POPULATION DYNAMICS, MOVEMENTS, AND SPAWNING HABITAT OF THE SHORTNOSE STURGEON, *Acipenser brevirostrum*, IN THE ALTAMAHA RIVER SYSTEM, GEORGIA

by

ROBERT JASON DEVRIES

(Under the Direction of Douglas L. Peterson)

ABSTRACT

In Georgia, the Altamaha River supports what is believed to be one of the largest remaining shortnose sturgeon populations south of Chesapeake Bay, however the current status and recent population trends of this population are unknown. A population estimate for shortnose sturgeon in the Altamaha River was generated using POPAN within Program MARK. Annuli on pectoral fin rays were used to determine age. Mortality estimates were calculated from catch curves. Radio telemetry was used to monitor movements and habitat use of 12 adult shortnose sturgeon. The results of this study indicate a population size of 6320 (95% C.I. 4387-9249) with a disproportionate number of juveniles. Ages ranged from 4 to 14 yr. Estimated annual mortality ranged between 29-34%. Spawning runs initiated in late December and were long, single-step migrations. Juveniles and adults coinhabited summer habitat in deep riverine stretches and appeared confined to freshwater when water temperatures exceeded 27 °C.

INDEX WORDS: Shortnose sturgeon, *Acipenser brevirostrum*, Abundance estimate, Population dynamics, Migration, Habitat, Radio telemetry, Altamaha River
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B.S., College of Charleston, 1998

A Thesis Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE

ATHENS, GEORGIA

2006
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August 2006
ACKNOWLEDGEMENTS

I would like to thank my advisor, Dr. Douglas Peterson for his guidance and support. I would also like to thank the other members of my committee, Drs. Cecil Jennings and Steven Castleberry.

Special thanks also go to David Higginbotham, for his help with logistics and statistics; Drs. James Peterson and Michael Conroy, for their help and input for the population estimation; to Paul Schueller and Jason Meador for their help with GIS; and to Brian White, Clay Fordham, and the host of technicians who assisted me during the course of this study.

I would also like to extend my gratitude to the Georgia Department of Natural Resources and Gordon Rogers for their input and expertise throughout this project. Funding was provided by the National Marine Fisheries Service.
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CHAPTER 1
INTRODUCTION AND LITERATURE REVIEW

The family Acipenseridae is composed of 27 species dispersed among 4 genera with a life history characterized by a long life span, delayed maturity, and protracted spawning periodicity (Artyukhin 1995, Bemis and Kynard 1997, Billard and Lecointre 2001). The shortnose sturgeon (*Acipenser brevirostrum*) (Figure 1.1) is the smallest species within this family. Although no historically large populations have been described, shortnose sturgeon were nevertheless exploited along with the sympatric Atlantic sturgeon (*Acipenser oxyrinchus*) (LeSueur 1818, Smith et al. 1984). Shortnose sturgeon became sufficiently scarce that they were declared an endangered species in the United States in 1967, and are considered a species of special concern in Canada (Dadswell et al. 1984, COSEWIC 2005). Today, few healthy populations exist and many anthropogenic factors continue to impede restoration efforts (Kynard 1997). Hydroelectric dams are perhaps the most significant limiting factor because they obstruct access to spawning grounds and alter many critical habitats (Auer 1996, Kynard 1997).

Taxonomy and Systematics

The earliest known appearance of acipenserids within the fossil record dates to the Upper Cretaceous with possible ancestors originating during the Lower Jurassic, some
Figure 1.1. Lateral view illustrations of two adult shortnose sturgeon, *Acipenser brevirostrum*. (Illustrations by Paul Vecsei)
200 million years ago (Gardiner 1984, Findeis 1997, Bemis and Kynard 1997, Choudhury and Dick 1998). Though many aspects of sturgeon phylogeny remain uncertain (Artyukhin 1995), most taxonomists have categorized the genus *Acipenser* as monophyletic (Bemis et al. 1997), although recent studies have disputed the validity of this classification (Birstein et al. 1997, Choudhury and Dick 1998, Birstein et al. 2002). More recently, genetic analyses have been used to further refine phylogeny as well as taxonomy within the Acipenseriformes. The shortnose sturgeon has been of particular interest because of its unique 16N ploidy, which has given rise to conflicting theories regarding the relationships and phylogeny of the order. Contrary to Birstein et al. (1997), who considered shortnose sturgeon a young species, Choudhury and Dick (1998) regarded the shortnose sturgeon as ancestral to all interior eastern North American acipenserids resulting from glacially induced isolation. Further complicating these phylogenetic arguments, Artyukhin (1995), Choudhury and Dick (1998), and Krieger et al. (2000) suggested that the shortnose sturgeon and the lake sturgeon (*A. fulvescens*) are sister species. Regardless of which of these arguments are correct, researchers agree that acipenserids are an ancient group and that surviving lineages are best explained by more recent geological and climatic changes (Choudhury and Dick 1998). However, determining actual relationships among species will continue to be problematic for years to come.

**Morphology**

Acipenserids are distinctive in morphology with characteristics such as trunk armoring scutes, a ventral mouth, rostral chemosensory barbels, spiral valve intestine,
and a swim bladder that has retained some of the lung-like characteristics of early actinopterigeans (Dadswell et al. 1984). The shortnose sturgeon is distinguished from other North American sturgeons by a wide mouth, absence of a fontanelle, nearly complete absence of postdorsal scutes, and preanal scutes often arranged in a single row (Scott and Crossman 1973, Dadswell et al. 1984). Dorsal, lateral, and ventral scute counts vary from 7-13, 21-33, and 6-11, respectively. Dorsal fin rays number 38-42 and anal fin rays number 19-22 (Scott and Crossman 1973, Dadswell et al. 1984). The rostrum is disproportionately large in juveniles, exceeding postorbital distance in individuals <39 cm FL, gradually decreasing as individuals age (Vladykov and Greeley 1963). Shortnose sturgeon have a large, transverse mouth averaging 74% of interorbital width (Vladykov and Greeley 1963). Mouth shape and size is similar to that of lake sturgeon (A. fulvescens) and is a prominent characteristic used to distinguish the shortnose sturgeon from the sympatric Atlantic sturgeon (A. oxyrinchus) (Figure 1.2) (see Vladykov and Greeley 1963, Dadswell et al. 1984). Barbels are situated closer to the tip of the snout than to the mouth. Gill rakers are long and triangular, usually numbering 22-29 on the first branchial arch (Vladykov and Greeley 1963, Scott and Crossman 1973).

Body armoring is extensive in shortnose sturgeon, although weakly developed in adults compared to that of other North American sturgeons (Vladykov and Greeley 1963, Dadswell et al. 1984). Sharp, apical hooks are prominent on scutes of juveniles but are gradually lost as adults. The body lacks scales, and adults are generally smooth-skinned. Body coloration is typically dark brown along the dorsal surface,
Figure 1.2. Head and mouth variations of adult shorthose sturgeon, *Acipenser brevirostrum*. (Illustrations by Paul Vecsei)
becoming a yellowish-brown laterally, and white or cream colored ventrally. Scutes are uniformly colored and are much lighter than the surrounding dorsal and lateral tissue. Scott and Crossman (1973) and Dadswell et al. (1984) noted that juveniles exhibited black blotches over much their body, although this has not been observed in juveniles of similar size observed from the Altamaha River.

**Genetics**

Polyploidy is currently thought to have had an important role in the evolution of the Acipenseriformes (Blacklidge and Bidwell 1993, Ludwig et al. 2001). All acipenserids can be genetically categorized into one of two groups: those with 112-120 chromosomes, those with 240-250, and those with more than 250 (Blacklidge and Bidwell 1993, Birstein et al. 1997, Fontana et al. 1999, Kim 2004). Within the acipenserids, the shortnose sturgeon and the Sakhalin sturgeon (*A. mikadoi*) are the only two known allopolyploids, having derived from 2 different ancestral species (Birstein et al. 1997). There currently is much debate on the specific ploidy number of shortnose sturgeons. Blacklidge and Bidwell (1993) categorized shortnose sturgeons as dodecaploid (12N), and proposed that this species originally derived from the hybridization between 4N and 8N species. Birstein et al. (1997) however, proposed that shortnose sturgeons were instead 16N because allopolyploidy was unknown in other sturgeon species. Ludwig et al. (2001) and Kim et al. (2005) disputed both these theories, with the former proposing that shortnose sturgeons were instead octoploids. Kim et al. (2005) however agreed with Blacklidge and Bidwell (1993) that the number of chromosomes possessed by shortnose sturgeon (362-372) was actually far less than
the 500 proposed by Birstein et al. (1997). Blacklidge and Bidwell (1993) also argued that the number of chromosomes was more indicative of dodecaploidy. Regardless of whether the chromosomal number is 500 or the more probable ~360, the shortnose and Sakhalin sturgeons have among the highest number of chromosomes yet reported for any vertebrate (Birstein et al. 1997).

Recent genetic studies also have attempted to explain shortnose sturgeon population stock structures. Wirgin et al. (2005) found that southern populations displayed genetic differences among rivers and argued that this could be explained by relatively small population sizes and their inherent susceptibility to stochastic drift. The large degree of genetic variation among southern rivers also may be explained by lack of influence of Pleistocene glaciation. Recolonization of northern rivers would have occurred over the past 10,000 years and genetic differentiation would not be as pronounced as in southern rivers (Wirgin et al. 2005). This pronounced difference in genetic stock structure among populations, particularly in southern rivers, indicates minimal gene flow among populations and genetic similarities may actually be indicative of environmental similarities (Quattro et al. 2002, Waldman et al. 2002). Gene flow, however, may be a function of population size rather than adjacent river proximity. For example, Kynard (1997) and Walsh et al. (2001) argued that the Hudson River was a possible source of individuals to other regional rivers because of its large population size.
Life History

The first studies focusing on shortnose sturgeon were conducted until the late nineteenth-early twentieth century. These studies were initiated primarily to investigate aquacultural techniques (Ryder 1890, Meehan 1910). More recent studies have focused primarily on life history, population dynamics, and habitat utilization. These studies have primarily originated in the northern extent of the range, where several large populations now exist as a result of conservation and recovery efforts (Dadswell 1979, Pekovitch 1979, Taubert and Dadswell 1980, Hastings et al. 1987, Hoff et al. 1988, Bain et al. 1995, Kynard et al. 2000, Secor and Woodland 2005). Studies of southern stocks have revealed a slightly different life history pattern in terms of spawning periodicity and migrational patterns (Heidt and Gilbert 1978, Marchette and Smiley 1982, Hall et al. 1991, Collins and Smith 1993).

Eggs

Shortnose sturgeon eggs are darkly colored, usually dark brown, black, or olive gray (Meehan 1910, Dadswell 1979, Hoff, 1988, Kynard 1997). Egg diameter is typically 3.00-3.20 mm (Dadswell 1979) and does not change after fertilization or immersion in water (Buckley and Kynard 1981, Dadswell et al. 1984). Fecundity estimates range from 76,000 to 95,200, but averages 11,600 eggs per kg of fish (Heidt and Gilbert 1978, Dadswell 1979, COSEWIC 2005). Eggs are not adhesive when first spawned. Special protuberances on the egg membrane that maximize surface area available for attachment develop within a few minutes after water exposure (Meehan 1910, Markov 1978, Dadswell et al. 1984). Development of fertilized eggs is directly
related to water temperature (Wang et al. 1985, Hardy and Litvak 2004). Meehan (1910) found that eggs in water temperatures of 8-12 °C hatched 13 days after fertilization—however incubation time was reduced to 8 days at 17 °C (Buckley and Kynard 1981).

Yolk-sac larvae

At hatching, yolk-sac larvae are between 7-11 mm TL. Larvae are dark gray, with a large, slightly pigmented yolk-sac, unpigmented eyes, undeveloped fins and an unopen mouth (Meehan 1910, Taubert 1980a, Taubert and Dadswell 1980, Buckley and Kynard 1981, Dadswell et al. 1984, Bain 1997). They are benthic and photonegative, often forming dense aggregations with other larvae when hiding (Buckley and Kynard 1981, Dadswell et al. 1984, Richmond and Kynard 1995, Bain 1997). Dorsal and lateral pigmentation is well developed by 15 mm TL and is most pronounced in the caudal region (Taubert and Dadswell 1980).

The spiral valve is discernable in individuals ≤11.6 mm and rudimentary gill structures are visible on specimens ≤9.5 mm TL (Bath et al.1981). At hatching, the mouth is merely a small indentation, but begins to develop at 8.4 mm TL and small, unicuspate teeth are present by 15 mm TL (Bath et al.1981, Taubert and Dadswell 1980, Richmond and Kynard 1995). Barbels first appear as tiny buds at 9.7 mm TL, but are well developed by 15 mm TL (Bath et al.1981, Taubert and Dadswell 1980). The eyes, fin buds, gills, and lateral line are either undeveloped or poorly developed in newly hatched yolk-sac larvae, but are well defined by 15 mm TL (Bath et al.1981, Taubert and Dadswell 1980, Richmond and Kynard 1995).
Post yolk-sac larvae

The larval stage begins with initiation of active feeding. Active feeding of larval shortnose sturgeon begins with the depletion of the yolk, which typically occurs after 12 days, or at 15 mm TL at 15-17 °C (Taubert and Dadswell 1980, Bath et al. 1981, Buckley and Kynard 1981, Kynard 1997). The finfold increases with size, gradually separating into the median fins, dorsal and anal fin ray basal supports, and dorsal and anal scutes (Bath et al. 1981). Spiracles, dermal ossification and scutes as well as fin rays, which were absent earlier, begin to develop at 18-19 mm TL (Bath et al. 1981, Gilbert 1989). Larvae become photopositive after yolk sac depletion and can become lighter or darker in response to changes in light intensity (Buckley and Kynard 1981, Richmond and Kynard 1995, Kynard and Horgan 2002). The duration of downstream drift by larval shortnose sturgeon is brief, usually about 2 days, and typically occurs at about 20 mm TL (Richmond and Kynard 1995, Bain 1997). Richmond and Kynard (1995) postulated that downstream movements of larvae serve to help disperse larvae from spawning grounds and to help them find suitable cover.

Larvae larger than 15 mm TL are active swimmers, but are only capable of short bursts of movement. At this stage most individuals are associated with the deepest water available (Taubert and Dadswell 1980, Bath et al. 1981, Hoff et al. 1988, Dovel et al. 1989, Richmond and Kynard 1995, Kynard and Horgan 2002). Swimming activity increases after 9-14 days (14-17 mm TL), possibly signifying that individuals would be migrating from the spawning areas (Richmond and Kynard 1995). This movement is most likely nocturnal to take advantage of low light levels and the increased cryptic coloration of the larvae (Buckley and Kynard 1981, Richmond and Kynard 1995).
Juveniles

Juveniles are morphologically similar to adults, possessing a full complement of rayed fins. At the onset of the juvenile stage, the tooth-filled mouth becomes toothless and protrusible (Richmond and Kynard 1995). The scutes, which are sharply tipped as juveniles, are maintained throughout the life of the sturgeon, demonstrating the relationship between the need for body armoring and the presence of large predators. As juveniles, the only confirmed predator of shortnose sturgeons is the yellow perch, *Perca flavescens* (Dadswell et al. 1984). In southern populations alligators (*Alligator mississippiensis*), sharks, or other fishes (e.g. catfish) also may be potential predators; however, predation on adult shortnose sturgeon has not been documented (Scott and Crossman 1973, Gilbert 1989).

Metamorphosis into the juvenile stage is complete by 31.5 mm TL. The juvenile stage continues until the fish matures after 3-10 years (Gilbert 1989, Richmond and Kynard 1995). Immature individuals remain primarily within river channels and commonly feed on aquatic insects, isopods, and amphipods (Dadswell 1979, Carlson and Simpson 1987, Bain 1997). Downstream migration continues throughout the first year and individuals age 1 and older utilize the same habitats as adults (Dovel et al. 1989, Kynard 1997). Juveniles older than 1 year also make seasonal migrations, moving upriver during warmer months where they shelter in deep holes, before returning to the fresh/salt water interface when temperatures cool (Flournoy et al. 1992, Collins et al. 2002a).
Although adult shortnose sturgeon may attain maximum lengths of 143 cm TL and weights greater than 20 kg, they rarely exceed 122 cm TL (Dadswell 1979, Gilbert 1989). However, maximum size varies with latitude with southern individuals attaining smaller maximum sizes (Dadswell 1979, Gilbert 1989). Growth rates and maximum ages also are thought to vary with latitude. Dadswell et al. (1984) and Heidt and Gilbert (1978) both assert that southern stocks grow faster and reach maturity earlier than do their northern counterparts. Contrary to the 67-year old shortnose sturgeon captured in the Saint John River, Canada by Dadswell (1979), the oldest reported individual from a southern population was 14 years old and measured 98.5 cm FL in the Ogeechee River, Georgia (Fleming et al. 2003).

Adult shortnose sturgeon also exhibit a latitudinal gradient relative to age of maturation, spawning time, and migratory behavior (Dadswell et al. 1984, Gilbert 1989, Rogers and Weber 1994). In Georgia waters, male sturgeon are thought to mature at 2-3 years while females mature by age-6 (Dadswell et al. 1984, Kynard 1997). In more northerly populations, such as the St. John River population, males may mature at 10-11 years of age and females at age 12-18 (Dadswell et al. 1984, Bain 1997, Kynard 1997).

Feeding Behavior

The shortnose sturgeon is a benthic invertivore that finds prey by using its barbels as tactile receptors and vacuuming either the substrate or plant surfaces with its protuberant mouth (Dadswell et al. 1984, Gilbert 1989). Juveniles feed indiscriminately,
often ingesting large amounts of mud, stones, and plant material along with prey items
(Curran and Ried 1937, Dadswell 1979, Carlson and Simpson 1987). Several studies
have documented juveniles with up to 90% of the gut content containing non-food
material (Curran and Ries 1937, Dadswell 1979, Marchette and Smiley 1982). The diet
of juveniles includes small insects and cladocerans (Dadswell 1979, Marchette and
also appear to feed indiscriminately, but may be more capable of separating food and
non-food material prior to ingesting, depending on substrate (Dadswell 1979, Dadswell
et al. 1984, Gilbert 1989). Studies of gut contents show that the diet of adult shortnose
sturgeon typically consists of small bivalves, gastropods, polychaetes, and even small
benthic fish (McCleave et al. 1977, Dadswell 1979, Marchette and Smiley 1982,

Adult shortnose sturgeon feed throughout the year; however, Dadswell (1979) found
that females ceased feeding nearly eight months before spawning. Conversely, males
continue to feed throughout the fall and winter as long as they are located in saline
waters (Dadswell et al. 1984). Dadswell (1979) also documented individuals of both
sexes actively feeding immediately after spawning. Feeding occurs primarily at night in
water 1-5 m deep, although depth is directly related to temperature with feeding
occurring deeper during warmer months (Dadswell et al. 1984, Gilbert 1989).
Habitat and Movements

Habitat

Shortnose sturgeon use several distinct habitats throughout their life cycle with each stage of development requiring a specific habitat. Adult and juvenile habitats differ depending on seasonal and stochastic variables. Seasonal changes in habitat have been well documented, but vary with latitude (Kynard et al. 2000). In northern populations, both juveniles and non-spawning adults use deep segments of rivers, often deeper than 10 m, during fall and winter months. In warmer months, they forage widely throughout the river and estuary (Dadswell 1979, Hastings et al. 1987, Geoghegan et al. 1989, O’Herron et al. 1993, Kynard et al. 2000, Welsh et al. 2001). In southern populations, individuals take refuge in deep, freshwater habitat during the summer, rarely moving from them, and forage widely throughout the estuary during winter months (Collins and Smith 1993, Rogers and Weber 1994, Weber et al. 1998). Small juveniles, however, are much less tolerant of salinity and grow more slowly in a saline environment and therefore remain primarily within freshwater habitats (Jenkins et al. 1993, Jarvis et al. 2001).

Shortnose sturgeon can be found over a variety of substrates, but probably select areas based on food availability and thermal tolerances (Crance 1986). Riverine habitats often are characterized by sandy-mud substrates, although shortnose sturgeon do not avoid vegetated areas as evidenced by the presence of ingested plant material likely consumed while foraging for gastropods (Dadswell 1979, Marchette and Smiley 1982). Specific data on the thermal preferences of shortnose sturgeon is limited, the best data relating only to spawning adults and small juveniles.
Migrational Behavior

Shortnose sturgeon display both random and non-random movements (Dadswell et al. 1984, Buckley and Kynard 1985). Although some populations are known to remain within the tidally influenced portions of their home rivers, only Taubert (1980b) described a population home range. Populations with access to the sea roam freely throughout estuarine and riverine environments although these movements are often dictated by temperature (Gilbert 1989). As water temperatures increase during summer, individuals typically move upstream and remain near the fresh-salt water interface until temperatures begin to fall (Dadswell et al. 1984, Buckley and Kynard 1985, Rogers and Weber 1994, Weber 1996, Collins and Smith 1997, Palmer 2001).

All sturgeon species undertake some type of spawning migration (either in the form of anadromy or potomodromy), and all spawn in freshwater (Auer 1996, Fontana et al. 2001). Upstream migrations usually are associated with spawning behavior, while downstream migrations normally are associated with feeding behavior (Bemis and Kynard 1997). Gerbilskiy (1957) and Bemis and Kynard (1997) described spawning migrations as either “one-step” or “two-step” movement patterns; the former typified by a long, uninterrupted spring migration followed immediately by spawning; the latter characterized by an abbreviated fall migration followed by an overwintering period near the spring spawning site. This distinction also can be used to differentiate sympatric subpopulations in many river systems (Bemis and Kynard 1997). Throughout the southern portion of the range of the shortnose sturgeon, single-step migrations are typical. Single-step migrations have been well documented in the Cape Fear (Moser and Ross 1995), Cooper (Palmer 2001), Savannah (Hall et al. 1991, Collins and Smith
1993), and Altamaha (Heidt and Gilbert 1978, Flournoy et al. 1992, Rogers and Weber 1994) rivers. Among northern coastal rivers, two-step migrations have been documented for shortnose sturgeon in the Hudson (Pekovitch 1979, Dovel et al. 1989), Connecticut (Buckley and Kynard 1985), and Delaware (O’Herron et al. 1993) Rivers, however, Kieffer and Kynard (1993) documented both migration types in the Merrimack River. Regardless of which pattern is used, each of these studies has shown that dispersal from the spawning site occurs immediately after spawning.

Distribution and Legal Status

Shortnose sturgeon inhabit large coastal rivers of the Atlantic coast of North America from the St. John River in Canada to the St. John’s River in northeast Florida (Vladykov and Greeley 1963, Moser and Ross 1995, Waldman et al. 2002, Collins et al. 2003). At present, most stocks are depleted or extirpated over much of this range (Collins et al. 2002). Within the United States, shortnose sturgeon currently are protected under the Endangered Species Act of 1973, having been listed by the U.S. Fish and Wildlife Service as endangered in 1967. In 1980, Canada listed the shortnose sturgeon as a species of special concern. The World Conservation Union (IUCN) has given the shortnose sturgeon Red Book status as a vulnerable species throughout the range.

Mechanisms Leading to Declines

Overharvest

Sturgeon have long been harvested for both their flesh and roe, which is typically processed for caviar. Klyszejko et al. (2004) found evidence that sturgeons were
commercially harvested in Europe dating back at least 1,000 years. Archeological
evidence from North America indicates that indigenous Americans also used sturgeons
as food for many centuries (Ritchie 1969). Beginning in the 1600’s, North American
sturgeon were commercially harvested for export to Europe (Murawski and Pacheco
1977). During the 1800’s, sturgeon were harvested not only for their roe and flesh, but
also used to make other products such as isinglass and paint additives (Scott and
Crossman 1973, Smith et al. 1984). In 1870, demand for sturgeon increased
dramatically and coastal stocks suffered serious declines. Landings fell from 2.9 million
kilograms 1892 in the Delaware Bay area to only 0.11 million by 1901 (Cobb 1900,
Gilbert 1989). After 1901, southern stocks became the major source of sturgeon in the
United States with harvest peaking in 1969 with 78,471 kg landed throughout the South
Atlantic Bight before declining once again (Murawski and Pacheco 1977, Smith et al.

The importance of shortnose sturgeon to total landings prior to 1973 cannot be
evaluated because no distinction between shortnose sturgeon and Atlantic sturgeon
was made (Murawski and Pacheco 1977, Smith et al. 1984). LeSueur (1818)
commented that fishermen valued shortnose sturgeon more highly than the sympatric
Atlantic sturgeon because they had a higher market price. However, by 1890 the
shortnose sturgeon had virtually no economic importance because of its small size and
scarcity relative to the larger, more profitable Atlantic sturgeon (Ryder 1890). Today,
Atlantic sturgeon continue to be more sought after than shortnose sturgeon in Canadian
waters, where harvest continues on a limited basis (Trencia et al. 2002).
Since the shortnose sturgeon was listed as an endangered species in 1967, concern over the frequency of incidental bycatch of shortnose sturgeon by commercial fisheries has increased. Spawning migrations of shortnose sturgeon and American shad overlap in time and space and commercial and recreational shad fishermen often catch the migrating shortnose sturgeon in their nets (Dahlberg and Scott 1971, Scott and Crossman 1973, Heidt and Gilbert 1978, Boreman et al. 1984, Collins et al. 1996, Weber 1996, Collins and Smith 1997, Collins et al. 2000). Moser and Ross (1995) and Weber (1996) reported that female shortnose sturgeon aborted eggs and returned downstream when captured more than once. Collins et al. (1996) found that shrimp trawlers, while routinely capturing juvenile Atlantic sturgeon, rarely encountered shortnose sturgeon, however the commercial shad fishery had much higher encounter rates (52 and 83% respectively) for both species.

Habitat Degradation

Shortnose sturgeon require specific habitats during various life stages and hence are sensitive to habitat alterations. Construction of dams restricts movements and often cuts off access to historic spawning grounds. Impoundments may also alter natural river flow and temperature regimes needed for successful spawning (Kieffer and Kynard 1996, NMFS 1998, Cooke and Leach 2004). Though shortnose sturgeon apparently are incapable of using modern fish ladders, fish lifts have been employed with limited success in some rivers. For example, the fish lift located at Holyoke Dam on the Connecticut River passed less than 5 shortnose sturgeon annually over a period of 21 years (Kynard 1998). With the loss of historic migratory routes, individuals downstream
of impoundments utilize spawning habitat similar to what had been historically utilized and may spawn in close proximity to the impoundment (Kynard 1997, Cooke and Leach 2004, Duncan et al. 2004). Additionally, reproduction and recruitment within the downstream segment of these impoundments is often poor, possibly prohibiting recovery of these populations (Kynard 1997, Cooke and Leach 2004, Cooke et al. 2004).

Shortnose sturgeon also are thought to be sensitive to contaminants, which are associated with impaired reproduction (Cameron et al. 1992, Longwell et al. 1992), early survival (Dwyer et al. 2000) and susceptibility to disease (Sindermann 1979). However, few studies have been conducted that examine these impacts. As long-lived, benthic feeders, shortnose sturgeon are susceptible to bioaccumulation of heavy metals and other contaminants (Dadswell 1979, Ruelle and Keenlyne 1993).

Other threats affecting recovery of shortnose sturgeon populations include dredging and poor water quality. Dredging of navigation channels can destroy feeding habitats, and there is documentation of mortalities from hydraulic pipeline operations (NMFS 1998). Industrial and agricultural discharge often contains contaminants that promote high biological demand that results in lowered dissolved oxygen levels (NMFS 1998). Low dissolved oxygen levels are of particular concern during early development of shortnose sturgeon. Jenkins et al. (1993) found high mortality of juveniles less than 100 days old when dissolved oxygen concentrations were less than 2.5 mg/L. Although shortnose sturgeon tolerance of low dissolved oxygen appears to increase with age, Flournoy et al. (1992) reported that adults were stressed during periods of high temperature and low dissolved oxygen levels. Over these periods, sturgeon often
congregate in deeper, cooler river regions that help alleviate the physiological stress associated with high temperatures (Flournoy et al. 1992, Mason and Clugston 1993). Absence of habitat that provide such refugia, especially in southern populations, has been attributed to high juvenile mortality and extirpation of some populations (Collins and Smith 1993, Rogers et al. 1994, Rogers and Weber 1995, Collins et al. 2000).

Management Approaches

Stocking and Reintroductions

Over the past two decades, increasing interest in shortnose sturgeon restoration has spurred debate over whether supplemental stocking is an effective method for recovering populations. From 1984-1992, the South Carolina Department of Natural Resources supplemented the Savannah River shortnose population with nearly 100,000 mostly juvenile individuals in response to low juvenile recruitment (Smith and Collins 1996, Smith et al. 2002). Subsequent captures of released hatchery-reared shortnose sturgeon in neighboring rivers revealed that many individuals did not remain within the Savannah River system. Those stocked individuals may now constitute a portion of the total population within those rivers in addition to the Savannah (Smith et al. 2002). Despite the augmentation of the Savannah River population of shortnose sturgeon, no increase in juvenile recruitment has been documented in either the Savannah or the adjacent Ogeechee River suggesting a recruitment bottleneck as juveniles mature (Collins et al. 2002a, Fleming et al. 2003). Based on the results of this stocking event, the National Marine Fisheries Service (NMFS) developed guidelines to determine if augmentation was feasible. Their effort focused on the population status, habitat quality
and availability, and availability of natal population broodstock (NMFS 1998). However, these guidelines have not yet been applied because many rivers with populations in imminent danger of extirpation continue to have significant anthropogenic factors prohibiting natural recovery (NMFS 1998). Because of the susceptibility of small populations to anthropogenic factors, there have been no approved stocking events since the Savannah River was augmented.

Habitat Protection and Restoration

Habitat loss and degradation threaten the continued survival of shortnose sturgeon in many rivers. To date, restoration efforts that failed to address the issue of habitat degradation have generally been unsuccessful (Beamesderfer and Farr 1997). These efforts have included supplemental stocking and habitat restoration. Because shortnose sturgeon are more susceptible than many other fish species to overexploitation because of their longevity, delayed maturation, and spawning periodicity (Beamesderfer and Farr 1997), they may serve as indicators for system degradation.

Research Objectives and Justification

Information about the shortnose sturgeon population in the Altamaha River system is meager. Heidt and Gilbert (1978), Flournoy et al. (1992) and Rogers and Weber (1994) provide some qualitative information about the status of the Altamaha River population prior to implementation of the National Marine Fisheries Service (NMFS) recovery plan. Because there are no current data, the effectiveness of the recovery plan for increasing
recruitment and protecting adults has not been evaluated. Additional quantitative data on population size and structure are needed to allow regulatory agencies, such as NMFS, to evaluate the effectiveness of the current recovery plan for the Altamaha shortnose sturgeon population. To date, implementation of this plan has been limited. Areas of interest have focused primarily on field research (mark-recapture, telemetry, essential habitat quantification, bycatch assessment, stock augmentation assessment, etc.). More recent studies have examined the genetic relationships among rivers. However, because not all populations are currently being investigated, information on many smaller populations may be outdated or absent.

Protection of spawning habitat is also a crucial component of the NMFS plan for recovering shortnose sturgeons. Although spawning habitats of shortnose sturgeon have not been identified in the Altamaha River, previous studies have shown that spawning shortnose sturgeon select habitats with suitable flow and substrate characteristics. For spawning to occur, current velocity of 37-125 cm/s is needed (Pekovitch 1979, Taubert and Dadswell 1980, Buckley and Kynard 1985). Slower flow allows eggs to clump together while higher velocity currents may prevent the eggs from adhering to the substrate (Dadswell 1979, Buckley and Kynard 1985, Kynard 1997). Substrates typically used by spawning shortnose sturgeon consist of sand, gravel, cobble, or rubble bottoms (Dadswell et al. 1984, Gilbert 1989, Hall 1991, Kynard 1997)

Given the general lack of knowledge regarding the current status of Altamaha River shortnose sturgeon, this study had three primary objectives: 1) to estimate the number of shortnose sturgeon, 2) to evaluate the current population age structure, and, 3) identify spawning sites of shortnose sturgeon in the Altamaha River. This population
assessment will help quantify what is thought to be a critically endangered population of shortnose sturgeon while providing insight into possible trends in abundance. Identification of spawning habitat will allow local management agencies to protect these areas in the Altamaha as specified in the NMFS recovery plan.
CHAPTER 2

STUDY AREA AND METHODS

Study Site Description

Located entirely within Georgia, the Altamaha River and its main tributaries, the Oconee and Ocmulgee Rivers, flow over 800 km from the headwaters near Atlanta, Georgia to the Atlantic Ocean near Darien and drains nearly one-third of the state (Figure 2.1). Encompassing approximately 36,000 km$^2$, this river system is one of the largest watersheds on the east coast of the United States and was recently listed as the seventh most endangered river in the United States by the advocacy group American Rivers. The Altamaha River is also second only to the Pascagoula River in Mississippi in length of unimpounded stretch of river from the ocean east of the Mississippi River. Dynesius and Nilsson (1994) attributed the more than 600 km of unimpounded river to a lower rate of exploitation by a smaller regional population. The Altamaha is formed at the convergence of the Ocmulgee and Oconee Rivers 215 river kilometers (rkm) inland. It averages 50-70 m in width and 2-3 m in depth with a maximum depth of 18 m (Heidt and Gilbert 1978). The Oconee and Ocmulgee Rivers contain the only impoundments within the watershed; however, none are found farther downstream than 361 rkm, which is well upstream of the known habitat of shortnose sturgeon in this system (Rogers and Weber 1994). Vegetation along the lower reaches of the watershed progresses from mixed hardwood to cypress swamp to salt marsh (*Spartina* spp.) near the estuary.
Figure 2.1  The Altamaha River watershed (gray) including the headwater tributaries, the Ocmulgee and Oconee Rivers with impoundments.
The average gradient over the lower 200 rkm is 0.13 m per km (GEPD 2003). Average annual discharge is 381 m$^3$s$^{-1}$, or 18% of the entire freshwater input to the South Atlantic shelf (Rogers and Weber 1994).

The sampling area of this study included the entire tidally influenced portion of the lower river from Altamaha Sound upstream to rkm 40 when (Fig 2.2). I chose net sampling locations based on the amount of woody debris on the river bottom. Input from individuals with prior experience in capturing sturgeon also was an important factor in site selection. To identify potential sampling sites, I first surveyed the river bottom with a Furuno LS-6100 depth finder prior to gear deployment to ensure that the river bottom was clear of debris or structure that might otherwise damage sampling gear. Sites where sampling was not possible either through loss of gear or having extensive bottom structure were eliminated from sampling. Water quality variables such as dissolved oxygen, temperature, conductivity, and salinity were measured with a YSI-85 © meter.

**Materials and Methods**

I sampled the Altamaha River tidal zone from 14 November 2003 to 18 December 2005. I captured shortnose sturgeon were captured with 94.4 m long, 3 m deep monofilament gill nets and trammel nets hung in a 2:1 ratio. Gill nets were constructed from single 10.2 cm or 15.2 cm stretched mesh panels and experimental gill nets from 3-30.5m panels of 7.6, 10.2, and 15.2 cm stretched mesh hung in varying orders of arrangement. Trammel nets were constructed from a single inner panel of 7.6 cm stretched mesh surrounded by 2-30.5 cm stretched mesh panels. Nets were deployed
Figure 2.2  Shortnose sturgeon capture sites in the tidally influenced lower 40 rkm of the Altamaha River (sampling sites are denoted by o).
only during slack tides—typically 45-90 minutes—due to the large tidal amplitudes and resulting currents. Nets were deployed perpendicular to the current, with net ends anchored on the river bottom by a 6.8 kg navy anchor attached to the net end by a 0.9 m bridle. Soak time was reduced to 25-30 minutes during summer months when temperatures exceeded 27 °C to minimize stress and reduce the chance of heat-related mortalities of shortnose sturgeon (Moser et al. 2000). During net retrieval, all shortnose sturgeon captured were placed in floating net pens until processing. Each fish was measured—total length (TL) and fork length (FL) to the nearest mm, weighed to the nearest 2 g (20 g for individuals heavier than 1.2 kg), and checked for tags. If a tag was not present, fish were injected with a passive integrated transponder (PIT) tag under the forth dorsal scute (125 kHz, Biomark). One centimeter segments also were removed from the leading left pectoral fin ray of a subsample of shortnose sturgeon to estimate age.

Abundance Estimates

I estimated population size using POPAN-5 within Program MARK (White and Burnham, Colorado State University). The POPAN-5 program used to estimate population size in this study is a robust parameterization of the Jolly-Seber model. Model selection in POPAN is determined by Akaike’s Information Criteria (AIC). Maximum Likelihood Estimation (MLE) addressed heterogeneity within the models (Williams et al. 2002). Assumptions with the models vary with the parameterization; however, the assumptions used in my study were 1) the population was closed to gains and losses during the each sampling period, 2) tags were not lost or overlooked and are
correctly recorded, 3) all fish had equal capture probabilities during all sampling periods, and 4) survival of each individual was independent of capture probability.

To compare this model with previous estimates for the Altamaha River shortnose sturgeon population, I conducted a Schnabel estimate for the summers of 2004 and 2005. The assumptions of the Schnabel estimator were: 1) the population was closed to gains and losses during the sampling periods, 2) marked and unmarked fish were equally vulnerable to sampling gear, 3) marked fish mix randomly with unmarked fish, and 4) tags were not lost and marks were not overlooked.

Data used both for the POPAN and the Schnabel estimates were for June-August of 2004 and 2005 only. This was because capture and recapture rates for the remainder of the year was very low comparatively and because Program MARK can not account for continuous sampling.

Population Age Structure

Age Determination

I evaluated population age structure using cross sections of pectoral fin spine samples collected from a stratified subsample of 68 shortnose sturgeon. Age of each shortnose sturgeon in the subsample was determined from a 1-2 cm segment of the left leading pectoral fin ray which was removed using a small coping saw (Fleming et al. 2003). This procedure was performed only during cooler months when water temperature was below 27 °C to minimize the risk of mortality associated with additional handling. Once removed from the fish, each segment was either allowed to air dry for 45 days or dried in an oven at 65.5° C for 4 hours. Once dry, a Buehler low-speed saw
was used to cut the segments to a thickness of 0.50-0.75 mm. Each cross section of each fin ray segment was mounted on an individual glass slide and viewed by two independent readers without prior knowledge of fish size, date, or capture location at 30x magnification on a Leica MZ6 dissecting microscope. All disagreements in assigned ages were reconciled by mutual agreement between observers.

I evaluated the precision of age estimates by coefficient of variation (CV) as given in the equation:

\[ CV = 100 \times \sqrt{\frac{\sum_{i=1}^{R} (X_{ij} - \bar{X}_j)^2}{R - 1}}, \]

where \( R \) is the number of reads per sample, \( X_{ij} \) is the \( i \)th determination of the \( j \)th fish, and \( \bar{X}_j \) is the mean age of the \( j \)th fish (Chang 1982). This formula gives a single value for each sample and reader which were averaged across of all spines to give a mean estimate of precision. The index values were used to evaluate whether error increased with older fish and to compare the error rate with reported values from other studies on long-lived fish. Differences in age estimates among readers were plotted and compared to a line where the slope is equal to 1 (complete agreement) to detect reader bias (Campana et al. 1995).

An age-frequency histogram was constructed to illustrate the age structure of the population. Annual mortality was calculated from the catch curve constructed from these data by linear regression.

I also used the von Bertalanffy growth equation to estimate both the growth coefficient and the maximum size potential of shortnose sturgeon in the Altamaha River. The von Bertalanffy growth model is described by the equation:
where $\text{TL}_t$ is the mean predicted length (mm) at age $t$, $\text{TL}_\infty$ is the average asymptotic length of shortnose sturgeon, $t_0$ is the x-intercept associated with the predicted age at which size is 0 mm, and $K$ is the Brody growth coefficient (Ricker 1975). Parameters were estimated using the program FiSAT II © (FAO-ICLARM Fish Stock Assessment Tools 2000), which uses regression to estimate the parameters $\text{TL}_\infty$, $t_0$, and $K$.

Predicted weight-at-age from the von Bertalanffy growth model was obtained using the equation:

$$W_t = a(TL)^b$$

where the growth parameter $b$ was fitted by regression. The von Bertalanffy growth model for weight is:

$$W_{t,t} = W_\infty \left[1 - \exp \left(-K \left(t-t_0\right)^b\right)\right]$$

where $W_t$ is the mean predicted weight (g) at age $t$, $W_\infty$ is the average asymptotic weight (g) of shortnose sturgeon, and $t_0$ and $K$ are parameterized as per the length-at-age model above. I used this equation to evaluate the growth rates of shortnose sturgeon in the Altamaha River over time.

**Gear Selectivity**

Because age data can be biased by gear selectivity, I also evaluated the effect that the sampling gear may have had on the size of shortnose sturgeon captured. I estimated mesh selectivity values through manipulation of the equation:

$$C_{m,l} = q_{l,m} N_l P_m S_{m,l}$$
where $C_{m,l}$ is catch by mesh size $m$ for a given length class $l$; $q_{l,m}$ is catchability of length class $l$ in mesh size $m$; $N_l$ is the abundance of fish of length class $l$; $P_m$ is the fishing power or efficiency of mesh size $m$; and $S_{m,l}$ is the selection of mesh size $m$ for length class $l$ (Hovgård and Lassen 2000).

For gear selectivity bias analysis, I used the Baranov model, which assumes that each mesh size will be the most efficient at capturing a fish of length, $l_o$. I also used the NORMSEP process within the program FiSAT II © (FAO-ICLARM Fish Stock Assessment Tools 2000) to generate selectivity curves under the assumptions of the Baranov model. This procedure uses maximum likelihood estimates to divide length-frequency classes for each mesh size into normally distributed selectivity curves. All curves were scaled to a maximum value of 1 (Hamley 1975).

**Data Analysis**

I evaluated gear selectivity separately for 2004 and 2005. Based on the results from 2004, evaluating gear selectivity became a secondary objective to this study. In 2004, I compared lengths of shortnose sturgeon captured in trammel nets with those captured in 10.2 cm and 15.2 cm gill nets. In 2005 I substituted the 10.2 cm and 15.2 cm gill nets for two experimental nets of 7.6, 10.2, and 15.2 cm stretched mesh hung in different arrangements and compared lengths of shortnose sturgeon to those captured in trammel nets only in 2005. To compare sampling efficiency among net types in the 2004, I used a two-way ANOVA with a factorial arrangement of treatments to compare the effects on catch per unit of effort (CPUE) of net type, tidal stage, and possible interaction of these variables. CPUE was calculated by determining the number of
sturgeon caught per net set. To evaluate potential size selectivity of different net types, I used Tukey’s honestly significant difference (hsd), which is a conservative means comparison test, to compare the mean size captured for each net type. Juveniles were considered to be all fish less than 600 mm TL. This number was derived using linear regression stipulating the size at maturity as reported by Rogers and Weber (1994). In 2005, I used a two-way ANOVA with a factorial arrangement of treatments to compare the effects of net types, tides, and possible interactions on CPUE of each net type and tidal stage for both shortnose sturgeon and other non-target species. To contrast size selectivity of the net types in 2005, I used t-tests to compare the mean sizes of shortnose sturgeon captured for each net type for juvenile and adult shortnose sturgeon. Juveniles and adults were analyzed separately to evaluate susceptibility of both life stages to the sampling gear. All statistical tests were conducted with an alpha of 0.05.

**Identification of Critical Habitat**

To identify potentially critical habitat locations of shortnose sturgeon, I used radio telemetry to monitor seasonal movements of 12 adult shortnose sturgeon. The radio tags, manufactured by Advanced Telemetry Systems (Isanti, Minnesota) measured 68 mm in length, 32 mm in width, and weighed 25 g in air. Each tag was programmed to operate on a 12-hour duty cycle at 48-49 MHz. The battery life of the tags was approximately 5 years. Tags were surgically implanted into adult shortnose sturgeon after each tag was coated with an inert elastomer to reduce rejection potential. Adult shortnose sturgeon selected for radio tracking weighed a minimum of 1,250 g to ensure
that weight was <2% of the fish’s body weight as recommended by Winter (1983). I performed surgeries on shortnose sturgeon in the fall and early winter after water temperature had fallen to 10.9 ° - 21.4 °C, to minimize handling stress (Moser and Ross 1995, Moser et al. 2000). Individuals implanted with tags were first anesthetized in a 250 mg/L solution of tricaine methanesulfonate (MS-222). The fish were then placed on a portable surgical table equipped with a recirculating pump that maintained a constant flow of anesthetic (85 mg/L MS-222 and 170 mg/L NaHCO₃ buffer in 60 L of water) over the gills during the procedure. Sex and reproductive condition was determined using a Karl Storz model 26006 AA laparoscope to examine the gonads of each fish as described by Hernandez-Divers et al. (2004). Only those fish observed to be in spawning condition were selected for insertion of radio tags.

This surgical procedure was performed by first making an incision about 4.5 cm long to allow for insertion of a transmitter. A cordless drill was used to drill a 2 mm hole into a ventral-lateral scute (located slightly posterior to the incision). A metal catheter was then inserted through this hole until it reached through the body wall and into the body cavity. The antennae was inserted through the catheter, the catheter removed, and the rest of the tag inserted into the abdomen. The incision was closed with a 3/0 cutting needle attached to a non-absorbable braided nylon suture. The entire procedure typically required less than 3 minutes. Prior to release, each fish was allowed to recover by holding the fish in non-treated river water and slowly moving the fish around. The fish was released once it had regained its balance and could swim without assistance.
Tracking of radio-tagged fish was conducted on a weekly basis from a small boat equipped with a scanning receiver and loop antenna. The area surveyed extended from 10 rkm above the confluence of both the Oconee and Ocmulgee rivers to the coast (Figure 2.3). Locations of radio-tagged fish were marked to the nearest meter possible using a handheld GPS receiver. GIS mapping of these data was used to identify potential spawning sites based on 1) the relative number of fish using an area and 2), the relative duration of each fish’s stay. I also used a ponar grab to determine bottom composition where each fish was located.

To confirm spawning at suspected spawning sites, I deployed artificial egg-sampling mats during February and March 2005. The egg mats were constructed from 40 cm x 20 cm x 10 cm cinder blocks wrapped with hog-hair filter material. Pairs of egg mats were placed 1 m apart and marked by a single buoy. The number of egg mats deployed at each site ranged from 5-15 and varied with current velocity and bottom composition. The egg mats were retrieved and visually examined every three days. Recovered eggs were preserved in 70% ethanol.
Figure 2.3. Altamaha River basin covered on a weekly basis by boat equipped with a scanning receiver and loop antennae.
CHAPTER 3

RESULTS

Abundance Estimates

In late 2003 and throughout 2004, I set a total of 612 nets and captured 644 shortnose sturgeon, 49 of which were later recaptured. In 2005, effort was reduced to 276 net sets, yet 283 shortnose sturgeon were captured with an additional 40 recaptured. In total, 929 nets were deployed and 927 captured shortnose sturgeon and 89 subsequently recaptured. Sizes of captured shortnose sturgeon ranged from 290 to 1166 mm TL (Figure 3.1). CPUE averaged 1.16 fish per net set (274.2 m of entanglement gear fished for 1 slack tide), but varied with season and gear type (Table 3.1). CPUE during July 2004 was greater than at any other time during the study, with a range of 1.0—23.9 fish/net set (Figure 3.2).

Population estimates ranged between 3400-8233 with the Schnabel method and was 6320 (95% C.I. 4387-9249) using POPAN (Table 3.2). The POPAN estimate assumed that apparent survival and recapture probability varied temporally and entry probability was constant. Initial population size did not affect the model through either temporal variation or constancy.
Figure 3.1. Size distributions of captured shortnose sturgeon from the Altamaha River, Georgia in 2004 (top) and 2005 (bottom). In 2004, individuals were caught in 10.2 and 15.2 cm gill nets and trammel nets. In 2005, gill nets were replaced with experimental gill nets constructed from 7.6, 10.2, and 15.2 cm panels.
Table 3.1. Trammel net and gill net capture comparison in 2004 and 2005. Trammel nets were constructed from an inner panel of 7.6 cm and 2 outer panels of 30.5 cm stretched mesh. Gill nets were constructed from 10.2 and 15.2 cm stretched mesh. Experimental gill nets were constructed from 7.6, 10.2, and 15.2 cm stretched mesh. CPUE is defined in terms of number of shortnose sturgeon captured per net set.

<table>
<thead>
<tr>
<th>Year</th>
<th>Net</th>
<th>No. Net Sets</th>
<th>No. Shortnose Captured</th>
<th>CPUE</th>
<th>Relative Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td>Trammel Net</td>
<td>144</td>
<td>252</td>
<td>1.75</td>
<td>100.0</td>
</tr>
<tr>
<td>2004</td>
<td>10.2 cm Gill Net</td>
<td>144</td>
<td>52</td>
<td>0.36</td>
<td>20.6</td>
</tr>
<tr>
<td>2004</td>
<td>15.2 cm Gill Net</td>
<td>144</td>
<td>104</td>
<td>0.72</td>
<td>41.3</td>
</tr>
<tr>
<td>2005</td>
<td>Trammel Net</td>
<td>48</td>
<td>112</td>
<td>2.33</td>
<td>100.0</td>
</tr>
<tr>
<td>2005</td>
<td>Experimental Gill Net</td>
<td>96</td>
<td>136</td>
<td>1.42</td>
<td>60.7</td>
</tr>
</tbody>
</table>
Figure 3.2. Monthly catch per unit effort (CPUE) of shorthose sturgeon in the Altamaha River for 2004 and 2005.

(Sampling not conducted during months denoted with an asterisk.)
Table 3.2. Estimates of shortnose sturgeon abundance in the Altamaha River, Georgia.

<table>
<thead>
<tr>
<th>Population Estimator (Model)</th>
<th>Model Type</th>
<th>( \hat{N} )</th>
<th>95% Confidence Interval</th>
<th>Sample Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schnabel</td>
<td>closed</td>
<td>8233</td>
<td>5083 – 21656</td>
<td>1 June 2004 – 31 August 2004</td>
</tr>
<tr>
<td>Schnabel</td>
<td>closed</td>
<td>3400</td>
<td>2008 – 11074</td>
<td>1 June 2005 – 31 August 2005</td>
</tr>
</tbody>
</table>
Population Age Structure

Age and Growth

Nominal ages determined for 68 fish ranged between 1 - 14, with a modal age of 4 and a mean age of 5.9 (Figure 3.3). Interpretation of annuli was difficult and agreement among observers was only 55%. However, disagreements of one year (37%) constituted the majority of the remaining fin ray samples. The greatest age discrepancy encountered was 2 years, which occurred in 5 individuals. Precision among observers was variable with a coefficient of variance of 4.58 across both observers and all age groups. A visual assessment of age-bias plots between observers (Figure 3.4) indicated that age estimates were relatively precise and that error rates did not increase with older fish.

Using the von Bertalanffy growth equation, I developed a single growth curve (Figure 3.5) for the Altamaha River population of shortnose sturgeon. The weight to length relation was

\[ W_t = 775 \left[ 1 - \exp\left(\frac{-0.09(t-1.58)}{3.40}\right) \right] \]

(Figure 3.6).

Total annual mortality based on uncorrected catch curves (Figures 3.7 and 3.8) was estimated to be 29% and 37%, respectively. This rate was estimated for fish between ages 4-12 only because fish from older age classes were rarely captured and because of the presence of a large cohort of juvenile fish (Tables 3.3 and 3.4). In 2005, this cohort began to affect the slope of the catch curve, indicating a higher mortality rate than expected. When the mortality rate was recalculated without this cohort, the
estimate fell to 34%. Maximum average life span, based on the uncorrected catch curves was estimated to be 14-15 years.

**Gear Selectivity**

Each net type and mesh size had a unique $l_o$ that corresponded with mesh size (Figures 3.9 and 3.10). The trammel net, with a 7.6 cm inner panel, had a lower $l_o$ in both sampling periods and $l_o$ increased with mesh size. Experimental gill nets and trammel nets had similar $l_o$'s and selectivity curves. Trammel net $l_o$’s increased from 2004 to 2005 as growth occurred over time.

Trammel nets caught a wider size range of shortnose sturgeon (Figure 3.11) than either the 10.2 cm or 15.2 cm gill nets in 2004. The results of the ANOVA show that trammel nets catch a significantly smaller mean size for both juvenile and adult shortnose sturgeon than did either the 10.2 cm or 15.2 cm gill nets (juveniles: $F_{2,178}=16.00$, $p<0.0001$; adults: $F_{2,166}=6.87$, $p=0.0014$). The 10.2 cm or 15.2 cm gill nets were also found to capture significantly different sizes of both juvenile and adult shortnose sturgeon (juveniles: mean difference=118.72, 95% confidence limit=15.65-221.787; adults: mean difference=75.77, 95% confidence limit=20.11-131.42).

Trammel nets caught significantly smaller individuals of juvenile shortnose sturgeon (Figure 3.12) than did the experimental gill nets ($t_{191}=2.59$, $p=0.0102$) in 2005. Trammel nets and experimental gill nets caught similar size ranges of shortnose sturgeon individuals, but experimental gill nets caught a higher number of individuals larger than 600 mm TL.
Figure 3.3. Nominal age frequency of shortnose sturgeon captured in the Altamaha River, Georgia in 2005. Ages of individual fish were determined from pectoral fin ray sections and interpreted by 3 independent observers.
Figure 3.4. Age-bias graph for 2 interpreters of sampled fin rays from Altamaha River shortnose sturgeon. The dashed line designates the 1:1 ratio line.

CV = 4.58%
Figure 3.5. Growth of shortnose sturgeon (both sexes) in the Altamaha River, Ogeechee River, and Hudson River.

\[ TL = 1389 \left( 1 - \exp \left( -0.09 \left( t - 1.58 \right) \right) \right) \]
Figure 3.6. Weight – length relationship of shortnose sturgeon (both sexes) from the Altamaha River, Georgia.

$R^2 = 0.9847$

$n = 1012$
Table 3.3. Age-frequency key for shortnose sturgeon captured in the Altamaha River system in 2004. Ages were determined from the first pectoral fin ray. Final ages from each individual subsample were applied proportionally across the same length-group. Note: age-2 or age-13 individuals were not obtained during this study.

<table>
<thead>
<tr>
<th>Length group (mm)</th>
<th>Number in sample</th>
<th>Number (age) in subsample</th>
<th>Sample allocation per age - group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Age 1</td>
</tr>
<tr>
<td>≤ 300</td>
<td>1</td>
<td>1(1)</td>
<td>1</td>
</tr>
<tr>
<td>301 - 400</td>
<td>277</td>
<td>5(1)</td>
<td></td>
</tr>
<tr>
<td>401 - 500</td>
<td>39</td>
<td>2(3), 8(4)</td>
<td>8</td>
</tr>
<tr>
<td>501 - 600</td>
<td>29</td>
<td>8(4), 8(5), 3(6)</td>
<td>12</td>
</tr>
<tr>
<td>601 - 700</td>
<td>37</td>
<td>2(5), 3(6), 4(7)</td>
<td></td>
</tr>
<tr>
<td>701 - 800</td>
<td>21</td>
<td>3(6), 2(7), 1(8)</td>
<td></td>
</tr>
<tr>
<td>801 - 900</td>
<td>24</td>
<td>4(7), 2(9), 2(11)</td>
<td>12</td>
</tr>
<tr>
<td>901 - 1000</td>
<td>14</td>
<td>1(7), 2(8), 1(9), 1(10), 1(12)</td>
<td></td>
</tr>
<tr>
<td>1001 - 1100</td>
<td>2</td>
<td>1(8), 1(10), 1(12), 1(14)</td>
<td></td>
</tr>
<tr>
<td>1101 - 1200</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; 1200</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>446</td>
<td>278</td>
<td>8</td>
</tr>
</tbody>
</table>
Table 3.4. Age-frequency key for shortnose sturgeon captured in the Altamaha River system in 2005. Ages were determined from the first pectoral fin ray. Final ages from each individual subsample were applied proportionally across the same length-group. Note: age-2 or age-13 individuals were not obtained during this study.

<table>
<thead>
<tr>
<th>Length group (mm)</th>
<th>Number in sample</th>
<th>Number (age) in subsample</th>
<th>Sample allocation per age - group</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 300</td>
<td>1(1)</td>
<td></td>
<td>Age 1  Age 3  Age 4  Age 5  Age 6  Age 7  Age 8  Age 9  Age 10  Age 11  Age 12  Age 14</td>
</tr>
<tr>
<td>301 - 400</td>
<td>4</td>
<td>5(1)</td>
<td>23  92</td>
</tr>
<tr>
<td>401 - 500</td>
<td>115</td>
<td>2(3), 8(4)</td>
<td>43  43  16</td>
</tr>
<tr>
<td>501 - 600</td>
<td>103</td>
<td>8(4), 8(5), 3(6)</td>
<td>5  7  10</td>
</tr>
<tr>
<td>601 - 700</td>
<td>22</td>
<td>2(5), 3(6), 4(7)</td>
<td>7  4  2</td>
</tr>
<tr>
<td>701 - 800</td>
<td>13</td>
<td>3(6), 2(7), 1(8)</td>
<td>10  5  5</td>
</tr>
<tr>
<td>801 - 900</td>
<td>20</td>
<td>4(7), 2(9), 2(11)</td>
<td>1  3  1  1  1  1</td>
</tr>
<tr>
<td>901 - 1000</td>
<td>8</td>
<td>1(7), 2(8), 1(9), 1(10), 1(12)</td>
<td>2  2  2  2  2  2</td>
</tr>
<tr>
<td>1001 - 1100</td>
<td>6</td>
<td>1(8), 1(10), 1(12), 1(14)</td>
<td></td>
</tr>
<tr>
<td>1101 - 1200</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; 1200</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>291</td>
<td></td>
<td>4  23  135  48  30  25  6  6  3  5  3  2</td>
</tr>
</tbody>
</table>

49
Figure 3.7. 2004 uncorrected catch curve for ages 4 – 12 of Altamaha River shortnose sturgeon.
Figure 3.8. 2005 uncorrected catch curve for ages 4 – 12 of Altamaha River shortnose sturgeon.
Figure 3.9. Size composition of shortnose sturgeon captured in trammel nets and gill nets from the Altamaha River, Georgia in 2004. Catch per unit effort is the number of shortnose sturgeon captured per net per slack tide.
Figure 3.10. Size composition of shortnose sturgeon captured in trammel nets and experimental gill nets (constructed from 7.6, 10.2, and 15.2 cm stretched mesh) from the Altamaha River, Georgia in 2004. Catch per unit effort is the number of shortnose sturgeon captured per net per slack tide.
Figure 3.11. Indirect selectivity of trammel nets, 10.2 cm, and 15.2 cm stretched mesh gill nets from the Altamaha River, Georgia in 2004.
Figure 3.12. Indirect selectivity of trammel nets, and experimental gill nets composed of 7.6, 10.2, and 15.2 stretched mesh panels from the Altamaha River, Georgia in 2005.
Habitat and Seasonal Movements

When water temperatures exceeded 27 °C, all radio tagged shortnose sturgeon were located above the salt-fresh water interface. In 2004, the interface was located as far inland as rkm 22. River bottom temperatures exceeded 31 °C and dissolved oxygen (DO) levels fell as low 4.53 mg/L throughout the tidally influenced portion of the river. Most captures (as many as 23.9 fish per net set) during this time period were in a single river segment at rkm 22.5 referred to as Ebenezer Bend. This stretch of river reaches a depth of 16 m at mean low tide and has large woody debris along much of the mostly sandy bottom.

From mid-August to September of 2004, multiple tropical storm systems moved through the area and caused discharge to increase and temperatures to decrease. When sampling resumed in mid-October, water temperature had fallen to 20.2 °C, DO increased to 5.82 mg/L and capture rates were lower above rkm 20 while increasing throughout the estuary. During winter, when water temperatures fell below 14 °C, adults were captured in Altamaha Sound in salinities greater than 18 ‰.

Eight male and 4 female (≥ 768 mm TL) shortnose sturgeon were radio-tagged between 14 November 2004 and 14 January 2005 (Table 3.5). Nine of these were tracked until the end of 2005. The remaining individuals were censored after movement was not detected, or they were not relocated, after a period of 4 months. Periodic checks for an additional 2 months also showed no movement. There were no known mortalities directly attributable to the implantation procedure; however, the status of individuals that were not relocated is unknown.
Upstream movement of radio tagged fish, possibly associated with spawning runs, commenced in mid-December when water temperature was 10.2\degree C. I observed ripening females as early as mid-November. Of the 4 females I radio-tagged, at least 3 of these made upstream migrations. The first radio tagged female left the estuary 4 December 2004 and was located near Doctortown (rkm 89). Additional movement was only 7 rkm upstream 5 days after it was initially located. Further movement was not observed. Two other females completed runs into the Ocmulgee and Oconee rivers (individually) and remained there for a period of one week prior to moving downstream at a rate of 40 km/day. One of these females traveled a distance of at least 340 rkm over 6 weeks and moved at a rate of nearly 5 km per hour (as determined by monitoring for a period of 1.5 hours) during downstream migration.

When tracking both of these females, contact was lost at the confluence of the Ocmulgee and Oconee rivers. This area is characterized by a sandy substrate with a deep hole excavated by the fast, converging currents. Eggs mats were deployed throughout this area and 2 eggs were recovered on 20 March, 2005, when the water temperature was 12 \degree C. I located two other individual shortnose sturgeon between rkm 159.6 – 178.4 prior to them returning downstream. A single male moved upstream to rkm 133.2 in late spring of 2006, but returned downstream to rkm 92-94, where it had resided for the previous year. Based upon these individuals, I was able to identify 1 confirmed and 2 suspected spawning sites (Figure 3.13).

Non-spawning habitat was located in 2 discrete areas: the tidally influenced portion of the lower river (rkm <40) and slightly below Doctortown (rkm 90-95) (Figure 3.14). This area was categorized as non-spawning habitat because individuals were present
throughout the year and attempts to recover eggs at this location were unsuccessful. This upstream habitat is much deeper (7.6 m) relative to the surrounding stretches of river (~3 m depth) and Ponar grabs revealed that the substrate is composed of sand with large numbers of small bivalves and aquatic insects. Movements greater than 2 rkm were not observed in either summering area while river temperatures exceeded 27 °C.
Table 3.5. Radio tagged shortnose sturgeon release dates and number of relocations in the Altamaha River, Georgia. The * denotes an individual tag that did not change locations after an initial ~100 km upstream migration after tag implantation. ** indicates a censored individual after x days at large.

<table>
<thead>
<tr>
<th>Radio Frequency</th>
<th>Sex</th>
<th>Date Released</th>
<th>No. Relocations</th>
<th>Days at Large</th>
</tr>
</thead>
<tbody>
<tr>
<td>49.771</td>
<td>male</td>
<td>11 Nov. 2004</td>
<td>15</td>
<td>340</td>
</tr>
<tr>
<td>49.781</td>
<td>male</td>
<td>22 Jan. 2005</td>
<td>0</td>
<td>unknown **</td>
</tr>
<tr>
<td>49.791</td>
<td>male</td>
<td>16 Dec. 2004</td>
<td>17</td>
<td>328</td>
</tr>
<tr>
<td>49.801</td>
<td>male</td>
<td>18 Nov. 2004</td>
<td>25</td>
<td>265</td>
</tr>
<tr>
<td>49.811</td>
<td>female</td>
<td>22 Jan. 2005</td>
<td>1</td>
<td>125 **</td>
</tr>
<tr>
<td>49.831</td>
<td>female</td>
<td>10 Dec. 2004</td>
<td>22</td>
<td>352</td>
</tr>
<tr>
<td>49.841</td>
<td>female</td>
<td>22 Jan. 2005</td>
<td>25</td>
<td>326</td>
</tr>
<tr>
<td>49.871</td>
<td>female</td>
<td>12 Nov. 2004</td>
<td>29 *</td>
<td>327 **</td>
</tr>
<tr>
<td>49.881</td>
<td>male</td>
<td>14 Jan. 2005</td>
<td>19</td>
<td>277</td>
</tr>
<tr>
<td>49.891</td>
<td>male</td>
<td>14 Jan. 2005</td>
<td>16</td>
<td>270</td>
</tr>
<tr>
<td>49.901</td>
<td>male</td>
<td>17 Dec. 2004</td>
<td>14</td>
<td>364</td>
</tr>
<tr>
<td>49.921</td>
<td>male</td>
<td>6 Jan. 2005</td>
<td>15</td>
<td>345</td>
</tr>
</tbody>
</table>
Figure 3.13. Confirmed and suspected spawning areas of shortnose sturgeon in the Altamaha River, GA (2005).
Figure 3.14. Non-spawning habitat of shortnose sturgeon in the Altamaha River, GA (April-December 2005).
CHAPTER 4
DISCUSSION

Abundance Estimates

Since shortnose sturgeon were initially listed as endangered in 1967, most populations have remained depressed (Moser and Ross 1995); however, the abundance estimate of 6320 (95% C.I. 4387-9249) obtained in this study is nearly ten times larger than the previous estimate of 650 reported by Kynard (1997—from Rogers and Weber, unpublished data). My results show that the Altamaha River population of shortnose sturgeon is probably the fourth largest in the United States, and the largest south of Chesapeake Bay (Squiers et al. 1982, Hastings et al. 1987, Bain et al. 1995, NMFS 1998). Although continued study is needed to determine if the population is remaining stable in the face of ongoing environmental challenges within the Altamaha watershed, the results of this study suggest that the Altamaha River supports one of the largest known populations of shortnose sturgeon. Furthermore, small populations in adjacent rivers may be sustained by immigrating Altamaha individuals in lieu of poor reproduction by resident individuals (Wirgin et al. 2005). Northern rivers with large populations (e.g., the Hudson and Delaware rivers) may also supplement adjacent smaller populations through immigrants and transients (Welsh 2002); however, the actual genetic contribution to these smaller populations is uncertain. Wirgin et al. (2005) reported that haplotypes of shortnose sturgeon from the Altamaha and
Ogeechee river populations were not significantly different, which suggests at least some gene flow between populations in these rivers. Further study is necessary prior to assessing the actual Altamaha River component both in the Ogeechee and other adjacent rivers.

POPAN-5 is capable of estimating abundance, survival and capture probability and was chosen because the field data best fit the program. The primary limitation of POPAN is that because the numbers of individuals not captured are also estimated, the parameter N includes unknown covariates. Therefore, covariates were not considered when calculating the population estimate in this study. The best-fitting model in this study assumed temporal variation in survival and recapture probabilities and constant immigration. Although these assumptions may have been met, low recapture rates had a considerable affect on the model and caused the model fit to decrease somewhat.

The Schnabel models used in this study assumed a closed population during each sampling period. This assumption was probably not met given the movements of radio tagged fish I observed. Furthermore, the estimates from the Schnabel model varied widely — 46% lower to 30% higher than those generated by the POPAN model, which suggests that management agencies should not use the simpler Schnabel model for monitoring future population trends.

**Population Age Structure**

**Age and Growth**

In recent years, the marginal pectoral fin ray has become the preferred structure for estimating the age of sturgeon because of the apparent non-lethality of this technique
and because cross sections from it are easier to interpret than those from other calcified structures (e.g., otoliths or scutes) (Currier 1951, Pycha 1956, Roussow 1957, Dadswell 1979, Brennan and Cailliet 1989, Doval et al. 1989, Keenlyne and Jenkins 1993, Rien and Beamesderfer 1994, Morrow et al. 1998). In sturgeons, these rays contain alternating opaque and translucent bands formed by the differences in summer and winter growth rates (Currier 1951, Roussow 1957, Dadswell 1979, Nakamoto et al. 1995, LeBreton and Beamish 2000, Paragamian and Beamesderfer 2003). The dark bands are created by rapid deposition of connective tissue during the summer (Nakamoto et al. 1995) whereas the translucent bands are formed during the period of metabolic inactivity that typically occurs during the winter when growth is slow, and mineralization of the ray is relatively poor (Chilton and Beamish 1982, Nakamoto et al. 1995). Within a typical sturgeon fin ray, the growth increments appear as consistently spaced rings formed throughout the juvenile phase. After maturity, however, growth slows causing the growth annuli to become more closely spaced (Dadswell 1979, Dadswell et al. 1984). This pattern of progressive “tightening” of the annuli in adult sturgeon often makes interpretation of growth increments more difficult in older specimens (Dadswell 1979, Doval et al. 1989, Nakamoto et al. 1995, Fleming et al. 2003).

Age determination of individuals in this study proved difficult, and independent observers regularly reported different initial age estimates from the same fin ray cross-section. The age estimates were relatively precise and were comparable to other long-lived species (Table 4.1). Coefficient of variance is an unbiased estimator of precision.
Table 4.1. Coefficient of variance (CV) of age estimates for between-observer precision for reported long-lived species.

<table>
<thead>
<tr>
<th>Species</th>
<th>CV</th>
<th>Maximum observed age</th>
</tr>
</thead>
<tbody>
<tr>
<td>White sturgeon A. transmontanus $^1$</td>
<td>7.8</td>
<td>104</td>
</tr>
<tr>
<td>Atlantic sturgeon A. oxyrinchus $^2$</td>
<td>4.8</td>
<td>42</td>
</tr>
<tr>
<td>Shortnose sturgeon A. brevirostrum $^3$</td>
<td>4.6</td>
<td>14</td>
</tr>
<tr>
<td>Monkfish Lophius vomerinus $^4$</td>
<td>6.3</td>
<td>11</td>
</tr>
<tr>
<td>Pacific ocean perch Sebastes alutus $^5$</td>
<td>4.9</td>
<td>78</td>
</tr>
<tr>
<td>Pacific hake Merluccius asper $^5$</td>
<td>3.2</td>
<td>16</td>
</tr>
<tr>
<td>Thorny skate Amblyraja radiata $^6$</td>
<td>2.8</td>
<td>16</td>
</tr>
<tr>
<td>Northern pike Esox luscus $^7$</td>
<td>1.2</td>
<td>11</td>
</tr>
</tbody>
</table>

Source: (1) Rien and Beamesderfer (1994); (2) Stevenson and Secor (1999); (3) this study; (4) Maartens et al. (1999); (5) Kimura and Lyons (1991); (6) Sulikowski et al. (2005); (7) Laine et al. (1991)
and allows comparison among species (Rien and Beamesderfer 1994). Among reported values for 8 other species, 4 had higher values for CV than my study.

Difficulty in estimating age based on fin rays is not uncommon (Kohlhurst et al. 1980, Rien and Beamesderfer 1994, Nakamoto et al. 1995, Morrow et al. 1998, Fleming et al. 2003). Several authors have questioned the validity of estimating the age of sturgeons based on the first pectoral fin ray, citing either low accuracy or an underestimation of age based on fish of known age (Rien and Beamesderfer 1994, Paragamian and Beamesderfer 2003, Hurley et al. 2004, Whiteman et al. 2004). Numerous studies of North American sturgeons; however, have used this method; Beamish and McFarlane (1983); Rossiter et al. (1995) for lake sturgeon *A. fulvescens*, Brennan and Caillet (1991), Rien and Beamesderfer (1994), and Paragamian and Beamesderfer (2003) for white sturgeon *A. transmontanus*, Stevenson and Secor (1999) for Atlantic sturgeon *A. oxyrinchus*, and Hurley et al. (2004) for pallid sturgeon *Scaphirhynchus albus*. For shortnose sturgeon, some studies using stocked fish or mark-recapture experiments have attempted to validate the method (Fleming et al. 2003, Paragamian and Beamesderfer 2003). Age validation was not possible in this study because known age fish were not available. Despite these difficulties, age determinations from the marginal fin ray method provide the best non-lethal means available to obtain information on growth, recruitment, and mortality of shortnose sturgeon.

The current age structure of the shortnose sturgeon population of the Altamaha River suggests that individuals from southern populations may not be as long-lived as their northern counterparts. Fleming et al. (2003) reached a similar conclusion regarding shortnose sturgeon on the Ogeechee River, where he estimated maximum
age to be less than 16 years. Shortnose sturgeon from southern populations, also appear to grow much faster than in northern rivers (Dadswell et al. 1984), as evident from both this study and that of Fleming et al. (2003). Dadswell et al. (1984) suggests that faster growth of shortnose sturgeon in southern rivers may be offset by smaller maximum size; however, age and growth data from both the Altamaha and Ogeechee rivers seem to disprove this theory. Individuals larger than 1000 mm TL were routinely captured in this study, with the largest measuring 1166 mm TL.

The current size structure of the Altamaha shortnose sturgeon population may be interpreted in several different ways. First, the relatively high abundance of juveniles suggests that the population is recovering. If this is the case, then the number of adults captured should increase and the numbers of juveniles gradually decrease with time as the population approaches equilibrium. On the other hand, the data could suggest that mortality between the juvenile and adult stages is unusually high, possibly a result of incidental mortality associated with the commercial shad fishery and the simultaneous spawning migration of shortnose sturgeon. If this is the case, then the large 2001 cohort would become indistinguishable as they were harvested over the proceeding years. Another possible interpretation is that adults are less constrained to the tidally influenced portion of the river than are juveniles and therefore are underrepresented in my catch data. Capture data from 2003-2005 indicates that at most, 40% of the resident population are adults; a potential increase of 30% from results reported by Flournoy et al. (1992).

The catch curves used to derive the mortality estimates of shortnose sturgeon in this study were based on several assumptions: 1) mortality was constant across the
sampling periods, 2) recruitment was constant across the sampling periods, 3) that mortality was equal among ages, and 4) that all age/size classes were adequately represented within the sample. The age-frequency histogram indicates that the latter two assumptions may not have been met. A potential source of bias in the catch curve data was the low sample size of fish older than age-10. A larger sample size of adults might have resulted in a lower mortality estimate. By representing older cohorts, a more representative distribution of adult size classes relative to age could have elevated the right side of the catch curve, thereby decreasing the angle of the regression line and subsequent mortality estimate. While I can not discount the possibility that adult shortnose sturgeon were inhabiting areas where I did not sample, the lack of samples of older fish was likely a result of a lack of those individuals within the population rather than a result of sampling bias. Other large fish captured during the course of this study, as well as reported preferred habitat in other studies on southern rivers (Flournoy et al. 1992, Weber 1996, Collins et al. 2001) is further evidence that adults are not as abundant in the Altamaha river population. In 2005, an unusually large 2001 cohort began to affect the mortality rate estimates by artificially inflating the portion of the curve represented by age-4 fish. The violation of the assumption of constant recruitment may have resulted in a higher mortality estimate in 2005. When age-4 fish were excluded from the catch curve analysis the mortality rate slightly decreased from 0.384 to 0.344.

Given that shortnose sturgeon are long-lived and that the population has been protected for over 30 years, I believe that adults should have been found in higher numbers. Telemetry data indicated that although adults do make long spawning runs into the upper reaches of the river where I did not sample, they did not spend much time
there outside of the spawning season, presumably because they prefer the tidally influenced habitats of the lower river. Similar behavior for shortnose sturgeon also has been documented in other studies in southern rivers (Collins and Smith 1993, Rogers and Weber 1994, Moser and Ross 1995, Weber et al. 1998). Therefore, I believe my data are reasonably representative of the current age-structure and that a particularly strong year class may be the reason for the relatively high abundance of juveniles observed in this study. A total annual mortality rate of about 30% is the highest ever reported for any shortnose sturgeon population. In contrast, Secor and Woodland (2005) reported a mortality rate of 22% for the Hudson River population.

**Gear Selectivity**

Several methods are used currently to sample sturgeon populations. Passive entanglement gears often are the most effective, but they tend to be size selective depending on the mesh sizes used and how they are deployed (Hamley 1975). This bias is minimized most often by fishing “gangs” of different mesh sizes or by using experimental nets that have been constructed using several mesh sizes (Hamley, 1975, Kieffer and Kynard 1993, Foster and Clugston 1997, Haxton 2002). Direct selectivity estimates can be derived through mark-recapture studies if the size distribution of the population is known (Hamley 1975). In this study, however, I employed an indirect method for estimating size selectivity because my recapture rate was low (9.6%) and because the size distribution of the population was unknown. The indirect method that I used required 2 assumptions. The first is that the degree of size selectivity depends on the geometry of a fish relative to a specific mesh size as described by Baranov (1948).
Hence, the width of any given selectivity curve (i.e., the size range of fish captured by any single mesh size) is proportional to the mesh size being fished (Hamley 1975). The second assumption of the indirect method is that each mesh size used is equally exposed to all fishes (Hovgård 1996). Because I used a variety of mesh sizes in standardized nets that were deployed with equal effort in each period, this assumption was met (Hovgård and Lassen 2000).

Because the population size-structure was unknown I standardized each selectivity curve to 1 (Hamley 1975). However, this distorted the selectivity curve for each net, especially for the 10.2 cm gill net. A total of 52 individuals were captured in this net, and the length frequency histogram had 3 peaks occurring at 200 mm intervals, with each peak comprised of only 5 fish. The effective range of fish sizes captured by the 10.2 cm gill net may be overstated by the curve. Because of the small number of captures in this mesh size, the modes at 375 mm and again at 850 mm more likely exaggerates the effective size range of fish captured by this mesh size. Given these problems I used the combined catch of trammel nets and experimental gill nets in my analysis of the population size-structure.

In comparing size distributions shortnose sturgeon captured in each gear type, I found that trammel nets and experimental gill nets caught a slightly wider size distribution of fish than did the 10.2 cm and 15.2 cm gill nets when fished in tandem. The implications of this analysis are that single-mesh gill nets can be used to efficiently sample specific size classes of sturgeon (e.g., juvenile cohorts), whereas experimental gill nets and trammel nets provide a much more representative sample of the population. Although this comparison showed that each gear may impart some size
selective bias to my catch data, the effect was probably not biologically significant. Furthermore, the results suggest that using both trammel nets and experimental gill nets may provide the best representation of the true population size.

Analysis of CPUE data from each gear type showed that trammel nets are more efficient than gill nets. In 2005, I attempted to compensate for the disparity in the size distribution between my trammel and single-mesh gill nets by fishing experimental gill nets constructed from 3 different mesh sizes, but twice the number of these nets were required to catch the same number of shortnose sturgeon as were caught in a single trammel net. Furthermore, the smallest mesh in the experimental gill nets increased bycatch to levels similar to those of trammel nets. This finding is noteworthy because a primary argument against the use of trammel nets in fisheries sampling is that gill nets are thought to produce less bycatch. Because site specific variables such as current velocity and bottom structure may affect sampling efficiency of both gill and trammel nets, sturgeon researchers should evaluate both types of gear in specific study areas before implementing a long term sampling program.

Habitat and Seasonal Movements

Habitat Use in Summer

During summer months when water temperatures exceeded 27 °C, shortnose sturgeon were not captured below the fresh-saltwater interface. All captures during this time occurred in areas deeper than the surrounding river stretches, with a maximum depth of 12.8 m. Similar habitats were used by shortnose sturgeon during the summer on the Savannah River (Collins et al. 2001), Ogeechee River (Weber 1996) and in a
previous studies on the Altamaha River (Flournoy et al. 1992). In the latter study, the authors postulated that deepwater habitats may contain coolwater springs that provide important thermal refugia for shortnose sturgeon during the summer months. In this study, however, we could detect no differences in bottom temperatures in the area between rkm 22-23. Hence, I believe that the summer aggregation of shortnose sturgeon in this area likely resulted from the combined effects of increasing temperature and the progressive intrusion of the salt wedge that essentially “drove” shortnose upstream to freshwater habitats. In fact, I observed the upstream movement of several tagged fish into this area coincident with the progressive intrusion of the salt wedge. Hence, I believe that summer aggregations of shortnose sturgeon at rkm 22-23 occur simply because this area contains the first deepwater habitat above the salt wedge that forms during summer, especially during periods of low discharge. Once the fish arrived at this site, most remained there until water temperatures began to decline in late summer or fall.

During the summer of 2005, water temperatures were 1-2 °C degrees cooler, and discharge was much higher than in summer of 2004. Increased rainfall during the summer months largely diminished the upstream intrusion of salt water in that year. Not surprisingly, shortnose sturgeon were captured throughout the summer as far downstream as rkm 15.4 and capture rates at rkm 22-23 were much lower than in summer of 2004. Movements of radio-transmittered fish also showed that shortnose moved freely throughout the lower portion of the river during summer 2005.
Habitat use in Fall, Winter, and Spring

Adult shortnose sturgeon actively moved throughout the river and estuary during the cool months of the year. Areas of summer aggregations were abandoned by early fall and individuals became scattered throughout the estuary. Captures of shortnose sturgeon occurred over a variety of substrates (e.g., mud and sand) and at salinities of 0.0 - 26.1‰. Catches of more than 5 individuals were rarely obtained from any single site, except in late January when 11 adults were captured at rkm 7-8. Subsequent laparoscopic examination of these individuals revealed the presence of both gravid females and ripe males. This aggregation of pre-spawning adults in the lower river during late winter suggests that shortnose sturgeon may gather in specific estuarine staging areas just prior to making their upstream spawning migrations. Although this behavior has been documented previously for shortnose sturgeon on the Hudson River (Bain et al. 2000), it has not been observed in a southern population and it has never been found to occur in an estuarine environment. The importance of this behavior is unknown; however, it may help to synchronize spawning migrations and the reproductive cycles of males and females.

Spawning Habitat

Temperature appears to be a key environmental factor governing the timing of spawning (Dadswell et al. 1984). Numerous studies from throughout the range of shortnose sturgeon have shown that spawning occurs at temperatures between 9° and 12 °C (Meehan 1910, Heidt and Gilbert, 1978, Dadswell 1979, Taubert 1980a, Buckley and Kynard 1981). This study documents the first confirmed spawn by shortnose
sturgeon in the Altamaha River. While water temperatures in the Altamaha at this time were consistent with preferred spawning temperatures of shortnose sturgeon reported in other studies, spawning substrates in the Altamaha were different than those previously described. Substrates of both confirmed and suspected spawning sites of shortnose sturgeon in this study typically consisted of course sand. Although Rogers and Weber (1994) suggested that shortnose may spawn at nearby sites containing large rock and gravel substrates, these areas were not found in this study. Although I sampled substrates in several sites in the headwater reaches of the river, it is possible that shortnose may spawn at several specific sites in this area of the river. Further studies are needed to identify specific spawning habitats of shortnose sturgeon in this area of the Altamaha System, including the lower reaches of both the Ocmulgee and Oconee Rivers.

In northern rivers, spawning migrations appear to begin in late fall with individuals overwintering just downstream of the spawning grounds (Dadswell 1979, Buckley 1982). In hypothesizing that this two-step migration pattern may also be used by shortnose sturgeon in the Altamaha, Rogers and Weber (1994) suggested that spawning adults may require additional time to accumulate the energy reserves needed to make long upstream migrations. In this study, I did find congregations of pre-spawning adults in the lower estuary during early winter, but their upstream migrations were rapid and continuous once they began. Although two-step spawning migrations can not be ruled out for Altamaha River shortnose sturgeon, this pattern was not observed in this study or in previous studies of shortnose sturgeon in other southern rivers (Hall et al. 1991, Collins and Smith 1993, Weber 1996).
Management Implications

This study has documented the largest known shortnose sturgeon population in the southern United States. Based on the criteria specified by the Shortnose Sturgeon Recovery Team (NMFS 1998), the Altamaha River population may be a possible candidate for future delisting from the Federal Endangered Species List. Under the terms of the Endangered Species Act, delisting of an endangered species (or a population of that species) can be considered only when sufficient evidence exists that the population is large enough to prevent extinction and that the loss of genetic diversity is unlikely (NMFS 1998). Before any such action is considered, however, several additional years of monitoring should be completed to ensure that the Altamaha population maintains or increases its current abundance and complex age structure. Although the results of this study have provided important new information about the adult population of shortnose sturgeon in the Altamaha system, additional studies are still needed to better understand recruitment mechanisms and habitat requirements of juveniles. Furthermore, the minimum population size required to protect genetic diversity has not been determined for any shortnose sturgeon population. Given that southern populations exhibit a shorter life expectancy and are subject to greater environmental stochasticity than their northern counterparts, delisting of any southern population is probably premature at this time.

In Georgia, the commercial fishery for American shad operates on several coastal rivers, including the Altamaha, from 1 January until the end of March. Because this fishery coincides with annual spawning migrations of shortnose sturgeon, the incidental
take of spawning shortnose sturgeon could be substantial, especially where fishermen employ bottom set gill nets. Previous studies by Collins et al. (1996) showed that mortality of shortnose sturgeon captured in set gill nets was 16%; however, similar studies in the Altamaha River have not been attempted.

Illegal harvest of shortnose sturgeon is also a potential threat to the shortnose sturgeon on the Altamaha River. Kynard (1997) reported that illegal harvest of shortnose sturgeon in southern rivers was widespread and that 80% of radio-tagged fish in the Cooper River (S.C.) were taken by poachers. Given that shortnose sturgeon pass through many remote reaches of the Altamaha River during their annual spawning migrations, additional studies are needed to quantify illegal harvest and to assess this potential threat.

Summary

Data collected in this study shows that the Altamaha River population of shortnose sturgeon is substantially larger than previously thought; however, the estimated mortality rate raises concerns that undocumented sources of mortality may be limiting further population growth. Growth rates of individual fish are higher than those reported for northern populations but maximum lifespan is substantially shorter, although this could be a result of anthropogenic factors. Unlike shortnose sturgeon in northern rivers, adults exhibit one-step spawning migrations in the Altamaha from early January through March. Spawning migrations, both upstream and downstream, are rapid and extensive with most fish moving at least 200 rkm in each direction. After spawning, most adults return to the brackish, or tidally influenced freshwater of the lower Altamaha. As
summer approaches and temperatures rise above 27 °C, the fish seek deep freshwater habitats just upstream of the salt-freshwater interface. During periods of high water temperature and low discharge, activity is reduced and the fish form large aggregations in these deepwater areas.

Based on the information obtained in this study, the shortnose sturgeon population of the Altamaha River appears to be in the midst of a robust recovery. Although the annual mortality rate of the population was surprisingly high, ~30%, the population appears to be increasing as indicated by the relatively high abundance of juveniles present in the catch data from both year of this study. Nonetheless, additional studies are needed to identify and quantify potential threats from both legal and illegal fishing, and to better understand factors that affect the abundance and survival of juvenile shortnose sturgeon in this system.
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