digestion for longnose gar to be approximately 24 hours for complete digestion.

Objective

Information concerning the biology and ecology of longnose gar is lacking, especially from tidal estuarine systems. Further, only studies concerning presence, abnormal coloration, or larval identification have been completed for longnose gar from Virginia. It was the goal of this study to provide data on the life history of longnose gar from tidal estuarine waters of Virginia. Data concerning age, growth, reproduction, sexual dimorphism, distribution, and diet were collected, analyzed, and compared to previous nontidal freshwater studies on longnose gar. This volume of work provides information concerning an apex predator whose role in the ecosystem is poorly understood, but nonetheless important.

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CHAPTER 2:
Age, Growth, and Reproduction in a Tidally Influenced
Population of Longnose Gar, *Lepisosteus osseus*

Abstract

Age, growth, and reproduction are some of the most important aspects for understanding the ecology of fishes. Information about these life history characters is lacking for longnose gar from tidal habitats. Many aspects concerning a species' ecology are variable and may be dependent on environmental conditions. This study found no differences between the age, growth, and fecundity parameters of longnose gar from tidal portions of Chesapeake Bay tributaries and previous studies in non-tidal environments. Several growth models were examined and the von Bertalanffy growth model with age inputted monthly and a birth date in June was the best fit for males, females, and all fish. Longnose gar grew rapidly in the first year of life and then growth began to slow and eventually reached a plateau after maturity (age three and six in males and females, respectively). Fecundity averaged 30,000 eggs and spawning occurred from April to June. Longnose gar represent a fish in the middle of the r - K continuum, with fast early growth and high fecundity, but also long life span and large maximum sizes. These attributes may contribute to the longevity of longnose gar as a species.

Introduction

Three fundamental factors – age, growth, and reproduction – dominate the study of the biology of fishes. Most actions that are undertaken by a species affect one or more of these factors, and allow an individual to live longer, grow larger, or reproduce more effectively than conspecifics. The allocation of resources between growth and reproduction is the essence of the theory of r and K selection (MacArthur and Wilson 1967; Pianka 1974). Animals that live in an unpredictable environment with high, nonselective mortality will invest most of their energy into reproduction, consequently remaining small and having a shorter lifespan. Conversely, energy will be allocated to individual fitness, larger growth and older ages, when an environment is relatively stable with a selective mortality (MacArthur and Wilson 1967; Pianka 1974). Typically, major groups of organisms can be described as r or K selected with few exceptions; however, this is not true for fishes, which span the range of the r - K continuum (Pianka 1974). Fishes range widely in maximum length (0.01 to 20 m), lifespan (months to 100+ years), and fecundity (1-300 million eggs). How fast and large a fish species can grow, its fecundity, and its maximum age are important variables to know for a more complete understanding of the ecology of these species, how they function in the ecosystem and for determining better management practices to maintain these species.

The longnose gar (*Lepisosteus osseus*) is one of seven extant species in the family Lepisosteidae. As a group, gars retain many plesiomorphic

features, such as the ability to breathe air, ganoid scales, an abbreviated heterocercal tail, and remnants of a spiral valve (Balfour and Parker 1882; Suttkus 1963). These characteristics, along with the geological longevity of the group and relatively early appearance in the fossil record, have earned them the title “living fossils”. Because the closest relative of longnose gar, †*Lepisosteus indicus*, is known from Upper Cretaceous, the longnose gar itself has a long evolutionary history (Wiley 1976; Wiley and Schultze 1984), during which it has experienced numerous climatic and habitat changes. Longnose gar reside throughout many of the aquatic habitats of the eastern half of the United States, and although they are more common in freshwater, they have been caught in salinities up to 31 ppt (Jean 1946; Goodyear 1967; Schwartz 2003). Longnose gar have been found in several estuaries along the Atlantic and Gulf coasts (e.g. Mississippi, North Carolina, Virginia, Maryland, and Quebec) (Uhler and Lugger 1876; Hildebrand and Schroeder 1928; Jean 1946; Goodyear 1967; Schwartz 2003). Longnose gar have been caught or observed in the deep portions of lakes and rivers and in the shallows along the water’s edge. They can utilize areas of low or high water flow and are often located around structure such as vegetation, stone outcrops, or downed trees (Suttkus 1963). This ability to reside in several habitats and a wide range of environmental conditions has enabled longnose gar to occupy a more extensive range of compared to other lepisosteids. More information on the basic life history of longnose gar, especially from populations occurring in estuarine environments, is needed to further

understand the range of variability in life history traits in this species and how this variability may have contributed to the persistence of this species through time.

Research on age, growth, and reproduction of longnose gar has primarily occurred in freshwater systems. In these environments, longnose gar grew quickly in the first two (male) or four (female) years of life, attaining approximately 400 mm TL by the end of the first year of growth (Netsch and Witt 1962; Klassen and Morgan 1974; Johnson and Noltie 1997; Ferrara 2001; Sutton et al. 2009). Only one length-weight study (Schwartz 2003) focused on a population of longnose gar inhabiting an estuary and their results were similar to those from freshwater populations (Netsch and Witt 1962; Klassen and Morgan 1974). These attributes enable longnose gar to quickly outgrow the period when they are more vulnerable to predation and become one of the top predators. Several studies have shown that females are larger than males at each age, except during the first year of life (Netsch and Witt 1962; Haase 1969; Klassen and Morgan 1974; Johnson and Noltie 1997). The growth rate of females was greater than that of males between ages two and five; males matured during this time, whereas the females did not (Netsch and Witt 1962; Haase 1969; Klassen and Morgan 1974; Johnson and Noltie 1997).

Fecundity and spawning of longnose gar have been described throughout their range in freshwater systems (e.g., Alabama, New York, Florida, Missouri, Oklahoma, and Wisconsin). Spawning generally occurred

between late April and early July; spawning typically occurred later in the year in populations residing at higher latitudes (Beard 1889; Holloway 1954; Netsch and Witt 1962; Haase 1969; Eschelle and Riggs 1972; Johnson and Noltie 1996; Ferrara 2001). Longnose gar deposited eggs on small stones in shallow water, large stones in deep pools, rocky shelves, vegetation, and in smallmouth bass nests (Beard 1889; Haase 1969; Goff 1984; Johnson and Noltie 1996). Hatching occurred 7-9 days after spawning (Haase 1969), and the newly hatched larvae are 8.8-10.0 mm TL (Yeager and Bryant 1983; Simon and Wallus 1989). Larvae have a papillose suckorial disc at the tip of their snouts that is used for sticking to vegetation or other substrata while the remainder of the yolk sac is absorbed (Balfour and Parker 1882; Simon and Wallus 1989). The disc and the yolk sac are mostly resorbed by 20 mm TL, correlating with time of first exogenous feeding (Eschelle 1968; Eschelle and Riggs 1972; Pearson et al. 1979; Simon and Wallus 1989).

Many aspects concerning the ecology of a species are variable and may be dependent on the environmental conditions a particular population endures (Glebe and Legget 1981; Jonsson 1985; Meador and Kelso 1990). Data concerning the age, growth, and reproduction of longnose gar from tidal habitats are generally lacking. In this paper, we present the first detailed study to provide this knowledge from longnose gar inhabiting tidal river environments in Virginia. Several body measurement relationships and growth characteristics, including length-weight, growth models, fecundity, and gonadosomatic indices (GSI), are compared to previous work on longnose

gar. Water temperature, habitat, and timing of reproduction are also discussed through examination of GSI and fecundity by month, the occurrence of eggs, and observations at known spawning grounds during the spawning season.

Methods

Longnose gar were collected opportunistically and through directed sampling from tidal portions of seven Virginia rivers between 2005 – 2010. Collections occurred throughout the York River System (YRS; = York, Poropotank, Pamunkey, and Mattaponi Rivers) and locally in the James, Rappahannock, and Potomac River systems (Figure 1). Specimens were provided from the by-catch of the Maryland Striped Bass Spawning Stock Survey, Maryland Juvenile Striped Bass Seine Survey, VIMS Striped Bass Spawning Stock Survey, VIMS Juvenile Fish and Blue Crab Survey, VIMS American Shad Pushnet Survey, VIMS Juvenile Striped Bass Seine Survey, VIMS American Shad Spawning Stock Survey, and VDGIF electroshocking surveys. In 2007 and 2008, directed sampling of longnose gar was conducted in the YRS. In 2007, this directed effort consisted of four-hour biweekly gillnet sets (two nets, 55.5 m² total area per net, 10.2 cm stretched mesh bar) from March to November at three fixed stations. One fixed station, located on the Poropotank River, represented individuals within the mesohaline portion of the river. The other two fixed stations in the Pamunkey and Mattaponi Rivers within freshwater and on typical spawning habitats (Figure 1). Collections

increased to once a week at the two locations in the Pamunkey and Mattaponi Rivers during the spawning season (April to July).

In 2008, sampling followed a stratified, random sampling design from March to October in order to increase the spatial and temporal coverage within the YRS. The YRS was divided into twelve ten-kilometer sections beginning at river-kilometer (RKM) 40 on the York River and extending to RKM 3 on the Poropotank River and to RKM 107 in both the Mattaponi and Pamunkey Rivers (these rivers are extensions of the York River and therefore RKM measurements for these rivers begin at the mouth of the York River). Two monofilament gillnets (gillnet #1 = 55.5 m² total area, 10.2 cm stretched mesh bar; gillnet #2 = 55.5 m² total area, three equal-area panels, 7.6, 10.2, and 12.7 cm stretched mesh bar) were set for four hours each in randomly selected sections every month from March to October.

Additional collections occurred during the peak spawning season (late April to late June) in 2008. The Pamunkey and Mattaponi Rivers were divided into eight four-kilometer sections from RKM 87 – 119. Gillnets (n=8, four of both gillnets described above) were set for two hours each week to increase spatial coverage of sampling at the spawning grounds. Gillnet locations were determined by dividing each four-kilometer river section into one-kilometer subsections and randomly selecting one subsection each week. Water temperature, air temperature, and salinity were measured and recorded at each gillnet location.

Longnose gar were brought to the lab and the following data were taken: total length (TL), total weight (TW), eviscerated weight (EW), sex, maturity stage, and gonad weight (GW); all lengths were taken to the nearest 1.0 mm, and all weights were taken to the nearest 0.1 g (Ferrara and Irwin 2007). Branchiostegals were removed and stored frozen until they were cleaned of flesh either by washing in a 5% KOH solution or by using dermestid beetles (Netsch and Witt 1962). Subsamples from each ovary were removed from the anterior, middle and posterior section of the ovary. Each subsample was weighed, fixed in 10% formalin, and then stored in 70% ethanol. Another subsample from each ovary was removed for immediate measurement of the diameter of ten eggs. Egg diameters were measured with a stereoscopic dissecting scope (Nikon SMZ 1500) and the images saved with Nikon Image System Elements software.

Age and Growth

The log of TL was regressed against the log of TW and differences between sexes examined with analysis of variance (ANOVA). If a difference between the sexes was found, then TL and TW were regressed separately for males and females. Results were then compared to those of published longnose gar studies to determine if differences exist between estuarine and freshwater populations.

Counting annuli on branchiostegals is the preferred method of aging gars, although it has not yet been validated (Netsch and Witt 1962; Klassen

and Morgan 1974; Johnson and Noltie 1997). Age was determined by counting the number of transverse lines that span the entire width of the bone (Netsch and Witt 1962). A picture of each branchiostegal was captured with aid of a stereoscopic dissecting scope (Nikon SMZ 1500; Figure 1). A randomly selected subsample of branchiostegals (n=100) was read by a second reader to test for symmetry and agreement between readers (Hoenig et al. 1995).

Three growth models were fitted with length-at-age data of longnose gar for all fish (including fish of unknown sex), for males, and for females:

Gompertz model (Ricker 1975)

$$L_t = L_0(e^{\lambda/k(1-e^{kt})}),$$

von Bertalanffy model (von Bertalanffy 1938)

$$L_t = L_\infty(1 - e^{-k(t-t_0)}),$$

and logistic model (Ricker 1975)

$$L_t = L_\infty / (1 + e^{-k(t-t_0)}).$$

Age was inputted monthly with a birth date June 1. June was selected *a priori* based on previous studies on spawning of lognose gar (Netsch and Witt 1962; Johnson and Noltie 1967; Haase 1969). The model with the best fit was chosen using Akaike Information Criterion (Akaike 1973). Differences in model parameters between the sexes were examined with a Fisher-Behrens test.

Reproduction

Descriptive statistics such as average female fecundity, male and female GSI, and egg size collected during the spring were compared to similar parameters reported in previous studies of longnose gar (Holloway 1954; Netsch and Witt 1962; Haase 1969; Ferrara 2001). The calculation for GSI was

$$GSI = GW / EW * 100 .$$

Ages were combined with maturity information to infer at what age 50% of the males and females were mature. Mature fish were determined when eggs (primary or secondary oocytes) were visible in a gross examination of the ovaries. Female fecundity and egg size along with EW, TL, and GW for both sexes were examined with q-q plots to determine if data transformation (e.g. log transformation) was needed. General linear models (GLM) were then used to assess relationships between:

Fecundity = TL

Fecundity = EW

Egg size = TL

Egg size = EW

Male GW = TL

Male GW = EW

Female GW = TL

Female GW = EW

for individuals collected prior to spawning in March - June and then compared to previous studies (Holloway 1954; Netsch and Witt 1962; Haase 1969; Ferrara 2001).

Male and female GSI, fecundity, and egg size were plotted monthly to examine yearly trends and to determine the end of the spawning season. Analysis of variance (ANOVA) was conducted on each of the above characters with month as the explanatory variable. Pairwise comparisons, with Bonferroni correction for multiple comparisons, were conducted to determine which months differed significantly from the month with the lowest values. The month with the lowest values signified the end of the spawning season. Environmental variables coinciding with the first witnessed spent female and eggs collected from egg mats were described and compared to previous longnose gar literature. Egg mats (plastic grass attached to bricks) were placed at Sandy Point on the Mattaponi River, a suspected spawning ground, from April to July in 2008 and checked weekly for the presence of longnose gar eggs.

All statistical analyses were performed with SAS (SAS Institute, Inc., Cary, North Carolina).

Results

Longnose gar ($n=689$) were caught each month of the year and in water temperatures from 1.9 – 30.7 °C and salinities ranging from 0 – 20.5 ppt. Total lengths ranged from 19 – 1350 mm and averaged 787 mm (Figure

3). Sex was not a significant factor in the length-weight regression ($F < 0.001$, $p = 0.97$). The log of TW was significantly related to the log of TL ($F = 20125.4$, $p < 0.001$; Figure 4).

Blind agreement between readers occurred for 51% of the subsampled branchiostegals, and age estimates were within one year of each other for 90% and within two years for 97% of the subsample. Estimation methods between readers (symmetry) were not significantly different ($\chi^2 = 19.6$, $df = 16$, $p = 0.24$). Ages ranged from 0 to 27 years old, with an average age of 8.6 years ($n = 646$). Females reached older maximum ages than males (27 and 22 years, respectively). Longnose gar grew quickly in their first year of life, often attaining 400 mm in less than 12 months (Figure 5). The von Bertalanffy growth model fit the data best for all three models (all fish, males, and females; Table 1; Appendix I). The model parameters between the sexes were significantly different (L_{∞} , $z = 205.4$, $p < 0.001$; k , $z = 40.2$, $p < 0.001$; t_0 , $z = 25.2$, $p < 0.001$). Longnose gar reached 50% maturity at ages 3 and 6 for males and females, respectively.

Average spring GSI for females and males was 15.0 and 6.4, respectively. Fecundity of female longnose gar prior to spawning ($n = 91$) averaged 33,971 eggs with a range between 12,157 - 66,358 eggs. Q-Q plots indicated log transformation was only necessary for the regressions of male GW with EW. Fecundity was significantly related to both EW and TL (EW, $F = 64.0$, $p < 0.001$; TL, $F = 58.3$, $p < 0.001$; Figure 6). Pre-spawning female egg size averaged 3.0 mm (± 0.02) with range between 2.5 - 3.7 mm. Egg size

was significantly related to both EW and TL (EW, $F=6.22$, $p=0.015$; TL, $F=7.66$, $p=0.007$; Figure 7). The relationships of GW and EW of females and log GW and log EW of males collected prior to spawning were also significant (females, $F=57.8$, $p<0.001$; males, $F=196.7$, $p<0.001$; Figure 8). The relationships of pre-spawning female GW and TL and male log GW and log TL were also significant (females, $F=34.1$, $p<0.001$; males, $F=128.5$, $p<0.001$; Figure 8). A significant relationship was not found between age and female fecundity ($F=1.72$, $p=0.194$), age and female GSI ($F=0.00$, $p=0.99$), and age and male GSI ($F=1.75$, $p=0.19$).

Spawning aggregations were witnessed at Sandy Point on the Mattaponi River on several occasions in May and June. Spawning occurred at the river's edge in a bed of *Hydrilla verticillata*. This was verified by collection of fertilized eggs from egg mats placed among the *H. verticillata*. Eggs were collected on egg mats from May 31 to June 15. One female caught in August appeared to have skipped spawning and was in the process of resorbing her eggs. Month was a significant factor explaining level of fecundity ($F=7.44$, $p<0.001$; Figure 9). Fecundity was the lowest in July when zero females were caught with secondary oocytes. Fecundity in July significantly differed from March ($t=5.11$), April ($t=5.24$), May ($t=3.63$), and September ($t=3.87$). Month was also a significant factor for GSI values of both males ($F=12.4$, $p<0.001$) and females ($F=10.3$, $p<0.001$) (Figure 9). The lowest GSI values for both males and females occurred in July, which was significantly ($p<0.05$) different from March ($t=5.38$), April ($t=6.02$), May ($t=4.22$), and June ($t=3.72$) for

females and significantly different from April ($t=6.72$), May ($t=4.22$), June ($t=4.34$), September ($t=5.43$), and October ($t=6.92$) for males. Month was also a significant factor when examining egg size ($F=26.3$, $p<0.001$; Figure 9). The smallest eggs occurred in July, which were significantly different from those measured in March ($t=8.01$), April ($t=10.78$), May ($t=10.11$), June ($t=9.66$), September ($t=6.39$), and October ($t=6.00$). The first spent longnose gar were caught during the first week of May in the years from 2006-2008, corresponding to an average water temperature of 17.8 °C. Spent fish were caught until the first week in August and these females retained an average of 171 eggs ($n=13$).

Discussion

The length-weight regression for longnose gar was very similar to that of previous studies (Netsch and Witt 1962; Klassen and Morgan 1974; Johnson and Noltie 1997; Schwartz 2003). The intercept and slope of the regression in all studies varied between 6.0 – 7.0 and 3.2 – 3.5, respectively. No differences were apparent in the length-weight relationships between estuarine fish (Schwartz 2003; present study) and non-tidal freshwater residents (Netsch and Witt 1962; Klassen and Morgan 1974; Johnson and Noltie 1997). Johnson and Noltie (1997) described a difference between the length-weight regression by sex, but did not employ statistics. The present study did not find a statistical difference between the length-weight regression of male and female longnose gar.

Age and Growth

The maximum ages reported for longnose gar were 32 and 29 years for females and males, respectively (Haase 1969). However, these are by far the oldest estimates recorded, most studies calculate the maximum age for longnose gar to be much younger (Klassen and Morgan 1974; Ferrara 2001). For instance, in Missouri, females and males were aged at 22 and 18 years, respectively (Netsch and Witt 1962; Johnson and Noltie 1997). The maximum ages in the present study were between those of the Missouri studies and Haase's (1969) study. Older ages estimated in this study could be a result of examining a larger sample size than previous work conducted on longnose gar. Larger sample size offered a better chance at catching the oldest individuals at the extreme end of the longevity profile for this species. Also important to note is that use of branchiostegals to age longnose gar has yet to be validated. Presently, various research groups are raising longnose gar to be sacrificed at a known age or are employing mark and recapture methods (McGrath unpubl.; Ferrara pers. comm.) to try and validate age estimates for longnose gar. Until validation occurs, the transverse lines on branchiostegals can only be assumed to be yearly age marks.

Longnose gar grew quickly in their first year of life, often attaining 400 mm TL. Growth rate then declined until it slowed significantly after maturity. These results are similar to those of previous studies (Netsch and Witt 1962; Haase 1969; Klassen and Morgan 1974; Johnson and Noltie 1997; Ferrara

2001; Sutton et al. 2009). Ferrara (2001) and Sutton et al. (2009) contributed the only published work on von Bertalanffy parameters for longnose gar. Ferrara (2001) used whole otoliths to age longnose gar in Alabama and calculated the growth coefficient (k) to be 0.17 and the maximum length (L_{∞}) to be 1306 mm. Discrepancies between the age estimates made from these different structures might explain the differences between the present study and that of Ferrara (2001). Sutton et al. (2009) examined a small sample size of longnose gar from Indiana and Illinois and produced a k of 0.21 and an L_{∞} of 1009 mm. These results are more similar to those of the present study. However, Sutton et al. (2009) had a limited sample size ($n=77$) and lacked data from the smallest and largest size classes. Ferrara (2001) and Sutton et al. (2009) also used year as the age variable, while this study found that separating yearly age into months explained more of the variability.

Males grew to their maximum size faster than females, but females attained larger maximum sizes. Males do not need as much internal space for their mature gonads as do females. Therefore, quick growth and smaller maturity sizes may benefit the lifetime reproductive output for males. However, females need to attain larger sizes in order to have the internal space and energy needed to produce 30,000 large diameter eggs. Further study is needed to determine reproductive output and reproductive success to evaluate the maintenance of this dimorphism (e.g., natural vs. sexual selection; Crow and Kimura 1970).

Reproduction

Pre-spawning GSIs for females from Virginia (14.49 - 16.38) were similar to longnose gar from Missouri (Johnson and Noltie 1997), while those of males (8.00 - 9.65) were lower compared to males from Missouri. Data from past literature also agreed with our average fecundity and the large range in the number of eggs (Holloway 1954; Netsch and Witt 1962; Johnson and Noltie 1997; Ferrara 2001). Egg size was also within the previously reported size range of 2.5-3.2 mm (Beard 1889; Simon and Wallus 1989; Ferrara 2001; Long and Ballard 2001).

All longnose gar may not spawn annually, based on the Johnson and Noltie's (1997) observations of one female leaving the spawning grounds without spawning and one female collected in Virginia with a large number of atretic eggs after the spawning season (McGrath pers. obs. 2007). In addition, occasional large growth increments late in life could be the result of a non-spawning year (Johnson and Noltie 1997; McGrath pers obs.).

Reproductive seasonality has not been measured in longnose gar, but it was characterized for Florida gar, *L. platyrhincus*, and spotted gar, *L. oculatus* (Orlando et al. 2003; Smith 2006; Orlando et al. 2007). Histological examination of females of these species revealed the presence of oogonia, primary oocytes, previtellogenic oocytes, and vitellegenic oocytes throughout the year, although the relative percentages of each egg stage varied seasonally. Primary oocytes were not examined in this study, but the number of secondary oocytes and GSI values were significantly smaller during July

than other times during the year. Florida and spotted gar were found to be group-synchronous spawners and began oocyte development in the fall following a quiescent period during the summer. Sex steroid concentrations also peaked in the fall along with the onset of gametogenesis and vitellogenesis in females and active spermatogenesis in males (Orlando et al. 2003; Orlando et al. 2007). The gonads of longnose gar in the present study also developed in early fall and gonads and eggs grew to prespawning sizes far in advance of the spawning season. This early maturation is probably due to the low energy consumption during the winter months (McGrath et al. unpubl.).

Conclusions

This is the first detailed age, growth, and reproduction analysis on longnose gar residing in an estuary and is also the first of its kind to report on these parameters for longnose gar in a Virginia estuary. This study is more comprehensive with respect to larger size range (larger) and temporal collection period (wider) than previous studies of this species. Growth and reproductive characteristics of longnose gar in the tidal estuaries of Virginia determined in this study were similar to those noted for longnose gar inhabiting non-tidal systems. The information from this study is vital for the complete understanding of Virginia's estuarine ecosystem. Future work needs to be completed on age verification and stock structure of longnose gar.

Growth of longnose gar was quick in the first years of life and reached a plateau after maturity at three and six years for males and females, respectively. Longnose gar also produced large numbers of large eggs. These characteristics classify longnose gar as being in the middle of the r - K continuum for fishes. The rapid growth in length, especially in the first year of life, along with the high fecundity, resembles r -selected species. However, the long life span, large maximum size, and large eggs resemble features commonly found in a K -selected species. These attributes of longnose gar, combined with their tolerance for a wide range of environmental conditions, reflect the longevity of the species and when compared to other family members its larger distribution.

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sympatric gar species (Lepisosteidae) in a Texas river and associated oxbows. *Ecology of Freshwater Fish* 17: 119-129.

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Table 1. Estimated parameters (L_{∞} , k , t_0) from a von Bertalanffy growth model with time expressed monthly and June 1 as the birthdate for males, females, and all fish (unknown sex and known sexes combined) for longnose gar, *L. osseus*, from tidal rivers of Virginia..

Age input	Model	Sex	L_{∞}	k	t_0
June	VB	Female	1132	0.18	-1.55
June	VB	Male	875	0.23	-2.11
June	VB	All	961	0.25	-0.43

Figure 1. Map of Virginia Rivers, longnose gar collection locations, boundaries of gillnet survey, and location of Sandy Point (+) on the Mattaponi River.

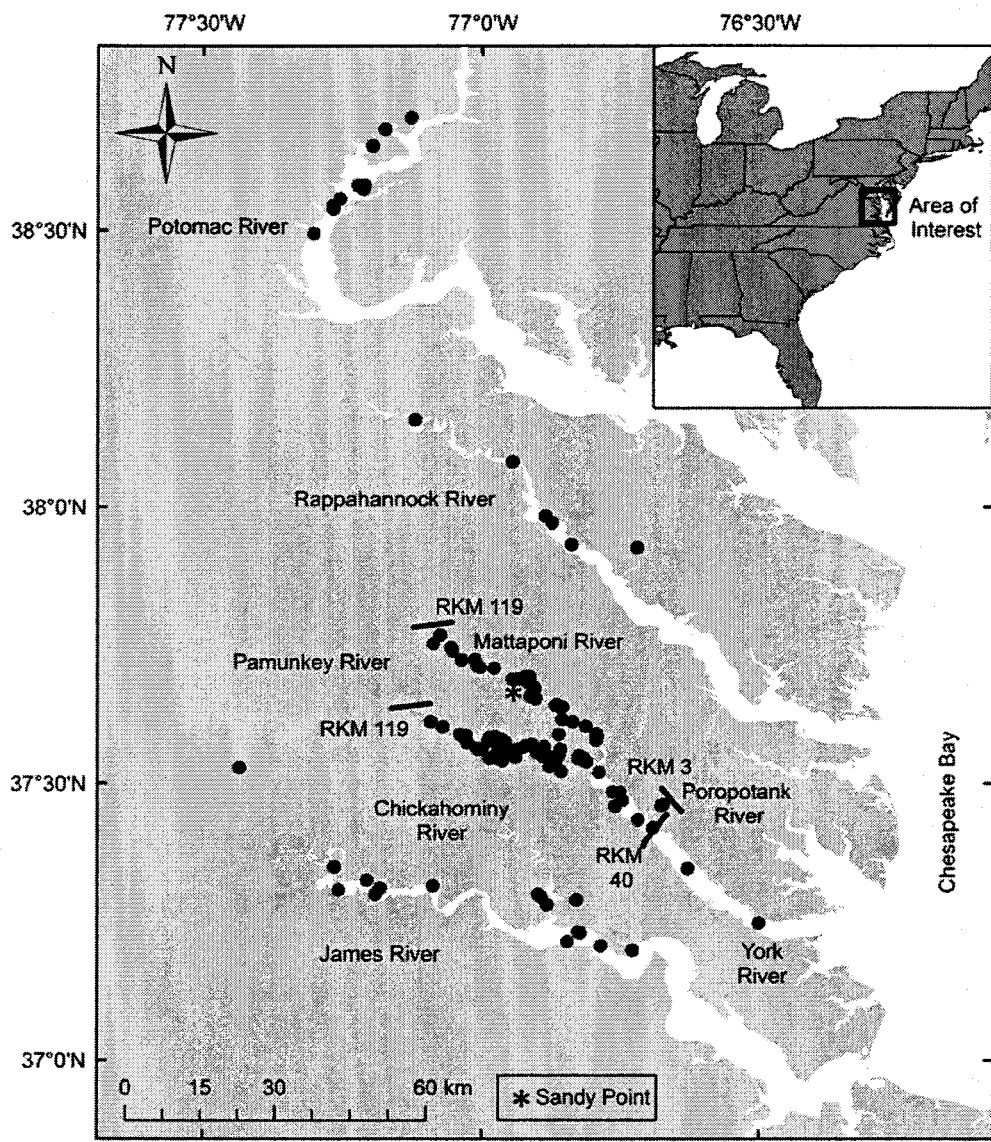


Figure 2. A) Right and left branchiostegals of a longnose gar determined to be 4 years old. B) Left branchiostegal of a longnose gar determined to be 12 years old.

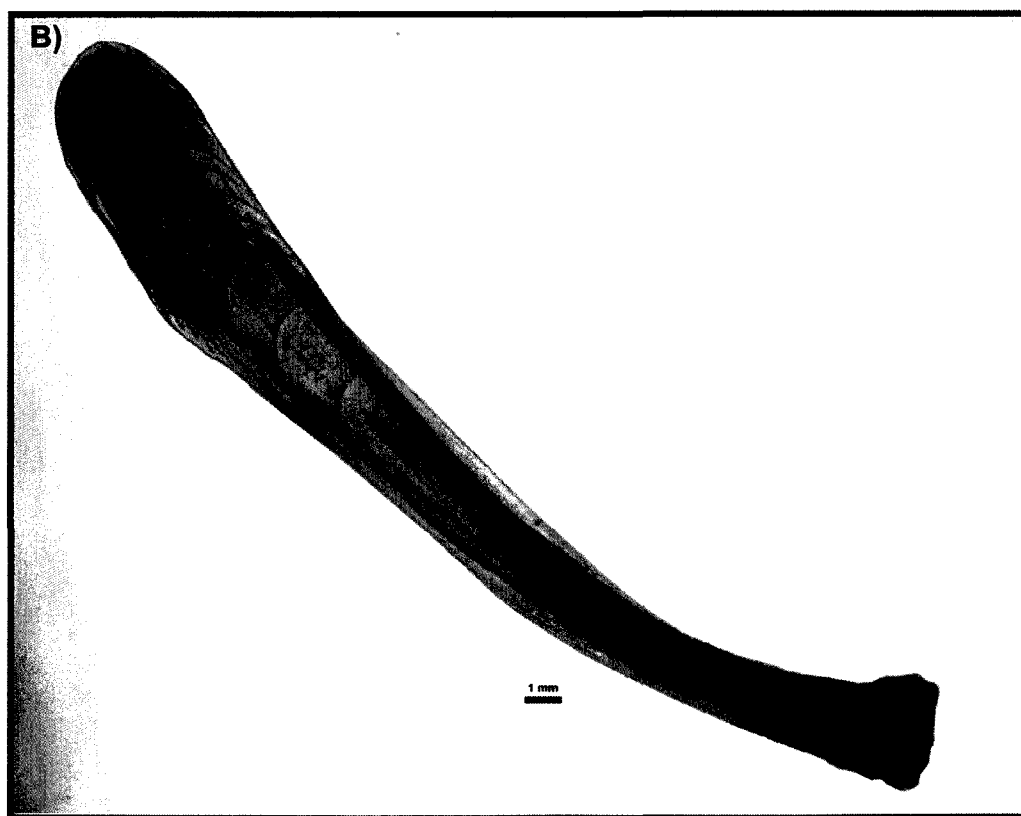
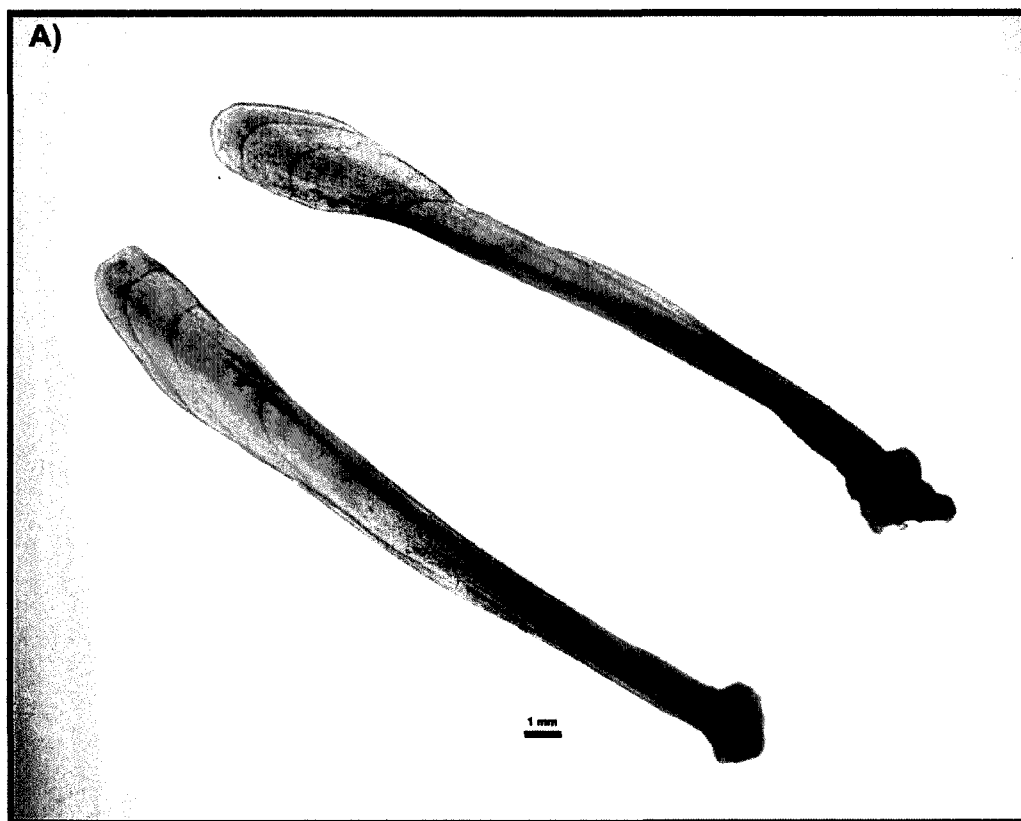


Figure 3. Size distribution of collected longnose gar separated by sex.

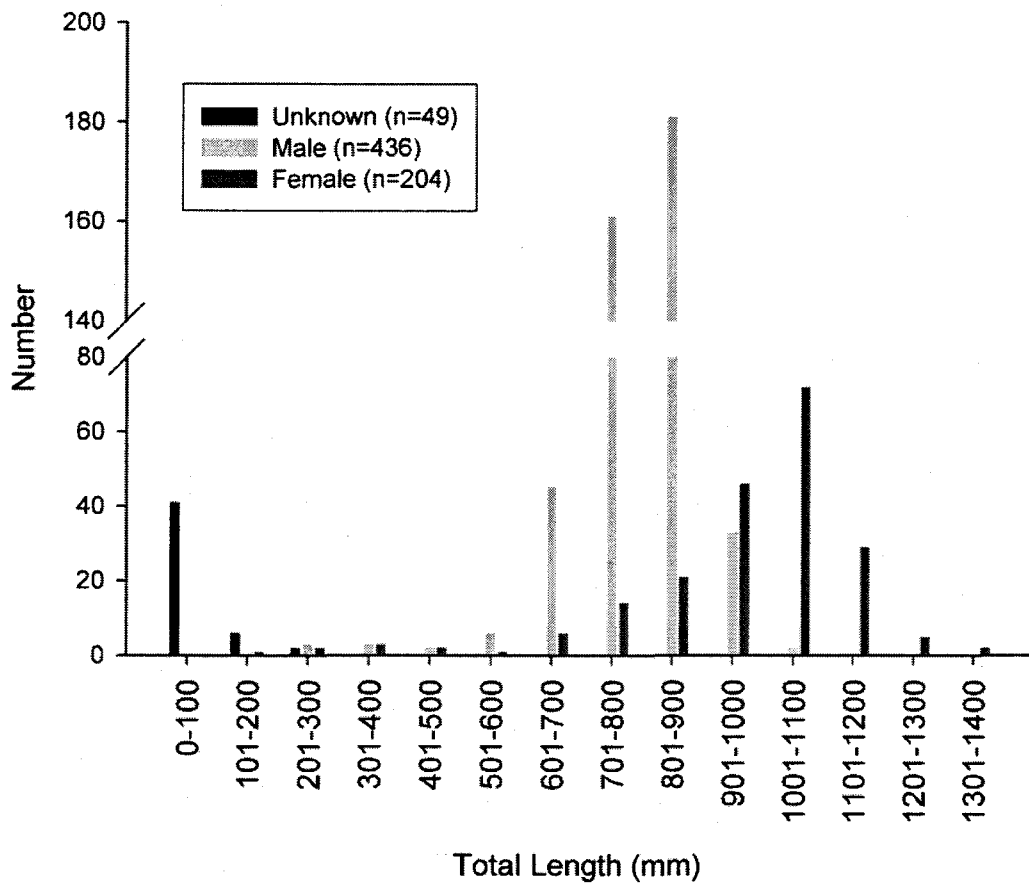


Figure 4. Regression of log of total weight and log of total length.

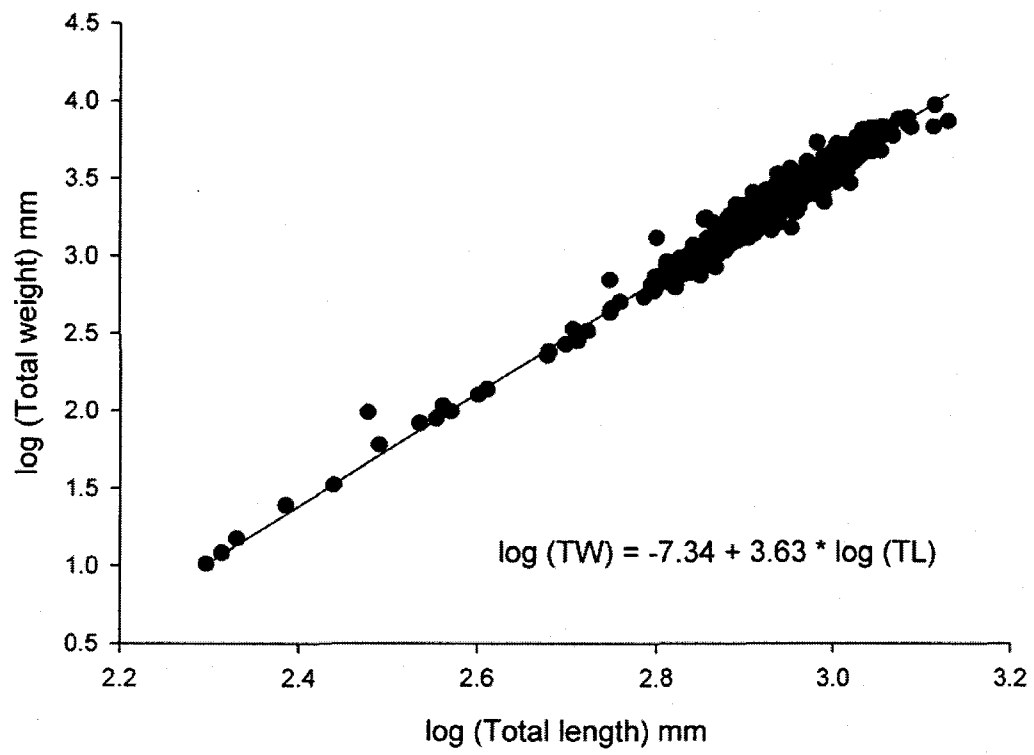


Figure 5. Von Bertalanffy growth model for male and female longnose gar.

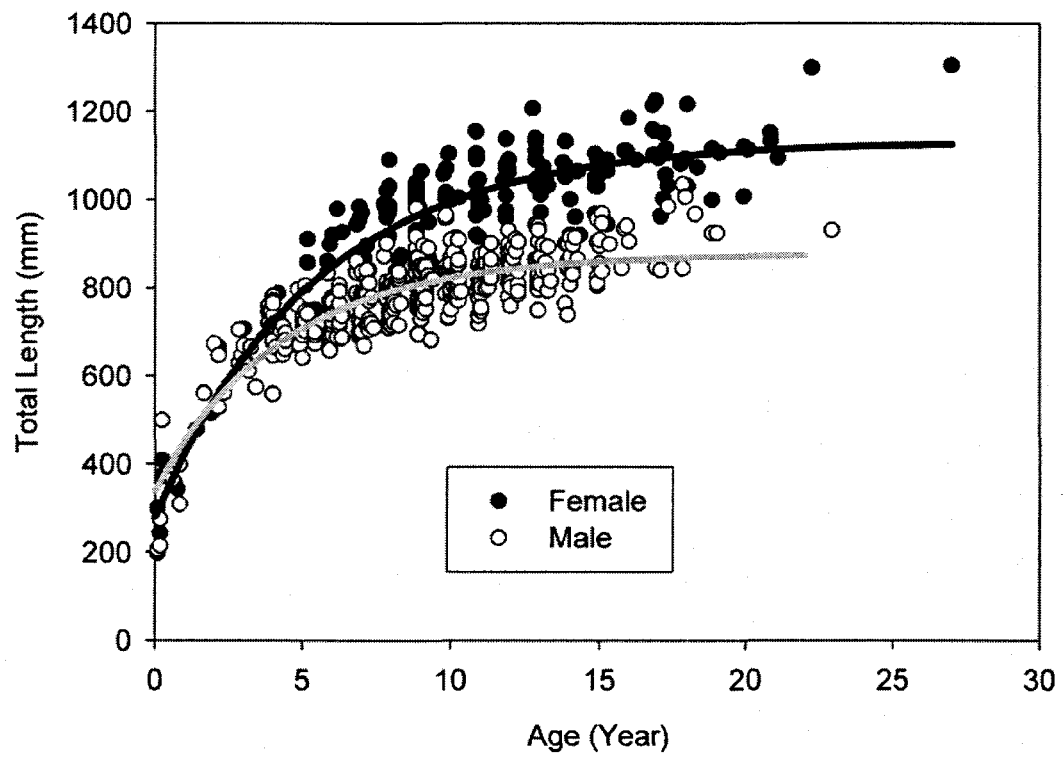


Figure 6. A) Fecundity vs. total length. B) Fecundity vs. eviscerated weight.

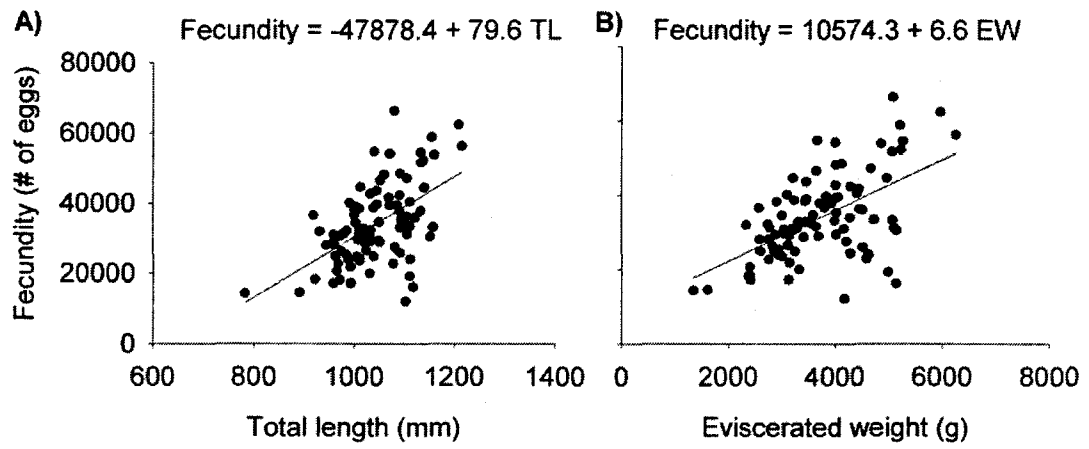


Figure 7. A) Egg size vs. total length. B) Egg size vs. eviscerated weight.

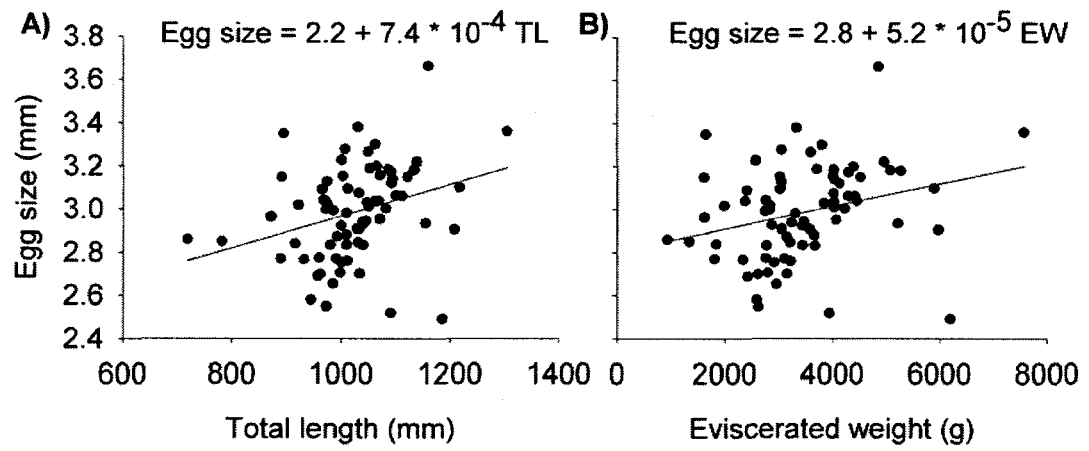


Figure 8. A) Female gonad weight vs. total length. B) Female gonad weight vs. eviscerated weight. C) Log of male gonad weight vs. log of total length. D) Log of male gonad weight vs. log of eviscerated weight.

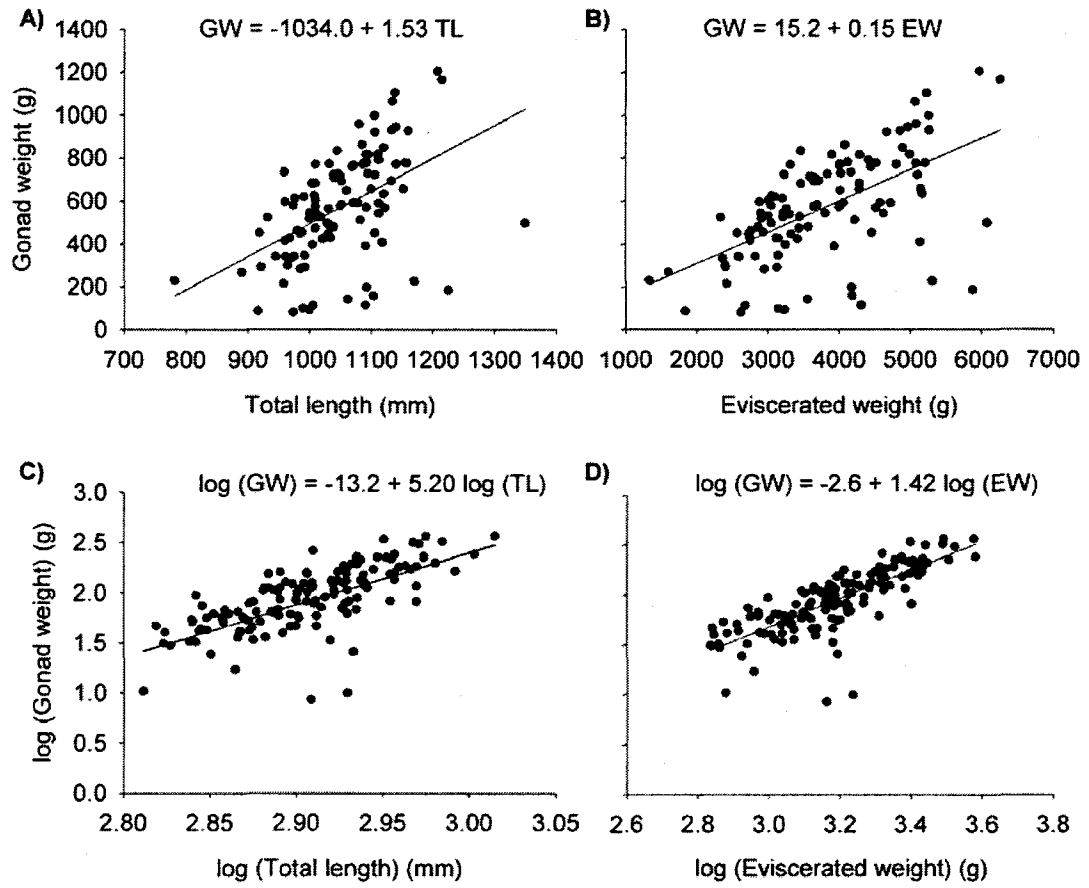
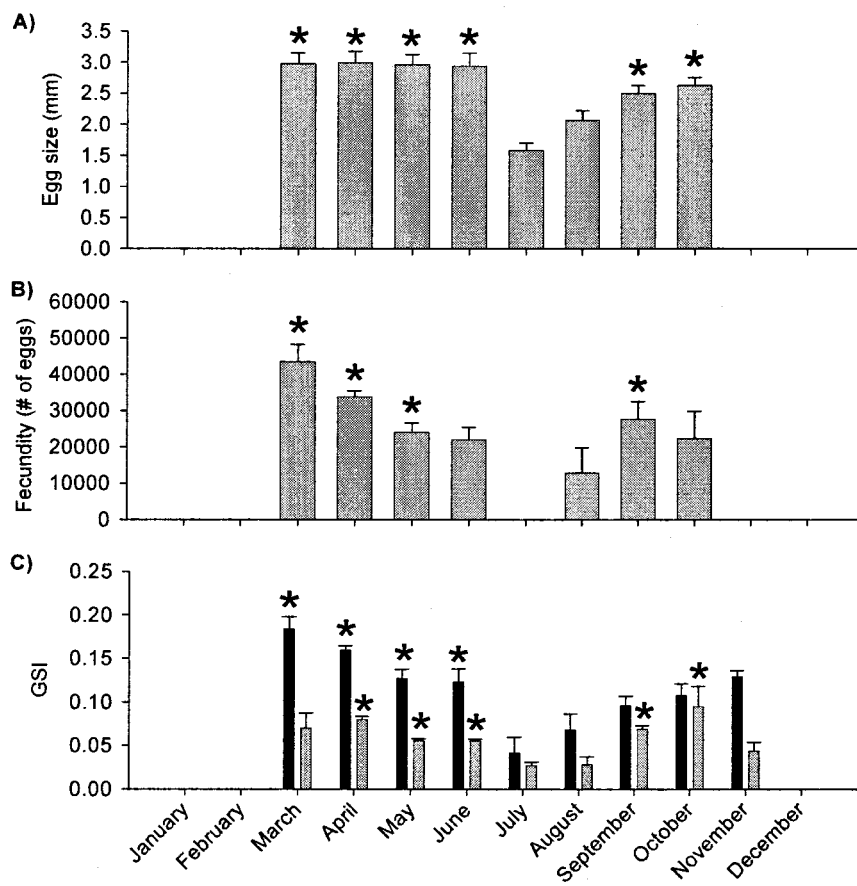


Figure 9. A) Egg size by month. B) Fecundity by month. C) GSI for both males and females by month. Star denotes significant difference from July.



Appendix 1. Four different age inputs (yearly and birthdate on January 1, May 1, and June 1) for the three different growth models tested, sex, AIC value, and parameter estimates.

age input	model	sex	AIC	L_{∞} or L_0	k	t_0	λ
June	VB	Female	1605.0	1132	0.18	-1.55	.
June	Gompertz	Female	1611.1	319	0.25	.	0.31
June	Logistic	Female	1619.0	1090	0.33	2.30	.
May	VB	Female	1622.3	1125	0.19	-1.76	.
Year	VB	Female	1622.3	1125	0.19	-1.76	.
May	Gompertz	Female	1626.3	346	0.27	.	0.30
Year	Gompertz	Female	1626.3	346	0.27	.	0.30
May	Logistic	Female	1632.3	1086	0.35	1.95	.
Year	Logistic	Female	1632.3	1086	0.35	1.95	.
January	VB	Female	1632.8	1124	0.20	-1.23	.
January	Gompertz	Female	1634.7	285	0.27	.	0.36
January	Logistic	Female	1639.6	1084	0.35	2.49	.
June	VB	Male	3264.5	875	0.23	-2.11	.
June	Gompertz	Male	3282.6	380	0.28	.	0.22
May	VB	Male	3284.0	877	0.23	-2.63	.
Year	VB	Male	3284.0	877	0.23	-2.63	.
June	Logistic	Male	3298.1	864	0.32	0.30	.
May	Gompertz	Male	3300.1	421	0.27	.	0.19
Year	Gompertz	Male	3300.1	421	0.27	.	0.19
January	VB	Male	3303.9	878	0.22	-2.21	.
May	Logistic	Male	3314.0	865	0.31	-0.16	.
Year	Logistic	Male	3314.0	865	0.31	-0.16	.
January	Gompertz	Male	3318.6	384	0.26	.	0.21
January	Logistic	Male	3331.1	867	0.30	0.28	.
June	VB	All fish	5996.7	961	0.25	-0.43	.
May	VB	All fish	6008.7	957	0.26	-0.34	.
Year	VB	All fish	6072.9	952	0.27	-0.53	.
January	VB	All fish	6084.4	950	0.27	-0.0016	.

CHAPTER 3:
**Sexual Dimorphism in Longnose Gar (*Lepisosteus osseus*) from Tidal
Rivers of Virginia**

ABSTRACT

Sexual dimorphism is common in fishes, and is often linked to aspects of mate recognition, male agonism, spawning behavior, and/or fecundity. Sexual dimorphism has been documented previously in two species of the family Lepisosteidae, *Lepisosteus osseus* and *L. oculatus*. Previous studies have demonstrated sexual dimorphism in total length, weight, and anal fin height. The present study of longnose gar dimorphism expands upon this previous work by examining a broader array of morphometric characters while removing the bias associated with overall body length. A stepwise discriminant function analyses (swDFA) found that five characters best distinguish the sexes: head width, mid-snout width, anal-fin height, anal-fin width, and pre-pectoral fin length. Discriminant function analyses (DFA) with the five characters yielded misclassification rates of 23.5% for females and 9.7% for males. Subsequent DFA using these six characters plus standard length yielded misclassification rates of only 8.8% for females and 6.2% for males. Our data reveal differences in head and anal-fin shape between male and female longnose gar that may have evolved to enhance predation or competitive abilities during reproduction. This study is the first to find that *L. osseus* exhibits sexual dimorphism in characters without the biases of overall size.

INTRODUCTION

Sexual dimorphism is one of the primary forms of intra-specific morphological variation in fishes (Hilton, 2002; Grande 2004; Hilton & Bemis, in press). Many fishes express such dimorphism, with differences in overall size being the most common (Parker, 1992). Sexual dimorphism in fishes may be associated with mate recognition, spawning behavior, greater female fecundity, and inter- and intra- sexual competition (Breder and Rosen, 1966; Parker, 1992; Komagata *et al.*, 1993; Oliveira and Almada, 1995; Britz and Bartsch, 1998; Love, 2002). Specialized sexually dimorphic characters also may develop in association with specific spawning behaviors, such as nest building or egg collecting (Britz and Barsch, 1998; Kitano *et al.*, 2007). In many fishes, females are of greater body size than males of comparable age, allowing females to increase their relative reproductive output because the associated increase in body volume provides more room for the development and storage of more numerous and/or larger eggs (Parker, 1992). In many species in which males attain the larger sizes, male-male competition is often cited as resulting in the dimorphism of body size or character development, allowing these males to defend a particular spawning location or partner (Parker, 1992). Inter-sexual competition may also produce larger male characters and/or sex-related colour differences for purposes of attracting spawning females (Seehausen *et al.*, 1998). Sexual dimorphism is most often

subtle but its identification is an important first step in a better understanding of ecology of a species.

In the family Lepisosteidae, sexual dimorphism has been documented in two species, spotted gar *Lepisosteus oculatus* Winchell and longnose gar *L. osseus* (L.). *Lepisosteus oculatus* from southern Louisiana were found to be sexually dimorphic by Love (2002): females are significantly longer and have longer snouts than males when mass and age are taken into account. Love (2002) hypothesized that the greater size of females enables them to produce larger and more numerous eggs, but did not discuss the possible selective advantage of the snout length dimorphism. Female *L. osseus* also attain greater total lengths than do like-aged males (Netsch and Witt, 1962; Klassen and Morgan, 1974; Johnson 1994, Johnson and Noltie, 1997), and larger weights, pelvic girths, anal-fin heights (= anal-fin length), and anal girths (Johnson, 1994). However, it remained unknown which, if any, characters best differentiated between the sexes independent of total length. The time of year and reproductive stage might have also affected the significance of longnose gar pelvic and anal girth.

This study tested for sexual dimorphism in *L. osseus* by analyzing head, body, and fin measurements while removing the bias associated with standard length. The measurements examined were also independent of reproductive condition. The possible roles of the sexually dimorphic

characters in light of the species' ecology, as well as the uses of our discriminatory ability in field studies, are discussed.

MATERIALS AND METHODS

SAMPLING

In 2008, 256 longnose gar (176 males, 80 females) were collected from March to October in tidal portions of the rivers James, Mattaponi, Pamunkey, and York, Virginia (Fig. 1). Most of the specimens (222 of 257) were collected during a gillnet survey of *L. osseus* (P.E. McGrath, unpubl.) in the rivers Mattaponi, Pamunkey, and York (York River system). The remaining specimens were taken from all five rivers during separate surveys being conducted by the Virginia Institute of Marine Science (VIMS).

MEASUREMENTS

All individuals were dissected to determine sex and life history stage (i.e., immature vs. mature; Ferrara and Irwin, 2001). Longnose gar exhibit rapid growth in their first year of life (Netsch and Witt, 1962; Klaassen and Morgan, 1974; Johnson and Noltie, 1997; Ferrara, 2001; PEM, unpubl. data); therefore, measurements were restricted to fish 400 mm standard length (L_s) and larger.

The 11 body measurements we made on each specimen included L_s (= snout tip to dorsal insertion of caudal fin), anal-fin base length (= distance between insertion of anteriormost and posteriormost anal-fin rays), anal-fin height (= base to distal end of first anal-fin ray), snout length (= snout tip to corner of the mouth), mid-snout width (= width of snout at mid-point of snout length), head length (= snout tip to posterior margin of extrascapular), head width (= width of head, including opercles, at posterior margin of extrascapular), prepectoral-fin length (= snout tip to anterior insertion of pectoral fin), prepelvic-fin length (= snout tip to anterior insertion of pelvic fin), predorsal-fin length (= snout tip to anterior insertion of dorsal fin), and preanal-fin length (= snout tip to anterior insertion of anal fin) (Fig. 2). All measurements were taken with a meter stick to the nearest millimeter, except for those under 100 mm, which were taken with calipers and measured to the nearest 0.1 mm.

ANALYSES

All statistical analyses were performed in SAS[®] (SAS Institute, Inc., Cary, NC; <http://www.sas.com>). In the first examination of the data, frequency distributions by sex were constructed for all measurements. The frequency distribution of each of the character measurements was then tested for normality (Kolmogrov-Smirnov test) to determine whether further data transformations were required to meet underlying analysis assumptions.

Next, the ten head, body, and fin measurements were regressed against L_s and the residuals were employed in a stepwise discriminant function analysis (swDFA) to determine which of the 10 characters best classified gar according to sex. Three separate swDFA methods were used (forward, backward, and stepwise selection) to test for agreement (Weiner and Dunn, 1966; Lachenbruch, 1975). Standard length was not included in these swDFAs because the goal here was to determine which characters best discriminate sex apart from overall body size, which had previously been shown to be sexually dimorphic (Netsch and Witt, 1962; Klassen and Morgan, 1974; Johnson 1994, Johnson and Noltie, 1997; McGrath, unpublished).

Two discriminant function analyses (DFA) were then performed, the first using the residuals of the characters selected by the swDFAs, and the second using these plus L_s . Cross validation was used to test the effectiveness of both DFAs, and the error rates were recorded (Quinn and Keough, 2002). For each character selected by the swDFA, we also used covariance analyses (ANCOVA) to test character size differences between the sexes with respect to L_s . Each ANCOVA model used the raw character measurement as the dependent variable, sex as the independent variable, L_s as the covariate, and $\text{sex} * L_s$ as the interaction term. If the interaction term was not significant, the regression slopes were deemed homogeneous and the ANCOVA was re-run without the interaction term. If the interaction term was significant, a t-test was used to test for gender differences in the

regression slopes. Because most specimens came from the York River system, between-river comparisons were not made.

RESULTS

The sexes in our sample were of similar minimum sizes (415 mm L_s female; 433 mm L_s male), but females attained a much larger maximum size (1208 mm L_s female; 892 mm L_s male; Table 1). The frequency distributions of 13 of the 22 sex-specific standardized character measures tested proved normal, and those failing the normality test were near-normal. Consequently, additional data transformations were deemed unwarranted.

All three swDFA selection procedures identified head width, mid-snout width, anal-fin height, anal-fin base length, and prepectoral-fin length as the best predictors of sex. Using these five characters simultaneously yielded error rates of 23.5% for females and 9.7% for males (average error rate of 16.9%). The addition of L_s to the DFA yielded much lower error rates (8.8% for females, 6.2% for males, and 7.5% for the average). Most of the error was eliminated with only the addition of three of the six measurements: mid-snout width, head width and L_s (average error rate of 9.0%).

According to the ANCOVAs, sex was only significantly different in three of the five characters selected by swDFA (mid-snout width, head width, and anal-fin base length), while L_s (the covariate) was always significant. The

three significantly different characters also increased with L_S at the same rate for both sexes (i.e., homogenous slopes); therefore, the interaction term was removed. Males had a larger mid-snout width (sex: $df=1$, $F=68.0$, $p<0.001$; L_S : $df=1$, $F=1530.7$, $p<0.001$), head width (sex: $df=1$, $F=46.57$, $p<0.001$; L_S : $df=1$, $F=3633.8$, $p<0.001$), and anal-fin base length (sex: $df=1$, $F=8.7$, $p=0.004$; L_S : $df=1$, $F=1275.2$, $p<0.001$) than females of a similar size. Sex was an insignificant factor in the measurements of anal-fin height (sex: $df=1$, $F=1.5$, $p=0.217$; L_S : $df=1$, $F=388.4$, $p<0.001$; L_S *sex: $df=1$, $F=2.8$, $p=0.096$) and prepectoral-fin length (sex: $df=1$, $F=0.9$, $p=0.340$; L_S : $df=1$, $F=3011.9$, $p<0.001$; sex* L_S : $df=1$, $F=8.8$, $p=0.003$).

DISCUSSION

In previous studies, longnose gar were shown to exhibit size sexual dimorphism, with females attaining longer body lengths and greater weights and pelvic girths than do males (Netsch and Witt, 1962; Klassen and Morgan, 1974; Johnson 1994; Johnson and Noltie, 1997). However, in Johnson's (1994) study, only individuals collected en route or leaving the spawning grounds were examined or measured. All the measurements analyzed by Johnson, except anal-fin height and total length, were potentially biased by reproductive condition. Additionally, raw measurements were employed in that study and no attempts were made to account for either size or mass of the individual. Unlike these previous studies of *L. osseus*, our study indicated

statistically significant dimorphism in head shape and anal-fin measurements with methods that avoided complications due to overall fish body size.

Our ability to correctly classify the sex of individual longnose gar was comparable to that of Johnson (1994). However, a greater than 80% correct classification rate was achieved without using L_S and using the residuals of the characters. Residual analysis freed the results from total length bias by not examining the raw data, in which females have larger body characters than males overall, but by examining how the sexes differed at each size from a common regression. Only three of the five head, body, or fin measurements selected for the DFA were significantly different between the sexes. Further exploration of the data found that most of the error was eliminated with three of the six measurements: head width, mid-snout width, and standard length. This reduction in number of characters to measure without a great increase in error rates enables future tagging studies to minimize handling fish while acquiring data to predict the sex of an individual.

FIN DIMORPHISM

Anal-fin measurements were found to significantly decrease our classification error rates in our DFA. However, only anal-fin base length was significantly different, with males having a longer fin base than females of similar sizes. Johnson (1994) found that anal-fin height also added significantly to his DFA concerning pre-spawning individuals. He did not

report which sex had a longer fin or any statistics concerning differences between the sexes.

Longnose gar are not unique in exhibiting sexually dimorphic anal fins, which occur in many groups of fishes (e.g., poeciliids, Constantz, 1989; cichlids, Oliveira and Almada 1995; mormyrids, Brown et al., 1996; polypterids, Britz and Bartch 1998; *Hiodon*, Hilton, 2002), and these have presumably evolved independently in response to different pressures. For example, in the Mozambique cichlid *Oreochromis mossambicus* (Peters), Oliveira and Almada (1995) hypothesized that larger anal and dorsal fins in males have arisen via intra-sexual competition, given that males erect these fins during agonistic male-male interactions, and that greater fins size maximizes the surface displayed to an opponent. In contrast, polypterids use their sexually dimorphic anal fins during inter-sexual interactions: during spawning, the male wraps his caudal and modified anal fin around the genital opening of the female to form a pocket to collect and hold the eggs that she releases (Britz and Bartch 1998). The male then fertilizes the eggs, after which he shakes his caudal region vigorously to scatter the eggs, which then stick to vegetation and other substrates. The function of the relatively longer anal-fin base in male longnose gar remains speculative. However, when spawning, gar courtship typically ends with a female, flanked by 4 to 5 males or more, coming to the surface and then rapidly swimming to the bottom where both sexes release their gametes while shaking their caudal regions

(Suttkus, 1963; Breder and Rosen, 1966; Haase, 1969; Johnson 1994). The effects of shaking the caudal region by the male may be enhanced by the presence of a long anal-fin base. This may help better distribute the milt evenly and into the protected interstitial spaces within the coarse substrate or vegetation over which the species usually spawns (Haase, 1969; Johnson and Noltie, 1996).

HEAD DIMORPHISM

The sexual dimorphism found in longnose gar head shape included males having significantly wider heads and mid-snouts relative to their body sizes than did females. Relatively larger head characters in males may help them defend preferred spawning sites and attract females. In longnose gar, males arrive at the spawning grounds first and leave last; suggesting, males may spawn with more than one female and that competition for access to females likely occurs (Johnson and Noltie, 1996). Although aggressive behavior between males has not been documented in this species, the larger head characters of males may relate to the nature of male–male interactions during the spawning season. A greater relative head size would aid in the defense of a preferred spawning area, which may be important if the availability of preferred spawning substrate is limiting. During our specimen collection in the tidal rivers of Virginia, longnose gar spawning events were frequently witnessed (PEM, unpublished). Although specific movements and behaviors were not quantified, spawning nearly always occurred over patches

of the aquatic macrophyte *Hydrilla verticillata* (L.f.) Royle. Egg collections from artificial spawning substrate placed within dense patches of *H. verticillata* confirmed these observations. This apparent specificity may render preferred spawning sites limited because water depth is dynamic in tidal rivers: eggs deposited too close to shore are subject to desiccation during extreme low tides, whereas deeper waters may prohibit adequate vegetation growth. Consequently, male-male competition may be important during the occupation of prime spawning locations.

Love (2002) found snout length to be significantly different between male and female spotted gar. Among lepisosteids, longnose gar are easily distinguished from their congeners by having comparatively longer and narrower snouts (Suttkus, 1963). This elongation results in a low mechanical advantage and a high transmission of motion to the jaws (Kammerer et al., 2006), enabling individuals to open and close their jaws quickly and thereby facilitating the rapid lateral slashing capture of fast-moving prey items. Lepisosteid jaw length differences have been linked to diet and the prey of *L. oculatus* is comprised of a greater variety of invertebrates and of fewer fish than *L. osseus* (Goodyear, 1969; Tyler and Granger, 1984). Thus, the selection pressures that contributed to the evolution of snout length dimorphism in *L. oculatus* likely differ from those facing *L. osseus*.

APPLICATION

The longnose gar is one of seven extant species of the two genera (*Lepisosteus* and *Atractosteus*) in the family Lepisosteidae (Suttkus 1963). Lepisosteids have been present in North America for approximately 100 million years (Wiley, 1976; Wiley and Schultze, 1984), and represent a unique component of the extant fish fauna of North and Central America and Cuba (Suttkus, 1963; Lee et al., 1983). Although longnose gar are often thought of as locally common, they are considered rare or extirpated on the margins of their range (e.g., Cooper, 1983; Kraft et al., 2006). Our findings suggest that longnose gar can be reliably sexed using external morphometric characters in such sparse populations. Although it remains to be determined if these findings are applicable to longnose gar from other portions of their range (e.g., non-tidal environments, different latitudes) or to other species of the family, this would facilitate assessment of the gender composition and demographics of populations in danger of local extinction while negating the need to sacrifice individuals for internal examination. This approach may also be applicable for other lepisosteids, especially those species that have shown significant declines in certain portions of their ranges. For example, the alligator gar, *Atractosteus spatula* (Lacepède), has been extirpated from many portions of its historical range and is listed as endangered or threatened by several states (Ferrara, 2001; Simon, 2006). Thus, our approach to identification of the sex of individuals, if applicable to other lepisosteids, may have valuable conservation implications.

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Figure 1. Collection localities in Virginia tidal rivers for specimens of *Lepisosteus osseus* used in this study.

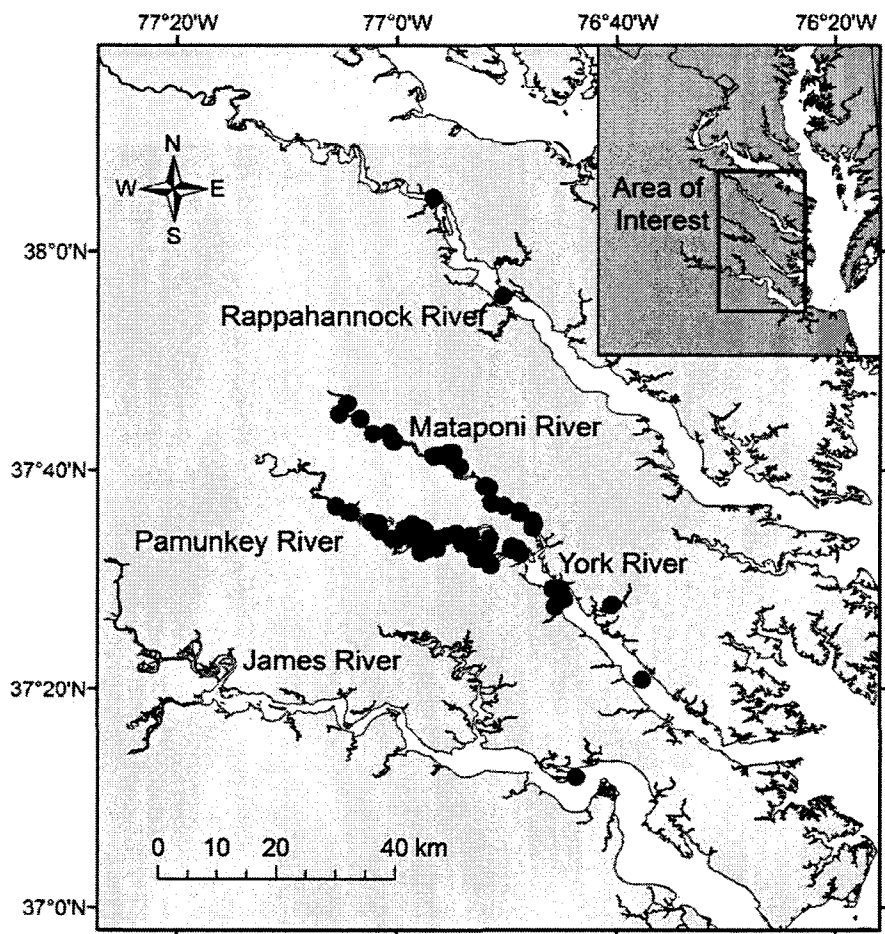


Figure 2. Measurements of *Lepisosteus osseus* taken in this study.

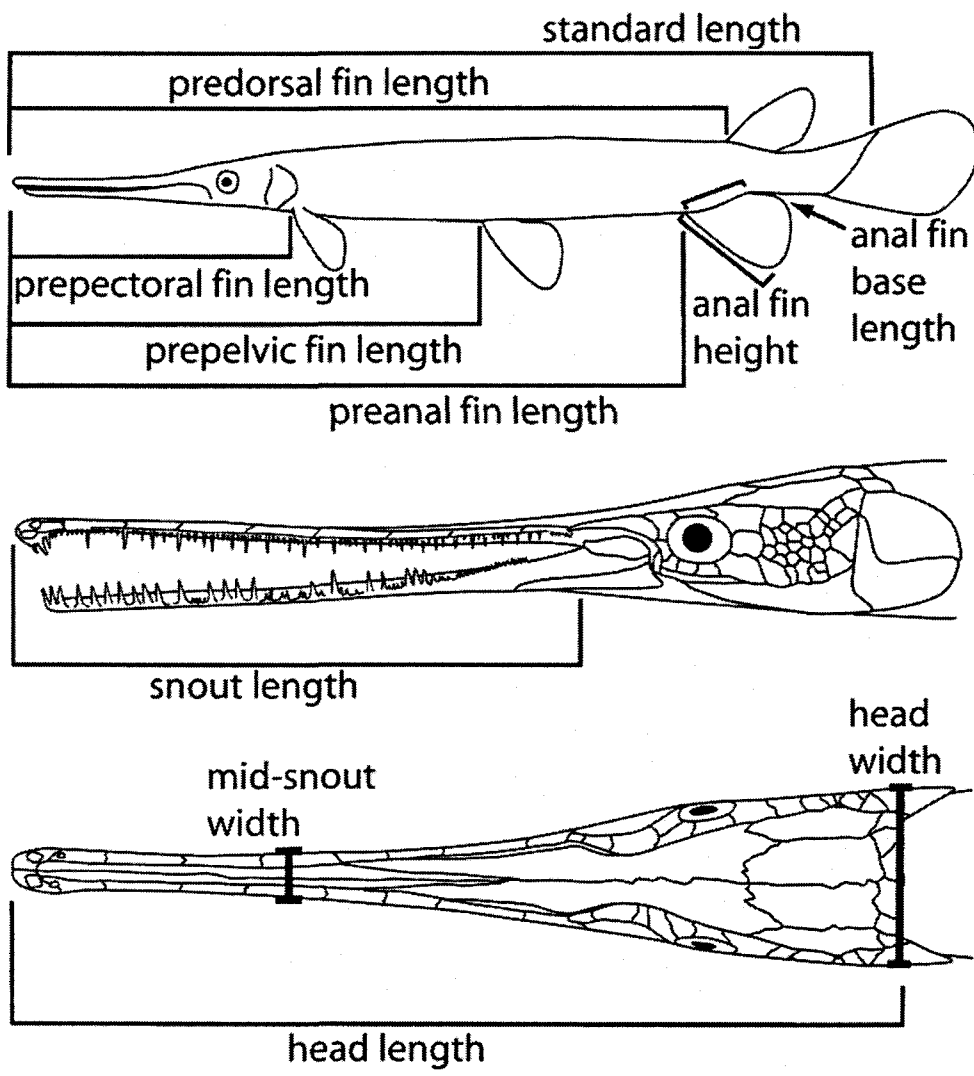
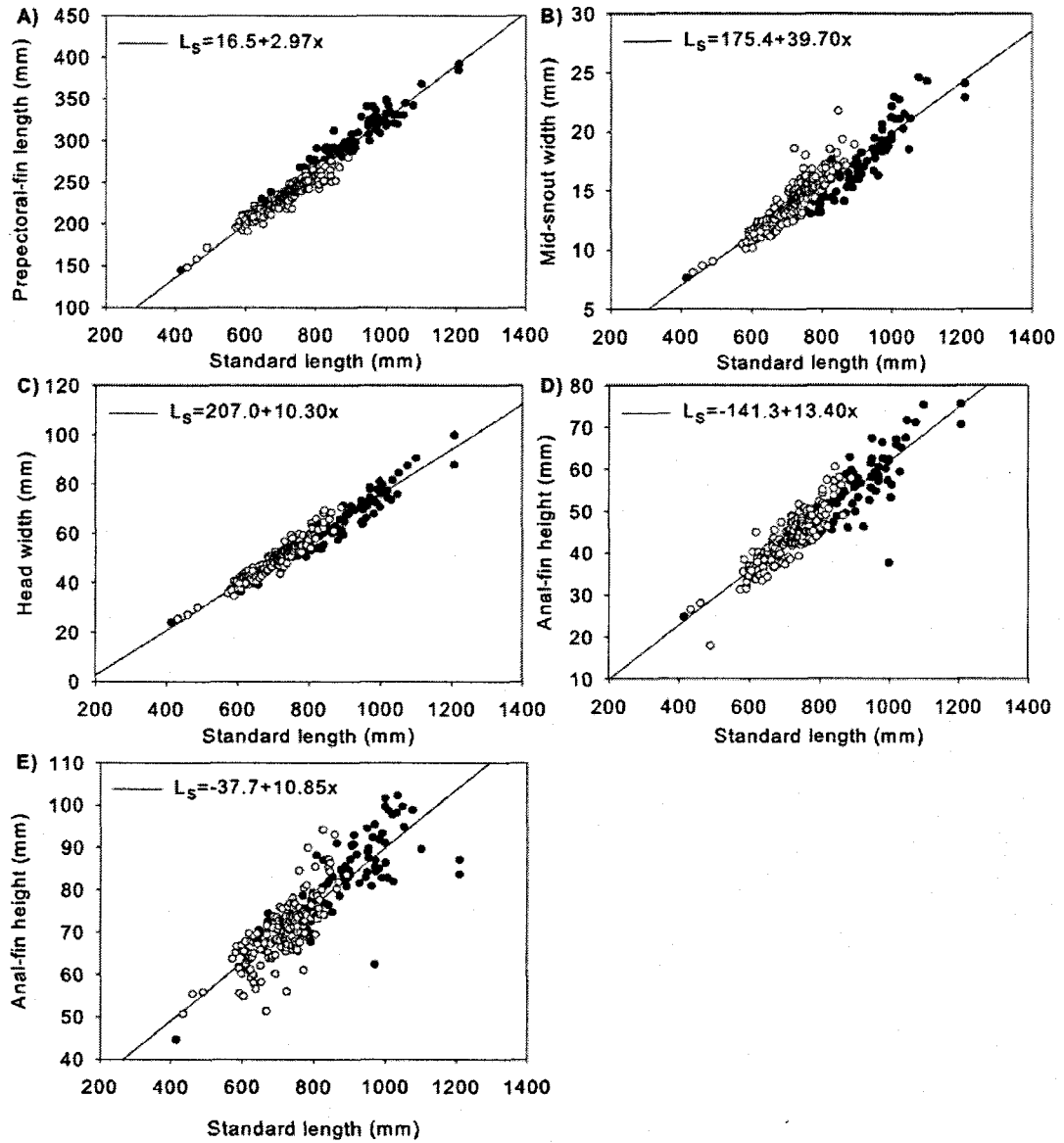


Figure 3. Regressions of the five measurements used in the discriminant function analysis (●, female; ○, male). A) Standard length vs. prepectoral-fin length. B) standard length vs. mid-snout width. C) standard length vs. head width. D) standard length vs. anal-fin height. E) standard length vs. anal-fin base length.



CHAPTER 3:

**First examination of seasonal distributions and movements of longnose
gar (*Lepisosteus osseus*) within the York River System, Virginia**

Abstract

Seasonal movements are common in many species of fishes, and can be related to spawning, environmental changes, or feeding. The seasonal movements of longnose gar are largely unknown, and the goal of this project was to characterize these movements by using both acoustic and conventional tagging methods and by examining historical catch records from a trawl survey. This study focused on a population in a tidally influenced river system in Virginia, and represents the first time that movements have been studied for an estuarine population of longnose gar. Longnose gar proved difficult to recapture and relocate during this study, possibly due to their long distance movements. Two individuals moved 69 and 74 km, which is greater than the distance observed in the only other report long-distance movement in this species. Spawning data were collected from two tagged longnose gar recorded by a passive listening station at a known longnose gar spawning location. Spawning residency time was approximately one month and tidal periodicity was observed for one of the tagged fish. This is also the first report of winter distributions of longnose gar. Winter locations occurred both inshore and mid-channel and the distributions were similar to those in the summer and fall.

Introduction

Fish movements can be short or long in duration, and may show daily or seasonal patterns. Short movements include avoiding predators or environmental stressors and locating prey and suitable habitat (Helfman et al. 2009). For species that exhibit site fidelity, these movements typically occur within an individual's home range, over the course of a day or a week, and often are correlated with total length (Minns 1995). Longer movements can also involve finding prey or suitable habitat and avoiding environmental stressors, but also include spawning. Many fishes undergo short or long spawning movements to find either suitable mates or habitat. Spawning movements are undertaken at many scales. Diadromy is one extreme in this behavior, but even many land-locked species move tens of kilometers to locate suitable spawning habitat (potomodromy) (Dodson 1997). Longer movements are typically seasonal and may be correlated with temperature, photoperiod, or hydrological data. Other factors such as latitudinal position or water body type also play important roles in both long and short movements (Helfman et al. 2009). It is important to understand both types of movements to describe the ecology of a species. Additionally, it is important to characterize the movements of species from different portions of their range and from different habitats, as these factors can affect the pattern and timing of movements. For instance, a latitudinal pattern in the amount of time spent in brackish water has been described for *Acipenser brevirostrum* Lesueur (shortnose sturgeon; Kynard 1997) and divergent migration patterns have been described for *Morone saxatilis* Walbaum (striped bass) from

different portions of its range (Rulifson et al. 1987; Dorazio et al. 1994; Haesaker et al. 1996).

Lepisosteus oculatus Winchell (spotted gar) were tagged with radio transmitters in the Lower Atchafalaya River Basin, Louisiana and were monitored throughout the year (Snedden et al. 1999). Areas of relocation were found to be the largest during the spring and smallest during the fall-winter. Movements increased as the water temperature and river stage rose in the spring and included the inundated floodplain, which provided spawning habitat. *Atractosteus spatula* Lacepède (alligator gar) have also been tracked in the Mobile-Tensaw Delta, Alabama and found to have linear ranges between 2.73 and 12.25 km (Sakaris et al. 2003). There has yet to be a study utilizing acoustic tags to examine movements and habitat preferences of longnose gar. Spawning appears to be the driving force for the furthest movements of lepisosteids, but it is unknown if this is also true for longnose gar from tidal habitats (Johnson and Noltie 1996; Snedden et al. 1999; Sakaris et al. 2003).

The seasonal movements of *Lepisosteus osseus* L. (longnose gar) are largely unknown especially for populations inhabiting tidal estuaries. The available literature primarily concerns spawning movements of entirely freshwater populations. Spawning movements of longnose gar have been characterized through conventional tagging as broad and extensive. Lacustrine longnose gar are known to migrate into lake tributaries to spawn, and Johnson and Noltie (1996) found the spawning migration to be positively correlated with stream flow and water level, and negatively correlated with temperature.

Longnose gar displayed a small degree of yearly site fidelity (12.5%) to the spawning ground, and fish were recaptured up to 48 km away after the spawning season (Johnson and Noltie 1996).

The goal of this project was to characterize the seasonal movements of longnose gar by using both acoustic and conventional tagging methods and by examining historical catch records from a trawl survey. The focal population of this study was in a tidally influenced river system in Virginia, and represents the first time that the movements have been studied from an estuarine population of longnose gar. The emphasis of this study was on the spawning movements and spawning-site fidelity in this population. These results were compared to those of Johnson and Noltie (1996), who focused on the spawning movements and habits of lacustrine longnose gar. Finally, the resulting movement, location, and habitat data were compared to previous work on lepisosteids.

Field Site Description

The Mattaponi and Pamunkey Rivers converge at West Point, VA to form the York River (Figure 1). These three rivers make up the York River System (YRS), which is the fifth largest tributary of Chesapeake Bay. The YRS is composed of a main channel that can vary between 6 and 14 m, with broad, shallow shoals less than 2 m in depth (Nichols et al. 1991; Reay and Morre 2009). The channel bed is dominated by a mud bottom, with occasional sand and shell, whereas the shoals are typically sandier (Friedrichs 2009). The mouth of the YRS is polyhaline with average tides of 0.7 m, whereas the upper reaches of

the Mattaponi and Pamunkey are freshwater with a tidal range of 1 m (Sisson et al. 1997; Reay and Moore 2009). Temperatures vary considerably with season, ranging from 0 to 31 °C (Murdy et al. 1997). Nine tidal wetland community types make up the YRS, ranging from Saltmarsh Cordgrass to Tidal Freshwater Mixed (Perry and Atkinson 2009). Submerged aquatic vegetation is dominated by *Zostera marina* L. (eelgrass) and *Ruppia maritime* L. (widgeon grass) at the mouth of the YRS and *Hydrilla verticillata* (L.f.) Royle (hydrilla) in the tidal freshwater regions (Orth et al. 2005; Shields 2008; Moore 2009). Sandy Point is located at RKM 75 in the tidal freshwater region of the Mattaponi River and is characterized by an approximately 10 m wide sand/mud shelf dominated by hydrilla. Freshwater marshes, with a mix of *Nuphar luteum* (L.) J.E. Smith (yellow pond lily), *Peltandra virginica* (L.) Schott (arrow arum), and *Pontederia cordata* L. (pickerel weed), occur on both the upriver and downriver sides of Sandy Point (McGrath pers. obs.).

Methods

Historical data collected by the VIMS Juvenile Fish and Blue Crab Trawl Survey between the years of 1979 and 2008 were examined for temporal trends in abundance and location of longnose gar within the Pamunkey and York Rivers. This trawl survey collects fishes from fixed and random stations monthly using a 30-foot otter trawl with tickler chain. Trawling is not an ideal method of collecting longnose gar and the abundance data is not indicative of their overall abundance. However, a comparison of abundance between each fixed station

can provide useful distribution data. Abundance at the fixed stations and general collection locations of longnose gar were compared between Winter (December, January, and February), Spring (March, April, and May), Summer (June, July, and August), and Fall (September, October, and November).

Longnose gar were caught in four-hour gillnet sets and assessed for health status through visual examination for lacerations and swimming behavior. Longnose gar (n=74) were tagged in May and June (spawning months) of 2007 and 2008 with anchor tags at Sandy Point, a known spawning location on the Mattaponi River (McGrath et al. in preparation). Healthy longnose gar were tagged with anchor tags on the left dorsolateral part of the body posterior to the dorsal fin and then released back into the river at the same general location. Attempts to recapture anchor-tagged fish occurred during a 2008 gillnet survey (March-October) and during three days of gillnetting at Sandy Point during the spawning season (June) in 2009.

Longnose gar (n=17) were also tagged with thirteen radio and four dual radio/ultrasonic transmitters (Lotek Wireless Inc., Newmarket, Ontario) to further evaluate seasonal and spawning movements and habitat preferences (Table 1). The radio transmitters are limited to freshwater, while the dual radio/ultrasonic transmitters can be heard in both freshwater and marine habitats. All individuals were tagged during the spawning season and on the spawning grounds. In the Pamunkey River, longnose gar were tagged in a creek off the Cumberland Thoroughfare near the Cumberland Nature Preserve. In the Mattaponi River, longnose gar were tagged at Sandy Point (Figure 1). A greater number of

longnose gar were tagged in the Mattaponi River due to a 24-hour tracking system stationed at Sandy Point. Longnose gar were caught by tended gillnets and tail-roped at the rivers edge or alongside the boat until surgery could be preformed. Healthy longnose gar were then measured and fitted with acoustic tags. Tagging methods were similar to those of Sneddon et al. (1999). In brief, tagging consisted of drilling two small holes through the scale jacket at the base of the dorsal fin, threading a thin metal wire attached to the tag through holes in the fish and the tag, and then knotting the wire to ensure the tag remained in place. The wound was then rinsed with iodine and the longnose gar were held for at least 15 minutes to allow for recovery. Once fish were swimming normally, they were released and tracked periodically over the life of the tag.

A Lotek yagi antenna (used when salinity was less than 1 ppt), hydrophone (used when salinity was greater than 1 ppt), and receiver were used during the active tracking portion of this project. Active tracking consisted of searching for tagged fish during bimonthly gillnet sets at the two freshwater fixed stations in 2007 and monthly gillnetting trips in 2008 on the Mattaponi, Pamunkey, and York Rivers from RKM 40 to 107. Active tracking also occurred opportunistically in the summer when I traveled up and down the Pamunkey and Mattaponi Rivers with the Juvenile Striped Bass Seine Survey (RKM 33 to 55; in 2007 and 2008) and American Shad Pushnet Survey (RKM 79 to 131; in 2007). When a longnose gar was located, the following information was recorded: longnose gar number, position (eTrex GPS unit, Garmin, Olathe, KS), air temperature, water temperature, and salinity.

A fixed listening station was placed at Sandy Point on the Mattaponi River from March 2008 to July 2009 (Figure 1). This listening station aimed to detect fish at the spawning grounds 24 hours a day and recorded when tagged longnose gar arrived, the duration of their stay, and their departure from the spawning ground. The complete area of detection on the spawning grounds was unknown, although it covered at least from the shoreline to the edge of the channel (approximately 10 meters). The listening station was programmed to search for a signal every minute; although for the purposes of analyses we examined detections every fifteen minutes. This reduced the number of detections and made it easier to identify tidal movements and duration of stays within the detection zone. Tidal stages were broken into three parts: high tide, low tide, and intermediate tide. High tide was 90 minutes before and after slack high water, low tide was 90 minutes before and after slack low water, and intermediate tide was the time between high and low tide.

Fish were either categorized as dead, missing, or alive. Dead fish were either inactive for more than six months or were individuals with signals that were coming from land. Missing fish were individuals located on fewer than three days. Alive fish were located and displayed movement on three or more days. Dead and missing fish were removed from the analyses. ArcGIS (ESRI, Redlands, CA) was used to examine minimum distance moved and trends in movement patterns.

Results

Longnose gar tagged with anchor tags ranged in size from 668 – 1001 mm total length (TL); unfortunately, none of these individuals (n=74) were recaptured and will not be included in the movements or habitat discussion. A total of 17 longnose gar were tagged with acoustic tags in 2007 and 2008, and ranged in size from 736 – 1110 mm TL. Most of the tagged fish were either declared missing (n=8) or dead (n=4). Five fish were presumed to be alive and were located on three or more days.

Acoustically tagged longnose gar were relocated between March and August in temperatures ranging from 11-31°C, and no fish were relocated in water with salinity higher than 1 ppt. The average time between initial release and last detection was 182.6 days, and the range in days between initial release and last detection was 35-396 days. The average distance traveled was 31.4 km, although two longnose gar traveled much further, moving between the Mattaponi and Pamunkey Rivers. Longnose gar #11 (LNG11) was tagged in June 2007 at Sandy Point on the Mattaponi River, and was relocated in the Pamunkey River in March 2008 (Figure 1). The minimum in-stream linear distance traveled from the initial tagging location was 69 km. This fish remained in the same general location in the Pamunkey River for the next few months until the tag presumably died at the end of June. LNG14 was tagged at Sandy Point in May 2007 and not relocated again until August 2007 in the Pamunkey River (Figure 1). The minimum in-stream linear distance traveled from the initial tagging location was 74 km. This individual was then relocated in the same general area of the Pamunkey (RKM 73-75) several times until the tag presumably died in June

2008. LNG49 was relocated seven times over the course of 70 days (Figure 1). This fish slowly moved downstream (9 km) in the Mattaponi River until it was no longer detected in August of 2008. This could have been a result of tag malfunction or movement into brackish water where signals become more difficult to locate.

Two individuals (LNG21 and LNG22) were the only individuals to be located by the fixed listening station. LNG21 was never located with active tracking equipment. This fish was first relocated by the listening station 20 days after being tagged, when it remained within the area of detection during low tide for one hour before moving away once the tide began to flood. LNG21 returned into the area of detection 10 days later and remained there for the three hours surrounding low tide. On two separate days, this fish was located in the area of detection 17 times during low tide, once between tides, and never at high tide. LNG22 was located 4.8 km upstream six days after tagging. This was the only instance that this fish was found during active tracking. LNG22 was located by the listening station nine days after tagging. This fish continuously swam in and out of detection range for 12 days with the longest continuous detection lasting 25 hours. LNG22 was relocated by the passive listening station twice more during the next two weeks, both times lasting less than 15 minutes. The last detection occurred 35 days after the initial tagging event. LNG22 was located by the passive listening station 52, 46, and 67 times during high tide, low tide, and intermediate tide, respectively.

Longnose gar (n=225) were caught by the trawl survey from RKM 38 to 64 (Figure 2). Water temperatures ranged from 4 – 31 °C and salinity values ranged from 0 – 18 ppt. More than half of the individuals (n=150) were caught from the fixed stations (referred to as indexed fish). The upper three index stations (n=149 @ 130, 135, and 140) had higher catch totals than the lower two stations (n=1 @ 120 and 125). The distributions of indexed fish mimicked the distributions of longnose gar included from all stations. During the spring, all of the longnose gar were caught in the Pamunkey River and most of the indexed fish were caught at the station 140 (RKM 64; Figure 2b). An average salinity value of 0.4 ppt reflected the upriver spring distribution. Summer and fall distributions were spread throughout the Pamunkey and upper York Rivers. Summer and fall salinity values averaged 6 ppt and 9 ppt, respectively. The indexed fish in the summer were more heavily caught at station 130 (RKM 48) and then decreased with each upriver index station, while indexed fish in the fall were evenly spread between the upper three stations (Figures 2c and 2d). Winter catches were the lowest of all seasons with only occasional catches occurring throughout the Pamunkey and upper York Rivers (avg. salinity = 4 ppt; Figure 2a).

Discussion

Longnose gar proved difficult to recapture and relocate during this study. The complete lack of recaptures of fish tagged with conventional tags may result from a negative effect on the fish post-tagging, such as death or disease. A controlled study was not performed to examine mortality caused by tagging on

longnose gar. Johnson and Noltie (1996) also tagged longnose gar, using tags similar to those in the present study, and had a recapture rate of only 12.5%. Therefore, we believe that our failure to recapture tagged individuals was not due entirely to tagging mortality. The size of the longnose gar population, the size of the river system, and the number of tagged individuals might also affect tag recovery. Johnson and Noltie (1996) tagged twice as many fish as were tagged in this study and tagging and recovery procedures occurred in a small, clear water creek associated with a reservoir. This study was conducted on an unknown population segment of longnose gar in a relatively large, estuarine river system. If the population is large enough, our inability to recapture tagged fish might be due to an inadequate number of tagged fish. Most individuals captured by gillnet were sacrificed for life history analyses and only when a large number of fish were caught (or during occasional trips designated for tagging) did we tag individuals with conventional tags. This limited the number of fish that were tagged and possibly also the recapture success rate. The recovery effort in this study was also extremely small compared to that of Johnson and Noltie's ability to catch every single fish that entered far enough into the study creek. A more extensive multiyear conventional tagging study is needed to provide an estimate of population size, mortality, and movements.

Most acoustically tagged fish were declared missing or dead. A controlled tank study is needed to examine the effects of the surgical procedures and tag placement on longnose gar. It is unknown if these stressors affect the behavior or mortality of the individuals. Two previous studies on spotted and alligator gars

(Snedden et al. 1999 and Sakaris et al. 2003, respectively) also did not complete a controlled tank study. This should be the next step before proceeding with future lepisosteid tagging studies.

The acoustic tag types and the estuarine environment also played a negative role in our ability to relocate tagged longnose gar. Radio tags are designed for low-conductivity rivers, while the Mattaponi and Pamunkey Rivers are muddy and brackish below RKM 75 (Winter 1996). A test of the tags in the freshwater region proved that when the tags were submerged below 2 m the tracking antenna had to be within ten feet of the tag to hear the signal. This weak signal decreases the chances of locating a fish in wide rivers such as these. Acoustic tags alleviate the problem with brackish water, but their range is greatly diminished (Winter 1996). An attempt was made to locate longnose gar in brackish water with the dual radio/ultrasonic transmitters, but only one of the four fish was relocated (LNG49) and this fish was never relocated in brackish water. Longnose gar were caught during this and other projects in the brackish portions of the YRS, although our acoustic tagging study was unable to detect and describe longnose gar brackish water movements and habitats.

Despite the limitations of our study, the five individuals that were successfully tracked have increased our understanding of longnose gar long-range movements and spawning habits. Two individuals moved from the freshwater region of the Mattaponi River through brackish water and into the freshwater region of the Pamunkey River. The distance travelled by both fish (69 and 74 km) was greater than the only other report on longnose gar long-distance

movements, which recorded movements up to 48 km (Johnson and Noltie 1996). The longer distance traveled by fish in this study might be due to differences between the two different studies. Johnson and Noltie (1996) tagged fish in a small creek tributary of the Harry S. Truman Reservoir, while our study was done in a large riverine system. The long distance movements were also greater than the furthest known movements of acoustically tagged alligator gar (Sakaris et al. 2003). Typically, larger fish require greater space and move farther than smaller fish (Minns 1995; Jones 2005). However, only one third (n=5) of the tagged alligator gar in that study were relocated more than five times. Future studies on lepisosteids would benefit from tagging more individuals and tracking them with more advanced equipment. Further research is needed to properly investigate if longnose gar range further than alligator gar.

Based on the recapture results of Johnson and Noltie's (1996) study, we hypothesized that a few of the acoustically tagged individuals would return to their tagging locations, presumably their spawning grounds, in subsequent years. However, tagged longnose gar were not recaptured at the original tagging location the following year in our study. As noted above, however, the lack of recaptures in this study could be due to the limited number of fish acoustically tagged, of which only five were successfully tracked. This small number of tracked fish was insufficient when the expected return rate was at most 12.5% (Johnson and Noltie 1996).

Two tagged fish remained around the tagging location and were relocated by the listening station, providing some insight into possible spawning behavior.

LNG21 and LNG22 were tagged on May 16, 2008 and located periodically for one month. This time frame coincides with longnose gar spawning season and is consistent with previously reported spawning residency times (Johnson and Noltie 1996). Residence times on the spawning grounds ranged from 15 to 94 days, with males staying on the spawning grounds longer than females (Johnson and Noltie 1996). Unfortunately, complete residency times from this study are under estimates because it is unknown when each fish arrived at the spawning grounds. The cessation of spawning, based on not having recorded them again at the listening station, appears to have occurred during the same week in late June for both individuals. This time frame for the end of spawning was also confirmed with a lack of egg collections and a decrease in GSI values (McGrath unpublished data).

Although the total duration was similar, the behavior on the spawning grounds was markedly different between the two tagged longnose gar. LNG21 was only located within the area of detection during low tide. Spawning at low tide may enable longnose gar to locate areas of vegetation that remain submerged at the lowest water levels, preventing the eggs from desiccating. Conversely, LNG22 did not display tidal periodicity, but rather swam within the area of detection at all stages of the tide cycle evenly. This fish was also located more often and remained within the area of detection for longer periods of time, although it is impossible to determine if courtship or spawning was occurring during this entire time or only around low tide. LNG22 displayed a flight response immediately after tagging, and was relocated upstream of the tagging location.

However, this individual, unlike most of the other tagged fish, returned to the area of tagging after nine days. If this flight response is a common reaction in this species it may explain why most of the tagged fish were never relocated at the original tagging location or within the area of detection at the Sandy Point spawning grounds. Additional acoustic tagging needs to be completed to examine if a flight response is common and if it affects natural spawning behavior.

Snedden et al. (1999) found shortnose gar to have larger areas of relocation in the spring (265.1 ha) and similar, smaller-sized home ranges in the summer (10.5 ha) and fall to winter (6.2 ha). The more extensive spring area was presumed to be associated with shortnose gar moving into flooded areas to spawn. Unfortunately, our acoustic tagging study did not capture the seasonal movements of longnose gar, but we can hypothesize that longnose gar also undergo extensive movements during the spring spawning season due to long distance movements of two tagged fish, lack of fish remaining near the spawning site, and Johnson and Noltie's (1996) results. The trawl survey data suggested upriver movements of longnose gar during the spring, possibly correlated to spawning. After the spawning season longnose gar appear to disperse, with summer distributions occurring farther down river. Catches were most evenly distributed among all sites during the fall and winter. This is the first report of winter distributions of longnose gar and although catches were far fewer in the winter, the locations where fish were found were similar to those in the summer and fall.

Habitat use by longnose and shortnose gars is markedly different.

Shortnose gar were more often located in oxbows and still, backwaters versus the main river channel (Holloway 1954, Goodyear 1967, Snedden et al. 1999, Robertson et al. 2008). Spotted gar were also shoreline orientated, preferred submerged branches as cover, and avoided areas of exposed bank (Snedden et al. 1999). In contrast, longnose gar were commonly found in the main river instead of the oxbows and can be associated with either the shoreline or mid-channel (Goodyear 1967; Robertson et al. 2008; McGrath pers. obs.). Future research, especially in locations where the congeners are sympatric, should examine if habitat differences translate into differences in sizes of utilization areas. Further acoustic tagging on longnose gar in estuarine, riverine, and lacustrine habitats is also warranted to examine if differences exist between longnose gar activity ranges in different habitats.

Conclusion

This study represents the first attempt to acoustically tag longnose gar to describe seasonal and short term movements and the first to examine the movements and distribution of longnose gar inhabiting an estuarine river system. Long distance movements and spawning site residency and behavior were recorded for a few individuals, but additional tagging studies are needed to confirm these results. This project provides the first description of spawning residence times for longnose gar in tidal rivers; however, many questions remain regarding their behavior at spawning locations in tidal systems versus those in

non-tidal freshwater lakes and rivers. Additional acoustic tagging studies, and where possible visual studies, are needed to determine spawning site residency times, spawning-site fidelity during one year and between years, and possible intermittent use of spawning sites coinciding with tidal periodicity. Identification of the sex of the tagged individuals (e.g., see McGrath and Hilton in review) will also enable future tagging studies to better examine the spawning behaviors of males and females. Spotted gar used areas of vastly different sizes during each season (Sneddon et al. 1999), and it is still unknown if longnose gar behave in the same way. This study is also the first description of longnose gar winter distributions, which were similar to areas utilized during fall and summer. Further research is warranted on the behavior and distribution of longnose gar to have a more complete understanding of these apex predators within the ecosystem.

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Table 1. Date, tag model, tagging location, size, time between initial tagging and last position recorded, number of relocations, minimum distance traveled, and status of acoustically tagged longnose gar.

Fish #	Date	Tag model (life span in days)	River	Size (mm TL)	Duration (days)	Relocations	Min. Distance (km)	Status
11	6/6/2007	MCFT-3FM (472)	Mattaponi	1110	383	14	69.0	Alive
12	6/7/2007	MCFT-3FM (472)	Pamunkey	880	356	9	3.7	Dead
13	5/25/2007	MCFT-3FM (472)	Pamunkey	1002	1	1	0	Missing
14	5/16/2007	MCFT-3FM (472)	Mattaponi	1018	396	11	74.0	Alive
15	5/25/2007	MCFT-3FM (472)	Pamunkey	860	345	5	3.5	Dead
16	6/6/2007	MCFT-3FM (472)	Mattaponi	900	1	2	0	Missing
17	5/16/2007	MCFT-3FM (472)	Mattaponi	857	335	3	1.2	Dead
18	5/10/2008	MCFT-3FM (472)	Mattaponi	801	74	7	7.0	Dead
19	5/10/2008	MCFT-3FM (472)	Mattaponi	736	12	2	2.0	Missing
20	5/16/2008	SR-TP11-25 (497)	Mattaponi	885	1	1	0	Missing
21	5/16/2008	SR-TP11-25 (497)	Mattaponi	885	29	19	0.2	Alive
22	5/16/2008	SR-TP11-25 (497)	Mattaponi	836	35	167	4.8	Alive
23	5/22/2008	SR-TP11-25 (497)	Mattaponi	885	1	2	0.2	Missing
46	6/5/2008	CS-11-25 (418)	Mattaponi	998	1	1	0	missing
47	5/22/2008	CS-11-25 (418)	Mattaponi	971	26	2	0.6	missing
48	5/22/2008	CS-11-25 (418)	Mattaponi	1085	1	1	0	missing
49	6/3/2008	CS-11-25 (418)	Mattaponi	900	70	7	9.0	alive

Figure 1. Locations of the five successfully tracked longnose gar, tagging areas, and listening station.

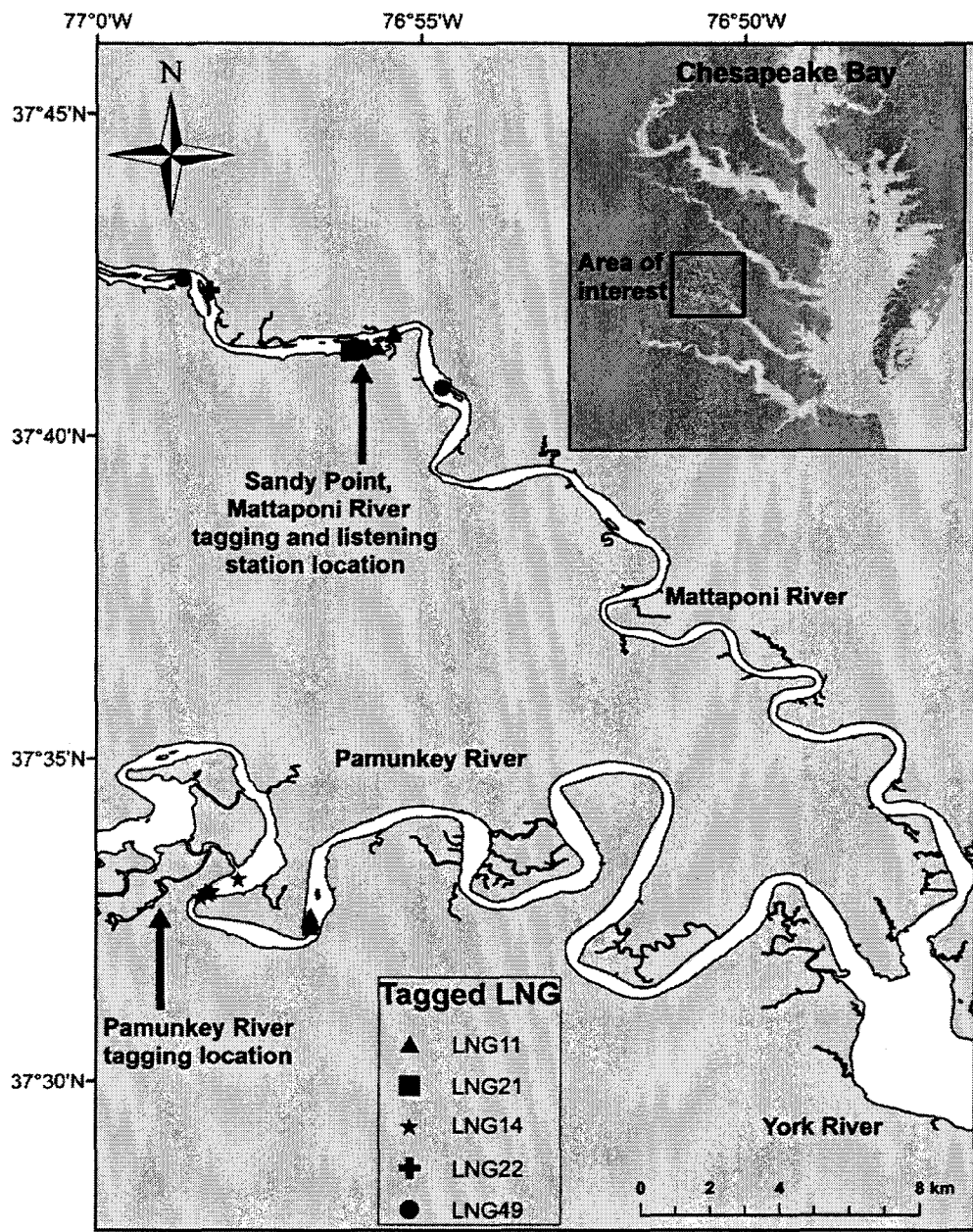
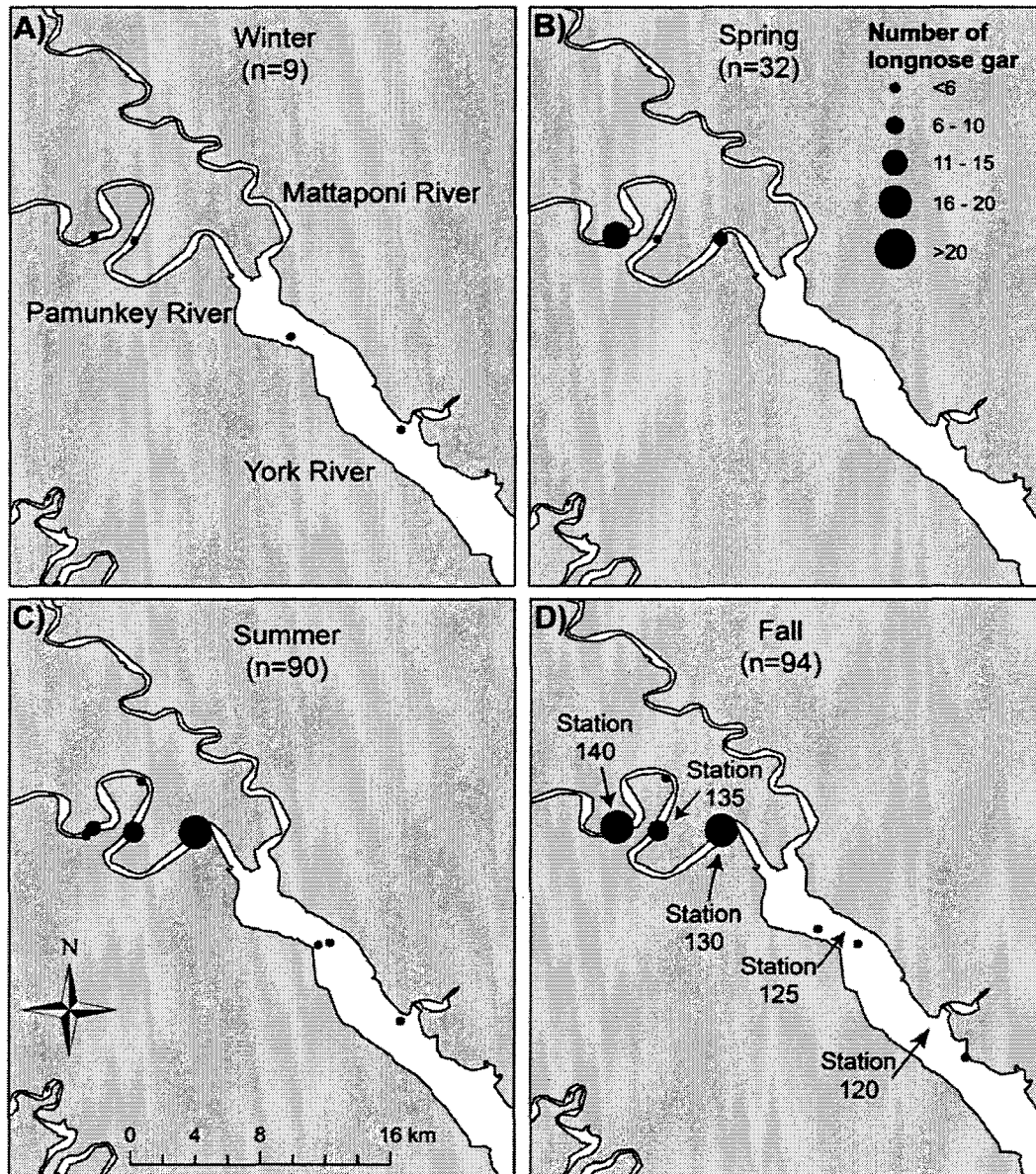


Figure 2. Location of VIMS juvenile finfish and blue crab trawl survey index stations and seasonal catch distributions and totals from 1989 – 2008. A) Winter. B) Spring. C) Summer. D) Fall.



CHAPTER 4:

The diet of longnose gar, *Lepisosteus osseus*, an apex predator in the tidal tributaries of Chesapeake Bay

Abstract

Chesapeake Bay is the largest estuary in the United States and comprises vast areas of polyhaline to freshwater, tidal fish habitat. These areas include nursery grounds that provide protection from large ocean predators, while supporting an abundance of prey for estuarine dependent fishes. However, a few large piscivorous species, such as longnose gar, are abundant in fresh and brackish nurseries and the impact of their predation is poorly understood. This study aimed to characterize the diet of longnose gar from tidal rivers in Virginia. The top five prey types were white perch, menhaden, killifishes, Atlantic croaker, and spot. Percent weight and number indicated that both marine and anadromous fishes (%W = 59.4%, %N = 56.5%) and resident fishes (%W = 40.6%, %N = 43.5%) were equally important in the diet of longnose gar. The diet composition varied with the seasonal prey fish assemblages, longnose gar length, and salinity, reinforcing the categorization of this species as an opportunistic predator. The seasonal influx of anadromous or coastal spawning fishes appears to be an important prey source for longnose gar in the upper estuaries of Chesapeake Bay.

Introduction

Chesapeake Bay is the largest estuary in the United States and has several tributaries, both large and small feeding into the Bay, which comprises vast areas of fish habitat in the form of polyhaline and tidal fresh water estuaries (Pritchard 1952). Many marine fishes in the Mid-Atlantic region of the western North Atlantic are estuarine dependent and utilize estuaries as nursery grounds, which provide higher survival rates for larval and juvenile fishes than coastal habitats (Beck et al. 2001; Able 2005). A diverse fauna of over 200 species of fishes reside in the Bay and its tributaries during at least some point during the year (Murdy et al. 1997). However, only about 30 species are year-round residents due to the extreme temperature differences between the winter and summer (Murdy et al. 1997). Many of the seasonal species are juveniles of marine or diadromous fishes. In spring, anadromous fishes, such as the striped bass (*Morone saxatilis*) and American shad (*Alosa sapidissima*), enter the rivers of Chesapeake Bay to spawn (Bilkovic et al. 2002). Juveniles of these fishes remain in the rivers for at least the summer, if not for several years, and utilize the tributaries as nursery grounds. Larvae of coastal spawning fishes, such as spot (*Leiostomous xanthurus*) in the spring and Atlantic croaker (*Micropogonias undulatus*) in the fall (Cowan and Birdsong 1985) also use the Bay as a nursery ground. These coastally spawned fishes reside in the Bay and tributaries at least seasonally where the larval and juvenile stages grow and escape the large predators of the open ocean (Beck et al. 2001; Able 2005). However, a few predatory species, such as longnose gar (*Lepisosteus osseus*), reside in the

tributaries, but predator-prey relationships within these tributaries have been poorly studied and ecosystem management plans need to include the fish mortality that occurs from this source of predation.

The longnose gar is an apex predator most commonly found in freshwater, but also in brackish, and occasionally in marine waters (Suttkus 1963). Longnose gar are common in the estuaries of the St. Lawrence River, Gulf Coast, and the southeastern US, including the tidal tributaries of Chesapeake Bay (Jean 1946; Goodyear 1967; Murdy et al. 1997). They are primarily piscivorous, and whereas their diets differ by location, they typically feed on the most abundant prey types; the longnose gar therefore has been characterized as a generalist predator (Seidensticker 1987). Longnose gar prey predominantly upon forage fishes (primary and secondary consumers), with clupeids forming the most common prey, followed by cyprinids, fundulids, and atherinids. Game fishes (secondary and tertiary consumers) are also consumed, but to a lesser extent, and include ictalurids, yellow perch (*Perca flavescens*), *Esox* spp. and centrarchids (Cahn 1927; Rimsky-Korsakoff 1930; Scott 1938; Lagler and Hubbs 1940; Bonham 1941; Frisby 1942; Lagler et al. 1942; Holloway 1954; Goodyear 1967; Suttkus 1963; Haase 1969; Crumpton 1970; Toole 1971; Seidensticker 1987; Tyler et al. 1994). Young-of-the-year (YOY) longnose gar diets are poorly known and the little research completed has found larval fishes and cladocerans to be important prey items (Eschelle 1968; Haase 1969; Eschelle and Riggs 1972; Pearson et al. 1979).

Most ecological information concerning longnose gar, including diet studies, come from studies on longnose gar inhabiting non-tidal habitats. The species is abundant in several major estuaries, but data concerning life history or predatory characteristics from these populations are lacking (Jean 1946; Suttkus 1963; Goodyear 1967). The only study concerning estuarine longnose gar was based in Mississippi (Goodyear 1967) and found the diets to be dominated by gulf menhaden (*Brevoortia patronus*). In that study, longnose gar fed on a size range of gulf menhaden from 3.2 – 21.0 cm TL, with juveniles constituting the bulk of the prey types. It was not uncommon to find a longnose gar stomach containing as many as 17 juvenile gulf menhaden (Goodyear 1967).

The present paper aimed to characterize the diet of a large size range of longnose gar over inhabiting tidal rivers in Virginia. We examined the stomach contents of longnose gar to determine if there were any differences among the diets of fish partitioned by sex, body size, river, month, and salinity. We also analyzed diets to determine whether longnose gar were preying more heavily on resident species or marine and anadromous species. We hypothesized that longnose gar diet would reflect the dynamic environmental conditions and resultant distribution of fish assemblages of Chesapeake Bay, and that the seasonal influx of juveniles of marine and anadromous fishes would be an important source of energy for longnose gar. Finally, we compared the length of prey items consumed to the length of longnose gar to examine if diet changed during ontogeny.

Methods

Longnose gar were collected opportunistically and through directed sampling from the tidal portions of eight Virginia rivers between 2005 - 2010. Collections occurred throughout the York River System (YRS; = York, Poropotank, Pamunkey, and Mattaponi Rivers) and locally in the James, Rappahannock, and Potomac River systems (Figure 1). Opportunistic specimens were provided from the by-catch of the Maryland Striped Bass Spawning Stock Survey, Maryland Juvenile Striped Bass Seine Survey, VIMS Striped Bass Spawning Stock Survey, VIMS Juvenile Fish and Blue Crab Survey, VIMS American Shad Pushnet Survey, VIMS Juvenile Striped Bass Seine Survey, VIMS American Shad Spawning Stock Survey, and VDGIF electroshocking surveys. In 2007 and 2008, a directed effort to catch longnose gar was employed in the YRS. In 2007, this directed effort consisted of four-hour gillnet sets (two nets, 55.5 m² total area per net, 10.2 cm monofilament mesh) every other week from March to November at three fixed stations. One fixed station was located on the Poropotank River and represented individuals residing in a mesohaline environment. The other two fixed stations were on the Pamunkey and Mattaponi Rivers and represented individuals residing in freshwater and on typical spawning grounds (Figure 1). Collections increased to once a week at the two locations on the Pamunkey and Mattaponi Rivers during the spawning season (April to July).

In 2008, the directed effort consisted of a stratified, random sampling design from March to October in order to increase the spatial and temporal

coverage within the YRS. The YRS was divided into twelve ten-kilometer sections beginning at river-kilometer (RKM) 40 on the York River and extending to RKM 3 on the Poropotank River and to RKM 107 in both the Mattaponi and Pamunkey Rivers. The Mattaponi and Pamunkey Rivers are extensions of the York River; therefore, RKM measurements begin at the mouth of the York River. Two monofilament gillnets (gillnet #1 = 55.5 m² total area, 10.2 cm stretched mesh bar; gillnet #2 = 55.5 m² total area, three equal-area panels, 7.6, 10.2, and 12.7 cm stretched mesh bar) were set for four hours each in randomly selected sections every month from March to October.

Additional collections occurred during the peak spawning season (late April to late June) in 2008. The Pamunkey and Mattaponi Rivers were divided into eight four-kilometer sections from RKM 87 – 119. Gillnets (n=8, four of both gillnets described above) were set for two hours each week in order to increase the spatial coverage of longnose gar at the spawning grounds. Gillnet locations were determined by dividing each four-kilometer section into one-kilometer subsections and randomly selecting one subsection each week.

Water temperature, air temperature, and salinity were measured and recorded at each gillnet location. Longnose gar were brought back to the lab and the following data were taken: total length (nearest mm), eviscerated weight (tenth of a g), and sex (Ferrara and Irwin 2007). The stomach was removed and placed in 70% ethanol for at least one week before the contents were removed and examined. Examination of stomachs and their contents consisted of recording weights for the stomach and contents and the stomach minus the

contents. The contents were then identified to the lowest taxon possible, measured, and weighed individually.

The percent of empty stomachs and a fullness index were examined monthly for trends in consumption. The fullness index (FI) was calculated as:

$$FI = \frac{\sum_{i=1}^n \frac{W_i}{E_i}}{n} * 100$$

where n = the number of stomachs collected in a month;

W_i = the total weight of stomach contents from longnose gar i ;

E_i = the eviscerated weight of longnose gar i .

Empty stomachs and stomachs containing unidentifiable material were removed from all future analyses. The mean percent weight (M%W) and mean percent number (M%N) were used to characterize overall diet. Mean percent weight of a given prey item was calculated as:

$$M\%W_i = \frac{\sum_{k=1}^m \frac{PW_{ik}}{TW_k}}{m} * 100$$

where PW_{ik} = weight of prey item i in stomach k ;

TW_k = total weight of prey items in stomach k ;

m = total number of stomachs.

Mean percent number of a given prey item was calculated as:

$$M\%N_i = \frac{\sum_{k=1}^m \frac{PN_{ik}}{TN_k}}{m} * 100$$

where PN_{ik} = number of prey items i in stomach k ;

TN_k = total number of prey items of stomach k ;

This method analyzes each stomach as if it was an independent unit and decreases biases as a result of a few stomachs containing an extraordinary number or weight of a rare prey item (Chipps and Garvey 2007). Percent occurrence (%O) was used to illustrate the frequency of a particular prey item in the diet. Percent occurrence was calculated as:

$$\%O = \frac{\sum_{i=1}^k F_{ik}}{m} * 100$$

where F_{ik} = an occurrence of prey item i in stomach k .

Canonical correspondence analyses (CCA; ter Braak 1986) were performed with the program CANOCO, vers. 4.5 (Microcomputer Power, Ithaca, NY) to examine the relationships between longnose gar diet and rivers, salinity, sex, longnose gar length, temperature, and month. The program was run twice, once with M%W and then once with M%N used to generate a response matrix for a given prey type and its given environmental variables. Canonical correspondence analyses were performed using methodology similar to that of Overton et al. (2009). In brief, M%W and M%N were transformed $\{\log_{10}(x+1)\}$ before analyses (Garrison and Link 2000). Month and river were coded using ordinal variables. Stomachs with prey items that occurred less than three times were excluded to eliminate variance issues related to small sample sizes (Latour

et al. 2008). Forward selection permutations tests were performed to test the statistical significance of environmental variables (Overton et al. 2009). If an environmental variable did not significantly add to the model, it was removed and the model was run again with the remaining variables. The final models were used to construct a biplot to examine the correlations between the factors and the canonical axes and to explore the trends of prey species associated with the environmental variables (Latour et al. 2008).

Comparisons between rivers were performed with a reduced data set because of a lack of spatial and temporal sampling in the James, Rappahannock, and Potomac River Systems. This CCA was performed with stomachs collected in water with salinity values less than 5 ppt and between April 1 and July 31. Each element of the response matrix was either M%W or M%N of a given prey type in a particular river, month, and longnose gar length combination. If river was found to significantly add to the model it was included into the CCAs and run with the full data set. CCAs run with the full set of data examined for trends between longnose gar diet and salinity, month, temperature, sex, and river (if found significant in the above CCA).

Percent weight (%W) and number (%N) of particular prey categories were used to measure the overall impact longnose gar may have on certain prey populations (Chipps and Garvey 2007). Percent weight was calculated as:

$$\%W_i = \frac{\sum_{i=1}^m PW_{ik}}{TW} * 100$$

Percent number was calculated as:

$$\%N_i = \frac{\sum_{i=1}^m PN_{ik}}{TN} * 100$$

The prey categories were marine/anadromous (transient) species versus resident species and game fishes versus non-game fishes. Changes in prey size with increasing longnose gar length were examined using a quantile regression technique (proc Quantreg; SAS 2000). Quantile regressions examined were the 5%, 50%, and 95% regression lines (Scharf et al. 2003; Overton et al. 2009).

Young-of-the-year longnose gar (total length <100 mm) were also collected during the summer of 2009 with fine mesh dipnet and a fine mesh seine (1.5 m x 2.0 m) at Sandy Point on the Mattaponi River. Individuals collected were either put on ice or placed into 70% ethanol soon after capture and returned to the lab, where they were measured (TL, nearest mm) and weighed (nearest 0.1 g, only samples kept on ice). The stomachs were then removed and opened for identification of prey items. Prey was counted and identified, typically to the family level; weights were not obtained for the prey items collected in YOY longnose gar. These samples were not included in the statistical characterization of longnose gar diets. Young-of-the-year longnose gar stomachs were analyzed separately and analyses consisted of examining the percentage of empty stomachs, %O, and M%N.

Results

Overall diet characteristics

Longnose gar (n=642) were collected in all 12 months; all individuals collected from December to March had empty stomachs. Longnose gar were collected in water temperatures from 1.9 to 30.7 °C and salinities ranging from 0 to 21.5 ppt. Total lengths of longnose gar ranged from 104 to 1305 mm with a mean of 838.2 mm. Empty stomachs (n=326) occurred in over 50% of longnose gar collected. The percentage of empty stomachs decreased in April and then rose again in June. Stomachs typically contained food items from April through the summer until November (Figure 2a). Changes in the fullness index were typically the converse of the percentage of empty stomachs. Low values were found in the late spring and fall, while higher values were obtained during the early spring, summer, and early fall (Figure 2b).

Stomachs containing prey items often were identifiable to the genus or species level (262 of 316 stomachs). Fishes formed 95.3% by %N and 99.8% by %W of the diet. The top five prey items by M%N, M%W, and %O were white perch (*Morone americana*), Atlantic menhaden (*Brevoortia tyrannus*), killifishes (*Fundulus* spp.), Atlantic croaker, and spot (Table 1, Figure 3). Atlantic menhaden had the second highest %O and was one of the top three prey items in each season and salinity range (Figures 4 and 5). Menhaden was also in the top three prey items for each size class except for ≤ 600 mm TL (Figure 6). White perch and *Fundulus* spp. were most commonly found in stomachs collected during the spring and from waters with salinities < 5 ppt (Figures 4 and 5). White perch also had the highest %O and was a common prey item for longnose gar > 600 mm TL (Figure 6). *Fundulus* spp. were one of the top three prey items in

longnose gar <800 mm TL (Figure 6). Atlantic croaker and spot were common prey items during the summer and fall and from waters with salinities >5 ppt (Figures 4 and 5). Spot was also one of the top three prey items found in longnose gar between 801-1000 mm TL (Figure 6). Bay anchovy (*Anchoa hepsetus*) and *Menidia* spp. were important prey items for longnose gar ≤600 mm TL (Figure 6).

Percent weight and number indicated that both marine and anadromous fishes (%W = 59.4%, %N = 56.5%) and resident fishes (%W = 40.6%, %N = 43.5%) are equally important in the diet of longnose gar. The diet of longnose gar was also equally formed by game fishes and non-game fishes by %N (49.5% and 50.5%, respectively), but game fishes (66.6%) form a greater percentage by %W than do non-game fishes (43.4%).

Longnose gar diet and environmental variables

Based on CCAs no significant differences were found among longnose gar from the different rivers in terms of prey consumed during spawning months (M%W, $p=0.47$; M%N, $p=0.11$); therefore, river was excluded from further analyses. CCAs were then run with the full data set ($n=260$ stomachs; two stomachs were removed due to the occurrence of one rare prey item in each) and only sex (M%W, $p=0.06$; M%N, $p=0.08$) was found to be insignificant. The CCA models were run again without sex, and temperature (M%W, $p=0.018$; M%N, $p=0.004$), month (M%W, $p=0.013$; M%N, $p=0.002$), salinity (M%W,

$p=0.002$; M%N, $p=0.002$), and length (M%W, $p=0.002$; M%N, $p=0.002$) were significant in both models.

Most of the variability was explained with the first and second canonical axes (64.0% and 25.4%, respectively for M%W; 57.4% and 36.0%, respectively for M%N). Environmental influences were the same for both models.

Temperature, month, and salinity weighted heavily on the first canonical axis, while length weighted heavily on the second axis. Temperature and month were also closely correlated in both models (Figures 7 and 8).

Three distinct prey groups could be defined by plotting prey species (M%W and M%N) on the first two canonical axes of the CCA models (Figures 7 and 8). Group A included catfishes, white perch, and blueback herring (*Alosa aestivalis*) and was associated with early months and lower temperatures and salinities. Group B was associated with later months and higher temperatures and salinities. Prey items included hogchoker (*Trinectes maculatus*), spot, Atlantic croaker, and *Cynoscion* spp. Finally, group C was associated with shorter longnose gar and included *Menidia* spp., bay anchovy, *Fundulus* spp., and centrarchids. Group C could be further broken down into subgroups of prey items associated with higher (*Menidia* spp. and bay anchovy) and lower salinities (*Fundulus* spp. and centrarchids).

Relationship between size of longnose gar and prey

Longnose gar used in the prey size regressions averaged 853.7 mm TL with a range of 24.1 to 1305 mm TL. The mean size of prey items consumed was

106.7 mm. Prey sizes ranged from 6.6 to 291 mm and the range of prey size increased with predator length (Table 1; Figure 9). The mean regression equation (50% quantile) was prey length = $-17.95 + 0.1441 * \text{longnose gar length}$. The slope of the 5% quantile regression (slope=0.093, intercept=-28.49) was significantly different than the 95% quantile regression (slope=0.1999, intercept=3.5; $z=4.85$, $p<0.001$). Longnose gar ≤ 600 mm TL did not consume prey larger than 70 mm. Larger longnose gar consumed larger prey, but also continued to eat prey less than 70 mm. The average size of the top five consumed prey items were: white perch (127.8 mm, $n=91$), menhaden (121.9 mm, $n=95$), *Fundulus* spp. (48.1 mm, $n=43$), Atlantic croaker (113.0 mm, $n=49$), and spot (107.4 mm, $n=41$; Figure 10).

Young-of-the-year longnose gar stomach analyses

Young-of-the-year longnose gar ($n=25$) were collected in June and July and ranged from 19 – 26 mm TL. Only 12% of the YOY fish had empty stomachs. The most common prey items were cladocerans with a M%N value of 71.8% and occurring in 86.4% of stomachs with prey items. Calanoid copepods occurred in 31.8% of the full stomachs and had a M%N value of 11.8%. Unidentified larval fishes (M%N = 9.6, %O = 13.6.), dipteran larvae (M%N = 4.8%, %O = 9.1%), and ostracods (M%N = 2.0%, %O = 27.3%) were also found in the stomachs of YOY longnose gar (Figure 11). The larval fishes (six total fishes found in three stomachs) were difficult to identify due to lack of scales and advanced state of digestion, although we believe that two of the remains were

larval *Fundulus* spp. and one other fish was either a larval longnose gar or larval needlefish. Stomachs with larval fishes had nothing or very little else in the gut.

Discussion

Chesapeake Bay and its tributaries act as nursery grounds for many species of fishes with comparatively fewer large predators exist in the upper parts of tributaries, especially in the mesohaline to freshwater environments. Longnose gar is one of those predators and its diet was found to be almost exclusively piscivorous. Longnose gar can be considered opportunistic because their diet was not dominated by any one species. Instead, at least five prey types occurred in greater than 10% of the stomachs and at least 22 different species of fishes were identified. Opportunistic behavior is common in lepisosteids (Crumpton 1970; Seidensticker 1987; Robertson et al. 2008). Longnose gar also fed on a variety of ecologically different prey items, including benthic (ictalurids, hogchokers, and sciaenids), mid-water to surface (clupeids), and near-shore (fundulids) associated species. Such diverse feeding locations have also been described for longnose gar in freshwater systems (Crumpton 1970; Toole 1971; Seidensticker 1987; Tyler et al. 1994; Robertson et al. 2008).

The top five prey items are all highly abundant in Chesapeake Bay. Juvenile white perch, Atlantic croaker, and spot are among the top six species collected by the VIMS Juvenile Finfish and Blue Crab Trawl Survey (Tuckey and Fabrizio 2009). Menhaden and *Fundulus* spp. are not often collected in the trawl survey due to their ecology as either midwater (menhaden) or edge associated

fishes, but are also extremely abundant within the Bay (Hildebrand and Schroeder 1928; Murdy et al. 1997; Hewitt et al. 2009). These five prey items are important to commercial and recreational fisheries directly or as prey items for harvested species.

Atlantic croaker, spot, and white perch are common recreational and commercial fishes. The juvenile index for these three species has typically been below average with an occasional high recruitment during the past ten years (Tuckey and Fabrizio 2009). The poor recruitment could be attributed to fishing pressure, loss in estuarine habitat, or change in weather patterns (Norcross 1991; Murdy et al. 1997; Wood and Austin 2009). Unfortunately, data from this study was not sufficient to properly examine diet trends of longnose gar between years. Fluctuations in these prey populations, however, will likely be reflected in changes within longnose gar diets.

Fundulus spp. are important forage fishes and can often be found in the diets of small and large estuarine fishes (Rountree and Able 1992; Kneib 1997a,b; Tupper and Able 2000; Nemerson and Able 2003). Fundulids are typically associated with marsh or near-shore habitats and are an important trophic link between marsh productivity and open water (Kneib 1997b). Menhaden is also an important prey species, and also supports the largest commercial fishery in Virginia by pounds landed (Hartman and Brandt 1995; Austin and Walters 1998; Uphoff 2003). Menhaden was a common component of longnose gar diet, having been found in stomachs throughout the year and in each salinity zone. These results were similar to the only other estuarine

longnose gar diet study, in which gulf menhaden was the most abundant prey component (Goodyear 1967). Longnose gar residing in freshwater also consume clupeids as an important portion of their diet (Goodyear 1967; Crumpton 1970; Seidensticker 1987; Robertson et al. 2008). Menhaden are often essential prey items for large predators and an integral part of many American estuarine ecosystems (Hartman and Brandt 1995; Scharf et al. 2003).

Longnose gar diet and environmental variables

The percentage of empty stomachs indicated that longnose gar conduct little to no feeding during the colder months. This behavior is common in fishes and often fish become sluggish or go into a state of torpor during the cold months, living off the fat reserves acquired during the summer and fall (Craig 1977; Guillenot et al. 1985; Cunjak 1988; Hurst 2007). Our data indicate that longnose gar feed heavily during the early spring and then again in the summer and early fall months. The early spring feeding allows longnose gar to recover from their winter fast and helps them build reserves for nourishment during a decrease in feeding during the spawning season. Feeding picks up again in the summer and early fall, which enables longnose gar to have enough energy to prepare for next years spawning event, growth, and to build up fat reserves for the coming winter.

The first canonical axis from the CCA analysis corresponded to the dynamic environmental conditions within the Bay's tributaries and explained greater than 50% of the variation in the diet. These conditions affect the species

community, and in turn affect the prey available to longnose gar. Temperature and month were closely correlated and reflected the changing seasonal assemblages of Chesapeake Bay and its tributaries where pulses of fishes entering and leaving the Bay, continuously change the available food sources for longnose gar (Murdy et al 1997; Tuckey and Fabrizio 2009). The diet of longnose gar has previously been described to change with different prey pulses associated with river flood stage (Robertson et al. 2008). Salinity also dictated the prey fish assemblages available to longnose gar, with the diet changing from mostly freshwater species to marine species with increasing salinity.

Prey species plotted on the first two canonical axes separated into three distinct groups. Each group could be described by the environment, longnose gar behavior, prey behavior, or a combination of the three. Group A was defined as low salinity, early months, colder water species and was represented by both resident, freshwater fishes and anadromous species. Longnose gar move up into the freshwater portions of the river during the spring to spawn. This upriver movement coincided with the spawning movements of anadromous fishes, such as white perch (semi-anadromous) and blueback herring (*Alosa aestivalis*; Mansueti 1961; Jessop 1993). Examining the average size of these two species consumed by longnose gar during this time, both blueback herring (240 mm) and white perch (132 mm) were adults possibly moving upriver to spawn (Mansueti 1961; Jessop 1993). The spatially overlapping movements of longnose gar and spawning prey fishes enable longnose gar to feed on fecund fishes with a high caloric content.

Spawning by longnose gar occurs during the late spring, often on the shallow water margins of the river (Haase 1969; Goff 1984; Johnson and Noltie 1996). This timeframe coincided with when *Fundulus* spp. formed a large portion of their diet, along with the occasional juvenile ictalurid. Based on observations of spawning by Haase (1969) in Wisconsin, longnose gar generally remained on the spawning beds during the day with a limited amount of dispersal at night. The dedication to spawning may decrease feeding by longnose gar during this time. We noted an increase in the percentage of empty stomachs and a decrease in the stomach fullness index during this time. When feeding did occur, it was not uncommon to see four to eight fundulids in the stomach of a large adult longnose gar captured at a spawning location. *Fundulus* spp. and juvenile ictalurids may be an important portion of their diet and help to sustain energy during the spawning season without leaving the spawning area. Robertson et al. (2008) also found catfishes and clupeids, along with minnows and mayflies, to be important food items in the spring for longnose gar in the Brazos River, Texas.

Group B, with the exception of the hogchoker, included shelf and lower Chesapeake Bay spawning species. These species spawn in either the spring or late fall months, but the juveniles are most abundant in the Bay during the late summer and fall (Murdy et al. 1997; Tuckey and Fabrizio 2009). Juveniles and larvae of marine species presumably enter rivers to avoid large coastal and open bay predators, while exploiting the habitat with abundant prey (Beck et al. 2001; Able 2005). This is a period of time when these marine species and adult longnose gar would benefit to consume enough energy to build up fat reserves

for the winter and to acquire enough energy to produce gametes for the next year. Supporting the hypothesis that this is an important time of feeding is the decrease in the percentage of empty stomachs and an increase in stomach fullness index.

Group C included prey species consumed by the smaller longnose gar, which did not feed on prey items larger than 70 mm. This size class of longnose gar appears to be gape limited, as seen in our prey size versus longnose gar size regressions. This limitation is probably the reason smaller longnose gar preyed heavily upon forage fishes, such as bay anchovy, *Menidia* spp., *Fundulus* spp., and juvenile centrarchids. *Menidia* spp. were also the dominant prey items of small (115 – 306 mm TL) longnose gar in Lake Texoma (Eschelle and Riggs 1972). All of these prey species do not attain large adult sizes and are typically abundant throughout the year in Virginia waters (Jenkins and Burkhead 1994; Kneib 1997b; Murdy et al. 1997; Hewitt et al. 2009; Tuckey and Fabrizio 2009). Within group C we further distinguished two groups based on salinity. The smaller longnose gar caught in the freshwater areas fed primarily on *Fundulus* spp. and juvenile centrarchids, while longnose gar in waters with higher salinity fed primarily on *Menidia* spp. and bay anchovies. This salinity gradient associated with prey types also indicated that most of the prey types identified as *Fundulus* spp. were *F. diaphanus*, a killifish typically found in freshwater versus *F. heteroclitus*, which is found in water with a higher salt content (Fritz and Garside 1974). However, the decision was made to continue to lump the two species because both species can overlap and it was difficult to distinguish

between the species when examining the stomach contents of longnose gar (Baker-Dittus 1978).

Relationship between predator and prey size

Length of longnose gar explained a large portion of the variation in the CCA models and represented much of the second canonical axis. Both the maximum size and the size range of prey items increased with increasing longnose gar length. This was evidenced by a group of small-sized fishes (group C) being singled out for smaller longnose gar in the CCA analyses; in contrast one specific size class of prey could not be defined for the larger longnose gar. This study also saw the size range of prey items increase with increasing longnose gar length. Larger longnose gar preyed upon larger items, but also continued to feed heavily upon smaller fishes. The expansion of prey length breadth was also found by Robertson et al. (2008) when examining longnose gar weight versus prey length. Many prey items of the larger longnose gar were juveniles of marine and anadromous species, which formed about 50% of the diet of longnose gar. The average size of four of the top five prey items, menhaden, white perch, Atlantic croaker, and spot, were all less than 130 mm and within the size range for juveniles of these species (Tuckey and Fabrizio 2009). The opportunistic nature of longnose gar probably leads to the heavy dependence on the abundant juvenile species in Chesapeake Bay.

Young-of-the-Year Longnose Gar

Young-of-the-year longnose gar diets are poorly understood and have never been examined from a tidal river. Longnose gar absorb their yolk-sac and begin feeding around 18 – 20 mm (Eschelle and Riggs 1972; Pearson et al. 1979). The present study on YOY longnose gar stomachs is admittedly preliminary and an increase in the number of individuals, locations, and years collected will be important. Nevertheless, this study is the first examination into what YOY longnose gar are preying upon in a tidal system. Young-of-the-year longnose gar stomachs were typically full, most often with cladocerans. Cladocerans were also an important prey type in other YOY longnose gar studies (Eschelle 1968; Haase 1969; Eschelle and Riggs 1972; Pearson et al. 1979). Pearson et al. (1979) collected YOY longnose gar during the early summer for two straight years from the Ohio River, Kentucky and reported a vast difference in the diet between years. In the first year, the dominant prey type was cladocerans, with fishes constituting only 13.3% of the food types. The results from the second year were completely different; larval fishes formed 84.1% of the diet (*Notropis* sp. was the dominant piscine prey) and cladocerans were the second most important type. Larval fishes were not as important a prey type in our study as the second year of Pearson et al.'s (1979) study, but a few YOY fish were piscivorous. Calanoid copepods also occurred in greater than 30% of the stomachs and is probably another important source of nutrition. Cladocerans and calanoid copepods are abundant (Muffelman 2006; Steinberg and Condon 2009) and probably the most accessible prey type to YOY longnose gar. It is important

to continue to collect data on YOY longnose gar to examine if the diet composition we have witnessed is constant or variable.

Conclusions

This was the first study to analyze the diet of longnose gar, an abundant large piscivore in the tidal rivers of Virginia, which are the primary nursery grounds of many important marine and anadromous fishes. This is also only the second study to examine the diet of an estuarine population of a predominantly freshwater species. Longnose gar were mostly piscivorous and their diet changed with the dynamic environmental conditions of Chesapeake Bay, seasonal fish assemblages, and salinity, reinforcing their categorization as opportunistic predators. These results are similar to studies completed in freshwater systems. However, longnose gar in our study fed more heavily on game fishes than most studies to date, most likely due to the abundance of juvenile game fishes utilizing areas where longnose gar occur as a nursery ground (Bonham 1941; Goodyear 1967; Crumpton 1971; Toole 1971; Seidensticker 1987; Tyler et al. 1994). Juvenile fishes were an important component in the diet, many of which were marine or anadromous species. The behavior of both longnose gar and their prey also determined the dominant stomach contents. Spring diets involved anadromous and freshwater fishes such as blueback herring, white perch, catfishes, and *Fundulus* spp.; the latter two became especially important when longnose gar were on the spawning grounds.

Estuaries act as important nursery habitat for many marine, anadromous, and resident species (Beck et al. 2001; Able 2005; Kraus and Secor 2005). If further understanding of the natural mortality of these estuarine dependent fishes is to take place, greater knowledge must be acquired on one of the largest predators to inhabit the southeastern Atlantic, Gulf of Mexico, and Great Lake estuaries (Smith and Bean 1898; Hildebrand and Schroeder 1928; Jean 1946; Goodyear 1967; Hastings et al. 1987; Schwartz 2003). It will be important for future studies to estimate the population size of longnose gar in these systems and to better understand their seasonal and daily movements. This information, combined with the knowledge of the diet components presented herein, will permit a better understanding of the ecological role of longnose gar in tidal environments.

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Figure 1. Map of the Virginia rivers, longnose gar collection locations, boundaries of gillnet survey, and location of Sandy Point on the Mattaponi River.

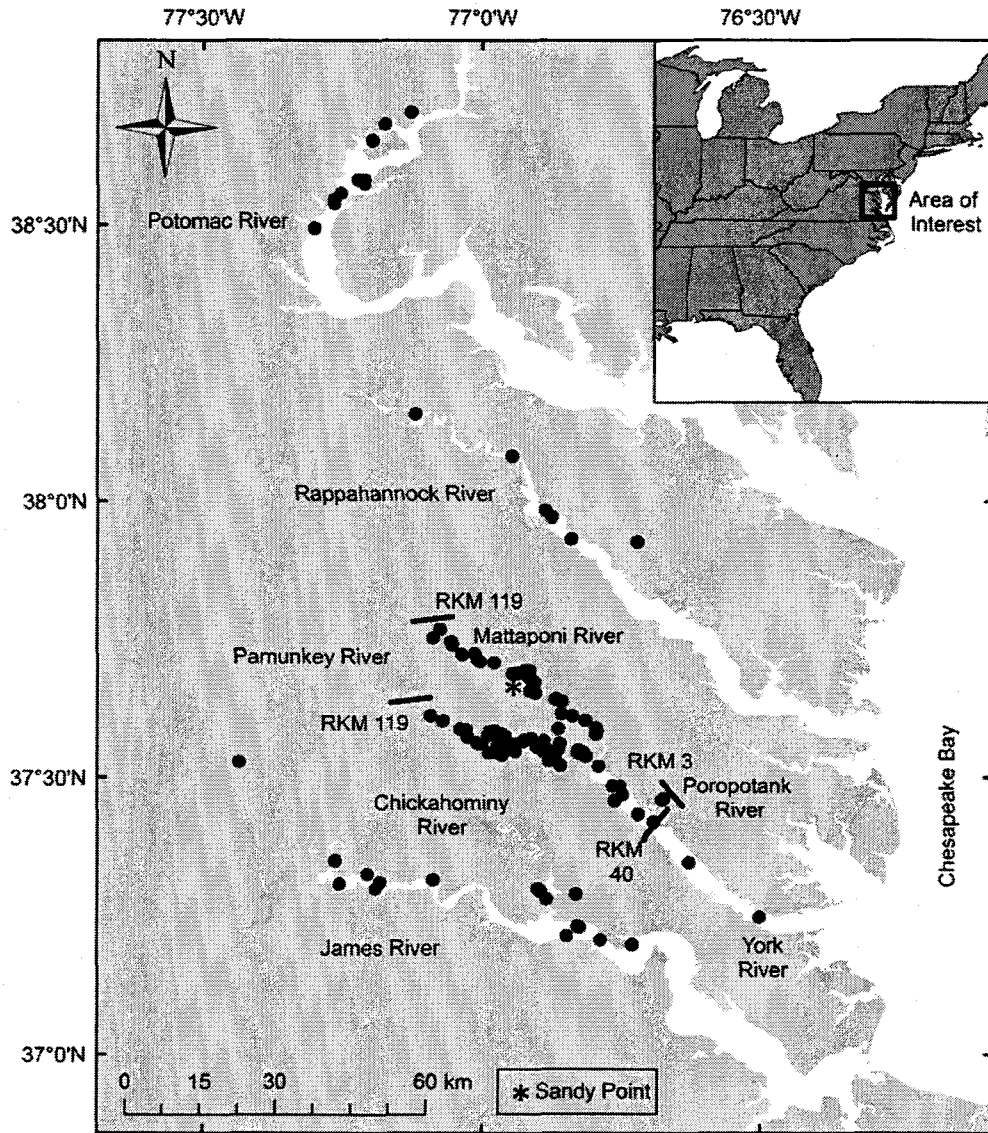


Figure 2. a) Percentage of empty longnose gar stomachs by month. b) Stomach fullness index by month.

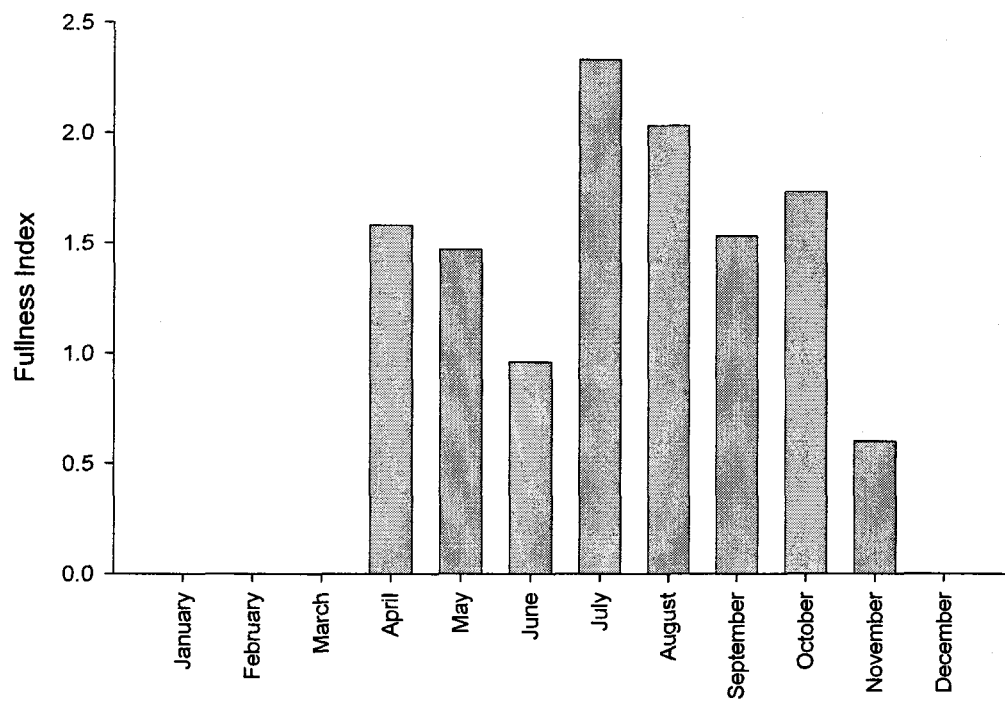
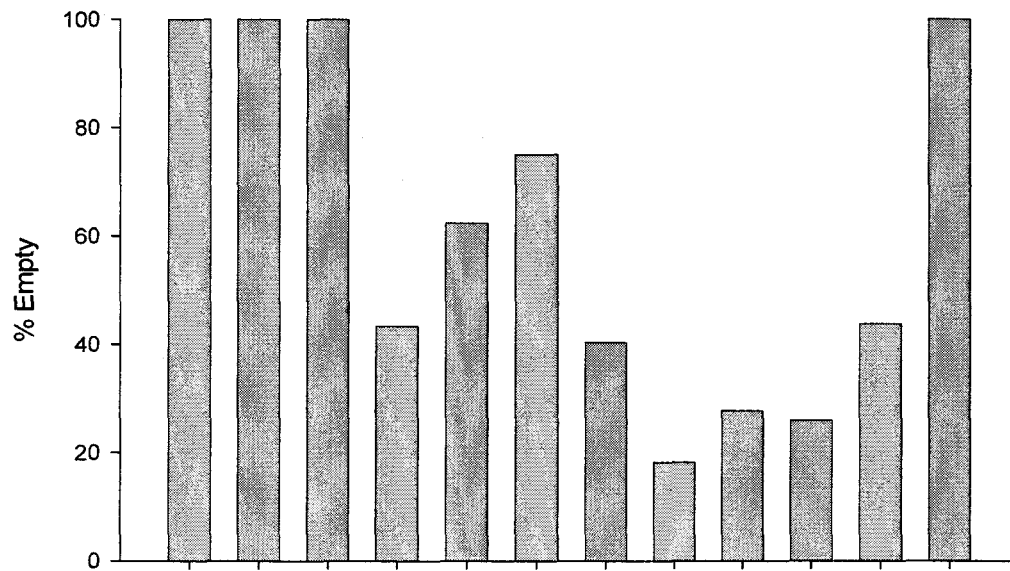


Figure 3. Top five longnose gar prey types by M%N, M%W, and %O.

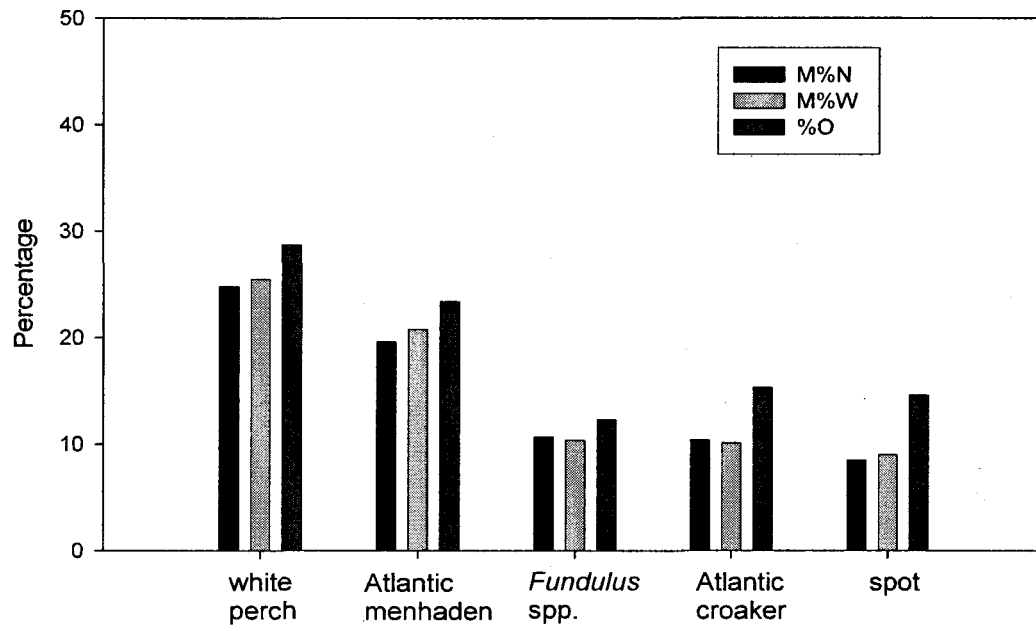


Figure 4. Top 5 longnose gar prey types by M%N and M%W for each season.

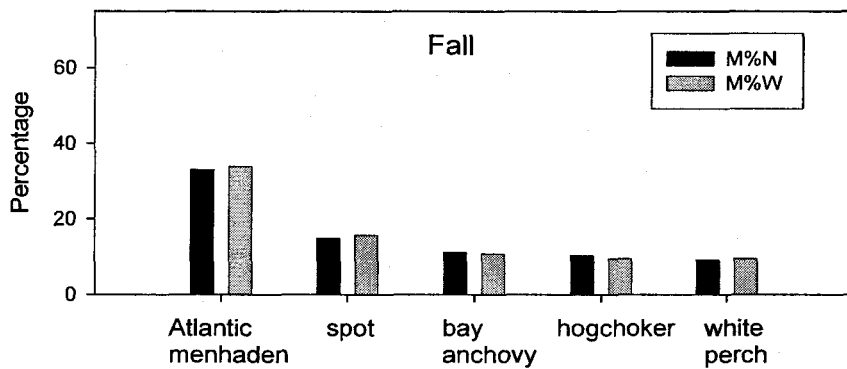
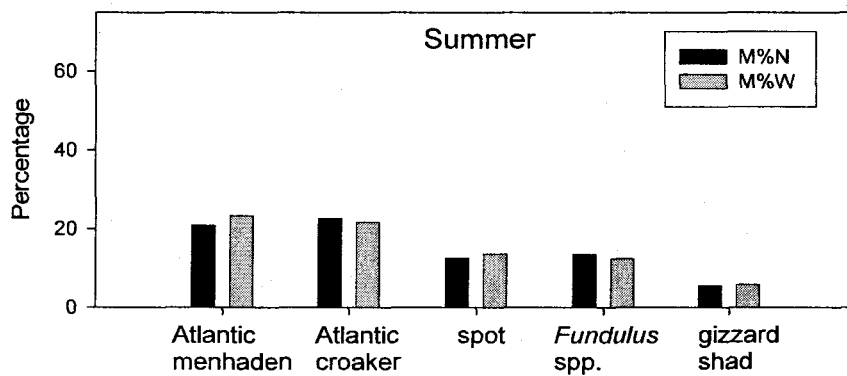
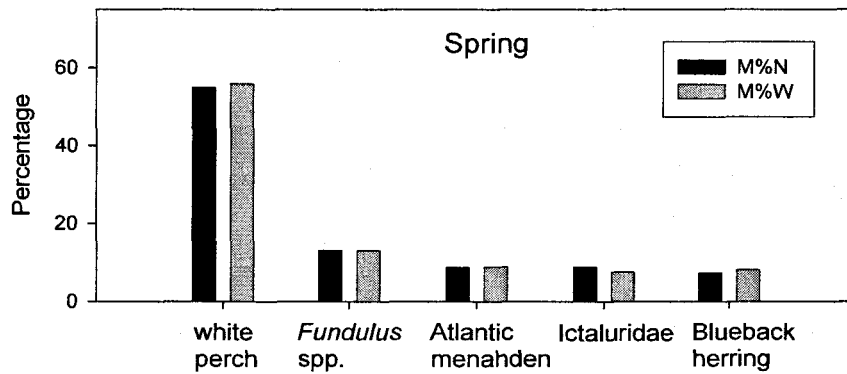


Figure 5. Top five longnose gar prey types by M%N and M%W for two different salinity regimes.

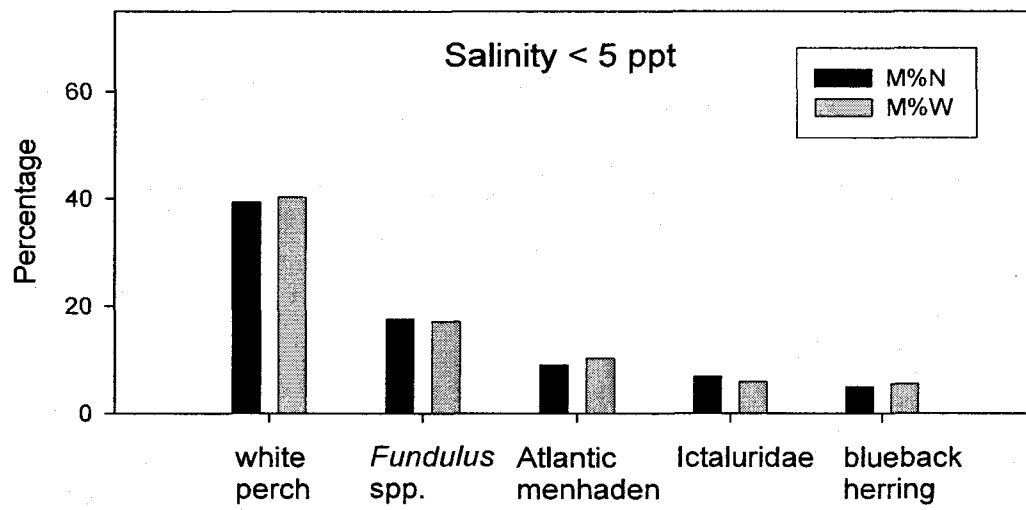
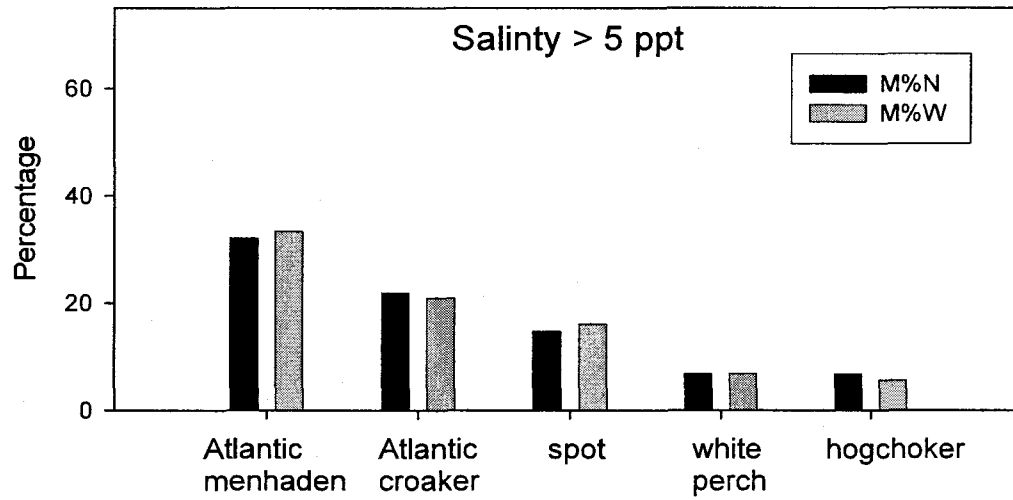


Figure 6. Top three longnose gar prey types by M%N and M%W for four different size categories.

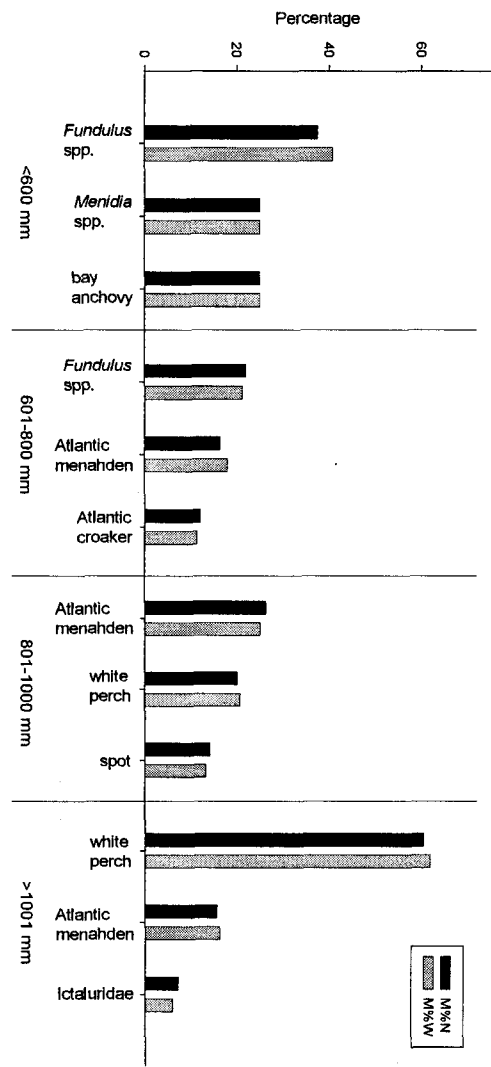


Figure 7. Canonical correspondence analysis biplot utilizing M%N for the diet of longnose gar. The arrows indicate significant explanatory variables and triangles denote specific prey items. Arrowheads denote positive direction for the variables. The canonical axes represent linear combinations of the four explanatory variables (longnose gar length, temperature, month, and salinity). The circles indicate groups of prey items influenced by similar variables.

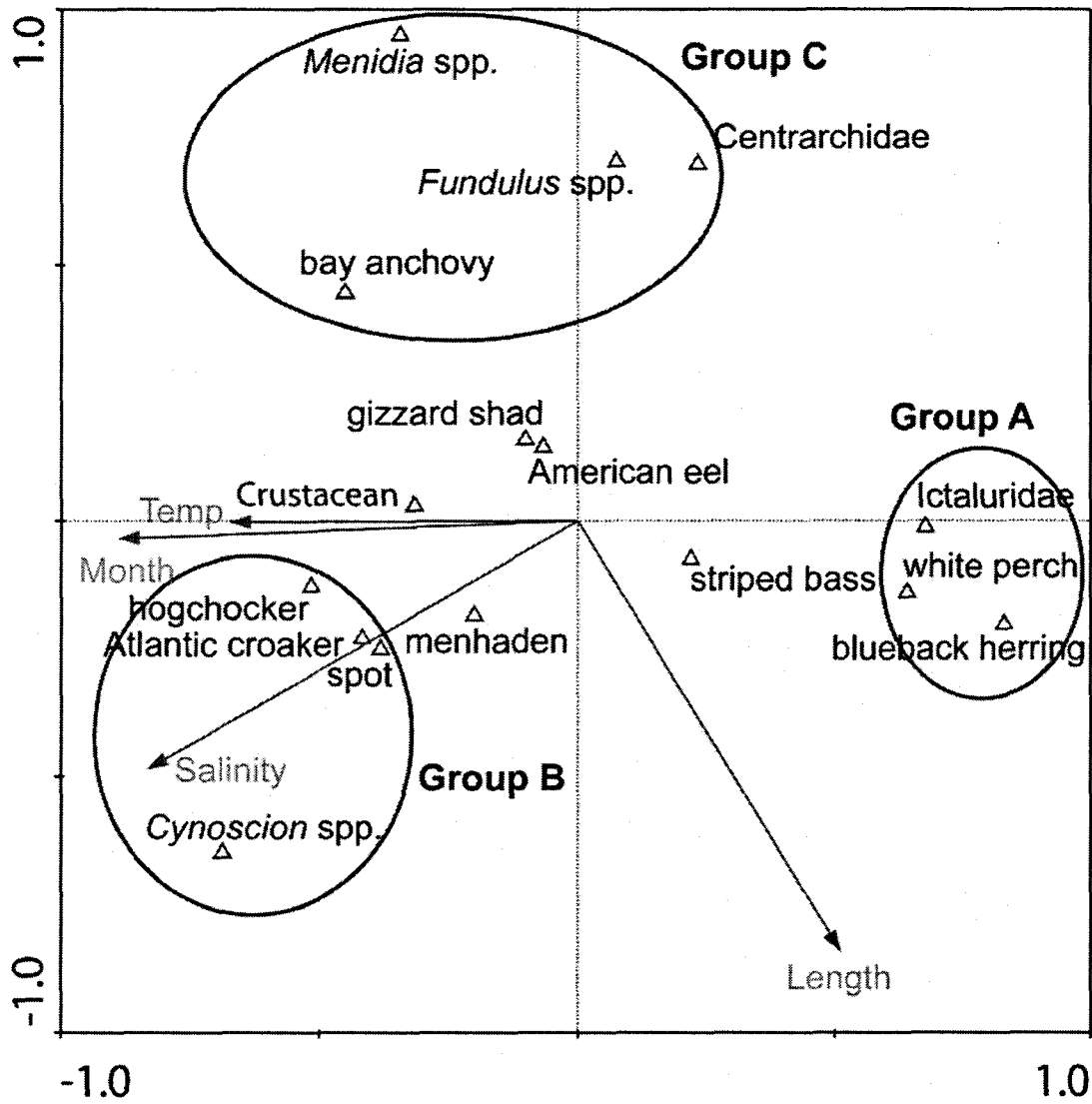


Figure 8. Canonical correspondence analysis biplot utilizing M%W for the diet of longnose gar. The arrows indicate significant explanatory variables and triangles denote specific prey items. Arrowheads denote positive direction for the variables. The canonical axes represent linear combinations of the four explanatory variables (longnose gar length, temperature, month, and salinity). The circles indicate groups of prey items influenced by similar variables.

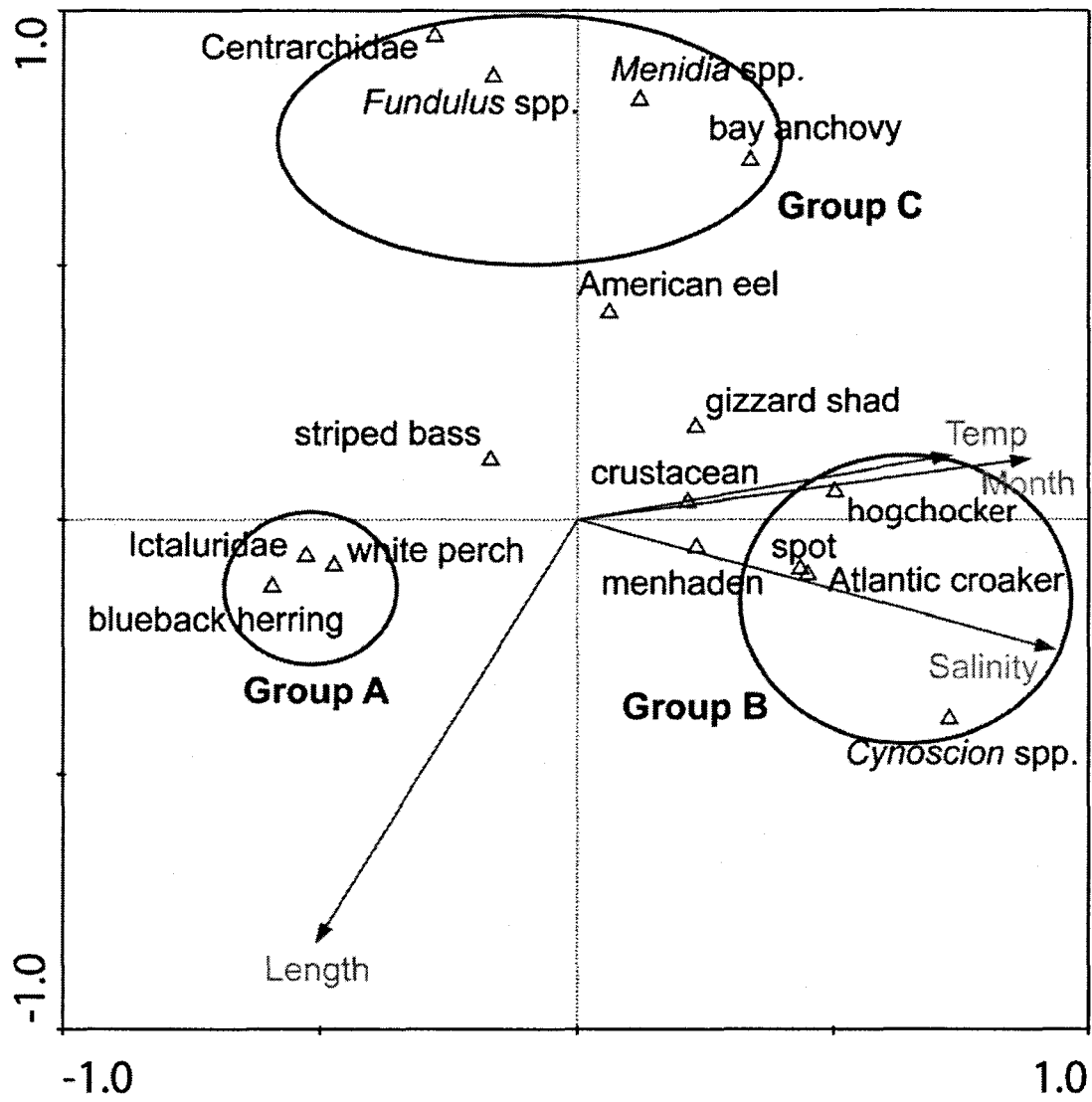


Figure 9. Quantile regressions (5%, 50%, 95%) of longnose gar total length versus prey total length.

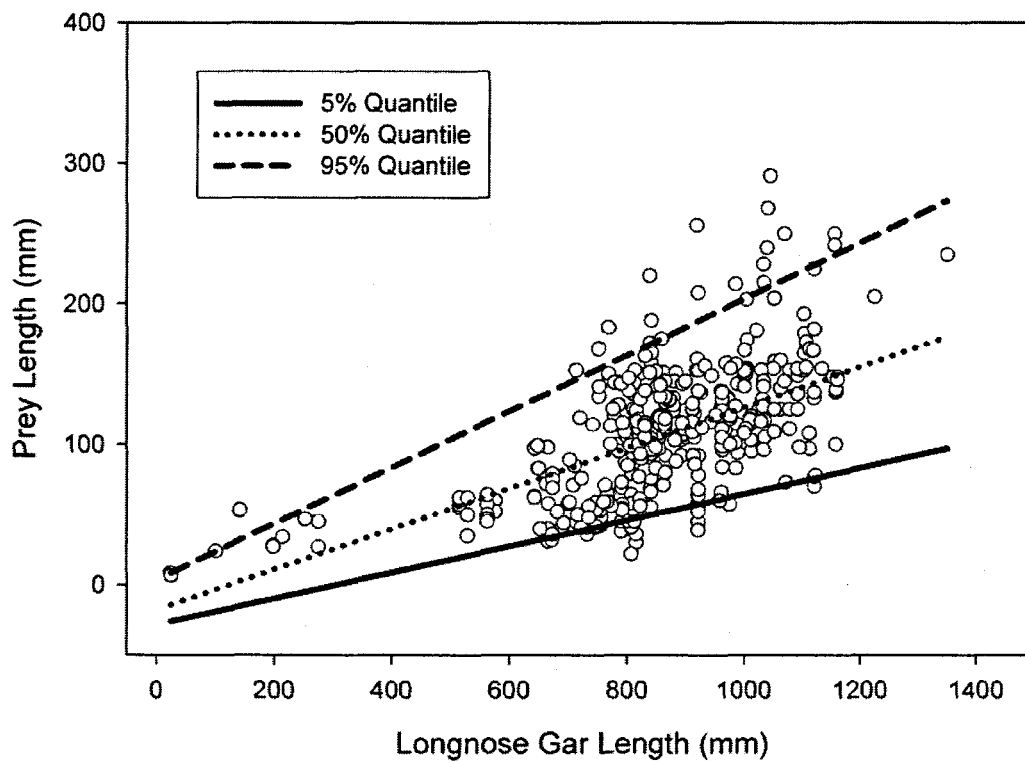


Figure 10. Size ranges of the top five longnose gar prey items.

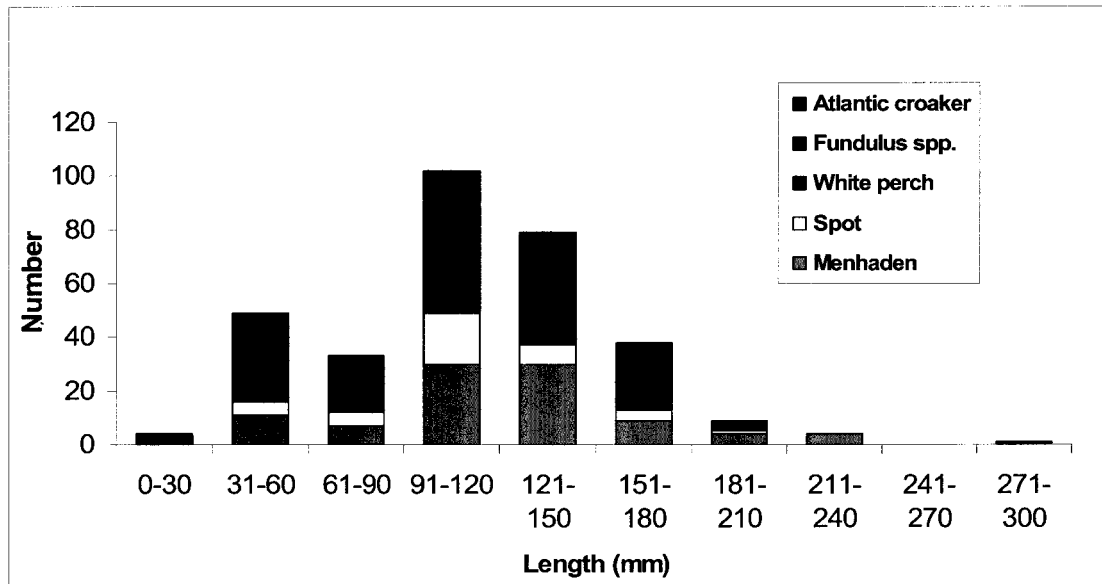


Figure 11. Top five post-larval longnose gar prey items by M%N and %O.

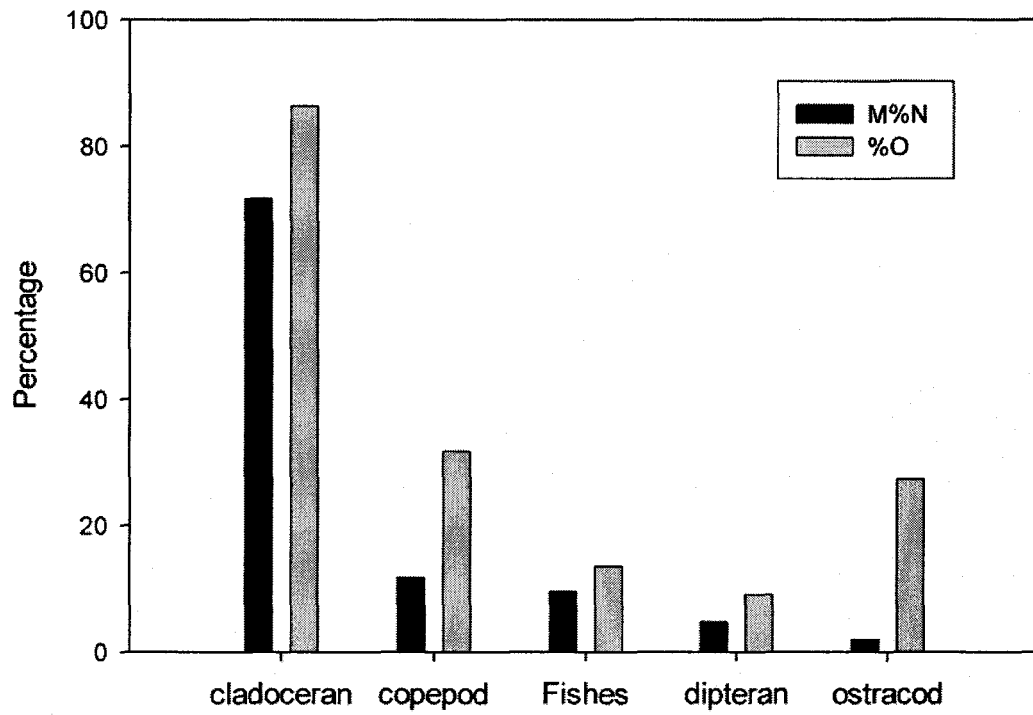


Table 1. M%W, M%N, %O, average size, and classification of each prey item identified from longnose gar stomachs (DNM=did not measure; NA=not applicable).

Prey item	M%W	M%N	%O	Average size (mm)	Resident/ Transient	Gamefish/ Non-gamefish
White Perch	25.6	24.7	28.7	127.8	resident	gamefish
Menhaden	20.5	19.5	23.4	121.9	transient	non-gamefish
<i>Fundulus</i> spp.	10.5	10.8	12.3	48.1	resident	non-gamefish
Atlantic croaker	10.1	10.5	15.3	113.0	transient	gamefish
Spot	9.0	8.5	14.6	107.4	transient	gamefish
Bay anchovy	4.4	4.7	5.4	58.4	resident	non-gamefish
Hogchoker	3.4	4.0	6.1	72.6	resident	non-gamefish
Ictaluridae	3.2	3.8	5.7	91.9	resident	gamefish
Blueback herring	3.0	2.7	3.4	239.9	transient	gamefish
Gizzard shad	2.1	2.0	2.3	DNM	resident	non-gamefish
Menidia spp.	2.1	2.1	3.1	52.5	resident	non-gamefish
Centrarchidae	1.0	0.8	1.5	40.5	resident	gamefish
Crustaceans	0.8	1.3	2.3	DNM	NA	NA
<i>Cynoscion</i> spp.	0.8	0.8	1.5	137.3	transient	gamefish
American shad	0.5	0.5	0.8	53.5	transient	gamefish
Spottail minnow	0.5	0.4	0.8	82.5	resident	non-gamefish
Insect	0.4	0.6	0.8	DNM	NA	NA
Harvestfish	0.4	0.5	0.8	82.5	transient	non-gamefish
Oyster toadfish	0.4	0.4	0.4	148.0	resident	non-gamefish
Alewife	0.3	0.2	0.4	256.0	transient	gamefish
American eel	0.3	0.3	1.1	156.5	resident	non-gamefish
Striped bass	0.3	0.4	1.1	94.0	transient	gamefish
Silver perch	0.2	0.2	0.4	87.0	transient	non-gamefish
Northern kingfish	0.2	0.2	0.4	DNM	transient	gamefish

VITA

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