BYCATCH OF SHORTNOSE STURGEON IN THE COMMERCIAL SHAD FISHERY OF THE ALTAMAHA RIVER, GEORGIA

by

ROBERT ANDREW BAHN

(Under the Direction of Douglas L. Peterson)

ABSTRACT

Although the shortnose sturgeon (Acipenser brevirostrum) has been federally protected as an endangered species since 1967, incidental capture of shortnose sturgeon in commercial shad fisheries has been documented as a source of mortality that may limit recovery of some populations. As such, shortnose sturgeon bycatch assessments were recently identified as a priority by the National Marine Fisheries Service. The objective of my study was to estimate total bycatch and mortality of shortnose sturgeon in the anchored gill net portion of the Altamaha River commercial shad fishery from 2007 - 09. During my study, total estimated bycatch of shortnose sturgeon was 71, 53, and 498 fish, respectively. Catch rates were highest during January and February of 2009 in upriver commercial nets near previously confirmed spawning locations in the river. Mortality of captured shortnose sturgeon was low in all three years (< 8%), although I did not assess post-release survival.

INDEX WORDS: shortnose sturgeon, Acipenser brevirostrum, bycatch, incidental capture, mortality
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DEDICATION

I dedicate this thesis to my beautiful and patient wife, Jessy, who agreed with my decision to leave a full-time job to return to school in pursuit of a career in natural resources. Thank you for your love and support through the long nights of studying, the long days away from each other, and the long months apart when I lived in the field.
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Joel Fleming established the survey and assisted with data collection and management. Frank Buchanan, Kyle Dresser, and others assisted with direct observations of commercial fishermen. I would like to acknowledge my fellow graduate students for their friendship and guidance.

Special thanks to the Altamaha River commercial fishermen who participated in observations and kept log books for this study.

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

1 Bahn, R. A., D. J. Farrae, and D. L. Peterson *in part to be submitted to* Reviews in Fish Biology and Fisheries summer 2010
The shortnose sturgeon, *Acipenser brevirostrum* LeSueur 1818, is the smallest member of *Acipenseridae*, and inhabits coastal rivers and estuaries along the Atlantic Coast of North America from the St. John River, Canada, to the St. John’s River in northeast Florida (Vladykov and Greeley 1963; Moser and Ross 1995; Bain et al. 2007). Like other members of the genus, shortnose sturgeon are long-lived, late maturing, diadromous fishes with a protracted spawning periodicity (Vladykov and Greeley 1963; Bemis and Kynard 1997). Historical abundance estimates are scarce, however, shortnose sturgeon were exploited for decades along with the sympatric Atlantic sturgeon, *Acipenser oxyrinchus* (Smith et al. 1984). During the last century, shortnose sturgeon had become sufficiently rare that they were listed as an endangered species in the United States in 1967 (National Marine Fisheries Service (NMFS) 1998). Today, few healthy populations exist and many anthropogenic factors impede restoration efforts (Kynard 1997). Many populations, particularly in southern rivers, continue to be threatened with extinction. With federal protection in place, the two primary factors currently affecting population recovery in the Southeastern U.S. are habitat degradation and fishing mortality as a result of unintended capture or “bycatch” in commercial fisheries targeting other species (Collins et al. 2000).

**Life History**

Sturgeon are long-lived, late maturing, diadromous fishes with a protracted spawning periodicity (Bemis and Kynard 1997). Populations of shortnose sturgeon have life history differences in their northern and southern
ranges, but southern populations have not been well studied. In southern rivers, shortnose sturgeon mature sooner, spawn earlier in the year, grow faster, and have shorter life spans compared to those in the northern part of the range (Vladykov and Greeley 1963; Heidt and Gilbert 1978; Dadswell 1979).

As an amphidromous species, shortnose sturgeon require riverine habitats to complete their life cycle, but they will migrate to estuarine and marine habitats for purposes other than spawning (Bemis and Kynard 1997). Shortnose sturgeon typically mature at 500-600 mm total length (TL), which is reached by 2-3 years for males and 3-5 years for females in southern populations (Dadswell 1979; Kynard 1997). After maturity, males spawn every 1-2 years; females spawn every 3-5 years (Dadswell 1979). Southern shortnose sturgeon are estimated to live less than 20 years, compared to 30-67 years for their northern counterparts (Rogers and Weber 1994; Kynard 1997). Spawning occurs from late January (D. Peterson, unpublished data) to March in southern rivers, where shortnose sturgeon migrate to the upstream portion of their population range (Heidt and Gilbert 1978; Bain 1997; Kynard 1997). In the Altamaha River, spawning is thought to occur between river kilometer (rkm) 167 and 215 (DeVries 2006; D. Peterson, unpublished data).

**Bycatch**

Fishing mortality from bycatch is a problem for many species that have life histories dependent on late maturation and protracted spawning periodicity (Boreman 1997; Stein et al. 2004). Although they are long-lived, sturgeons only
spawn once every 3-5 years (Dadswell 1979). Hence, sturgeon populations are especially sensitive to loss of reproductive potential from bycatch mortality (Boreman 1997).

Bycatch of sturgeon in riverine, estuarine, and marine fisheries is a threat to the recovery of many sturgeon populations (Stein et al. 2004; Munro et al. 2007). Although shortnose sturgeon are federally protected, they are frequently captured across their range in commercial fisheries targeting other riverine species (Kynard 1997). Most of this bycatch occurs in anchored and drifted gill net fisheries for American shad (Alosa sapidissima; Collins et al. 1996; Kynard 1997).

Bycatch of shortnose sturgeon by commercial shad fisheries is well documented (Heidt and Gilbert 1978; Dadswell 1979; Collins et al. 1996; Weber 1996; Kynard 1997; Collins et. al 2000). Collins et. al (2000) states that the use of anchored gill nets in essential habitats by commercial fishermen is a threat to the recovery of sturgeon populations. In Georgia, commercial shad fisheries are open from January 1 to March 31. Based on total fishing effort, the shad fishery is one of the largest commercial fisheries operated in Georgia (Collins et al. 1996). Adult shortnose sturgeons are vulnerable to incidental capture by commercial shad fisheries because their upstream spawning migration coincides with the peak commercial fishing effort (Collins et al. 2000). Soak time directly affects sturgeon mortality rates in anchored gill net fisheries (Atlantic Sturgeon Status Review Team [ASSRT] 2007). In the Altamaha River, commercial fishermen use both drifted and anchored gill nets in different portions of the river.
Anchored gill nets must have a minimum of 11.43 cm stretched mesh with a maximum length of 30.48 m. Nets must be spaced at least 182.88 m apart with one end attached to the shore, allowing open fish passage through at least ½ of the river channel. Most gill nets deployed upstream of the estuary in the Altamaha River from 2004-08 were anchored gill nets (D. Peterson, unpublished data). Drifted gill nets can be used throughout the river, but are mostly used in the estuary. Only drifted gill nets are permitted in the Altamaha Sound. Collins et al. (1996) and Stein et al. (2004) state that the time non-target species spend tangled in drifted gill nets is likely less than that of anchored gill nets because drifted gill nets must be tended constantly to prevent these nets from becoming entrained on benthic debris. Collins et al. (1996) also states that catch per unit effort (CPUE) of sturgeon may be lower in drifted gill nets because they often do not fish the lower portion of the water column.

Previous studies of shad fisheries have shown that shortnose sturgeon bycatch can be significant. Collins et al. (1996) reported that shad fishermen captured 240 shortnose sturgeon from 1990-92 in the Savannah River. In this study, 97% of captured shortnose sturgeons were mature adults (TL 560 -1060 mm). In 1994, the shortnose sturgeon population in the Savannah River was calculated to be 1676, but this estimate was deemed incorrect because not all assumptions of the Schnabel model were met (NMFS 1998).

Both shortnose sturgeon and American shad migrate to upstream spawning sites in southern rivers during February and March (Hall et al. 1991; Collins and Smith 1995). Spawning shortnose sturgeons leave the estuary in
mid-December, migrating upstream for several hundred kilometers throughout the winter (DeVries 2006). Although Georgia’s commercial shad fishery does not open until January, DeVries (2006) documented adult shortnose sturgeon continuing upstream migrations throughout February and early March. Hence, the temporal and spatial overlap of shortnose sturgeon migrations and the commercial fishery creates a potential for serious threat of incidental capture of spawning shortnose sturgeon. Although commercial fishermen must immediately release any sturgeon caught, soak time of commercial gear is not regulated. Consequently, most commercial fishermen check their nets once daily, thereby increasing the potential for injury or death of entangled shortnose sturgeon. Aside from direct mortality caused by long soak times of anchored gill nets, prolonged entanglement of sturgeon can have sublethal effects, but they have not been well studied (Moser and Ross 1995; Boreman 1997; Kynard 1997). Previous studies have reported instances where radio-tagged shortnose sturgeon aborted their spawning migrations after being captured in commercial anchored gill nets (Moser and Ross 1995; Weber 1996).

Mortality and injury of sturgeons because of bycatch in shad fisheries has been identified as a serious threat to southern sturgeon populations (Kynard 1997; Collins et al. 2000). Because the Altamaha River contains the largest population of adult shortnose sturgeon (~1800 adult individuals) south of the Delaware River, bycatch of shortnose sturgeon in the shad fishery is a concern to both state and federal agencies (NMFS 1998; DeVries 2006). The observed mortality rate of over 30% in the Altamaha River shortnose sturgeon population...
(DeVries 2006) is high compared to 22% in the Hudson River (Secor and Woodland 2005). The effect of bycatch on the mortality rate of shortnose sturgeon in the Altamaha River is unknown; however, Collins et al. (1996) documented a 16% mortality rate and a 20% injury rate among shortnose sturgeon captured in the commercial shad fishery of Winyah Bay, SC.

Research Objectives and Justification

The objective of my study was to estimate the bycatch of shortnose sturgeon in the commercial shad fishery of the Altamaha River, GA. The National Marine Fisheries Service has identified studies of shortnose sturgeon bycatch in commercial fisheries as a research priority throughout the Atlantic Coast (NMFS 1998). In a previous study of shortnose sturgeon bycatch in the Savannah River, Collins et al. (1996) recommended the use of a standardized creel survey methodology for future assessments in other southern rivers. Because the effects of sturgeon bycatch have not been well studied, little is known about how Georgia’s commercial shad fisheries may be affecting recovery of shortnose sturgeon throughout the state. Although surveys conducted during the 1980s and 1990s documented mortality of shortnose sturgeon in Georgia’s shad fisheries, the population level effects were difficult to quantify because shortnose sturgeon abundance estimates were not available (Collins et al. 1996). A recent study by DeVries (2006) however, reported new abundance estimates for Altamaha River shortnose sturgeon, providing a context for quantifying the effects of bycatch. The results of this study provide the first quantified estimates
of bycatch and mortality rates of shortnose sturgeon in the Altamaha River commercial shad fishery. The application of these results will provide a framework for evaluating current commercial shad fishing regulations in Georgia and on other rivers where shortnose sturgeon populations exist.
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CHAPTER 2

BYCATCH OF SHORTNOSE STURGEON IN THE COMMERCIAL SHAD FISHERY OF THE ALTAMAHA RIVER, GEORGIA

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\(^2\) Bahn, R. A. and D. L. Peterson \textit{to be submitted to} Transactions of the American Fisheries Society summer 2010
Abstract

Although the shortnose sturgeon (*Acipenser brevirostrum*) has been federally protected as an endangered species since 1967, incidental capture of shortnose sturgeon in commercial shad fisheries has been documented as a source of mortality that may limit recovery of some populations. As such, shortnose sturgeon bycatch assessments were recently identified as a priority research objective by the National Marine Fisheries Service, as part of the iterative process of identifying and reducing threats to East Coast sturgeon. The objective of our study was to estimate total bycatch and mortality of shortnose sturgeon in the anchored gill net portion of the Altamaha River commercial shad fishery from 2007 - 09. Using a roving creel survey, we conducted on-the-water counts of commercial shad nets to estimate total fishing effort. Catch-per-unit-effort was estimated from log books and direct observations of net retrievals by randomly selected commercial fishermen. During the three years of the study, total estimated bycatch of shortnose sturgeon was 71, 53, and 498 fish, respectively. Recent studies have estimated the abundance of adult shortnose sturgeon in the Altamaha River to be approximately 1800 individuals. Results of our study showed that catch rates were highest during January and February of 2009 in upriver areas where previous research had identified several spawning locations. Our results also showed that mortality of captured shortnose sturgeon was low in all three years (< 8%), although we did not assess post-release survival. Future studies are needed to better assess population-level and sub-lethal effects of incidental capture on shortnose sturgeon. Because bycatch is
highly variable annually, future studies need to be conducted over several seasons and throughout the extent of the population range in a particular river.

Introduction

The shortnose sturgeon (*Acipenser brevirostrum*) is an amphidromous species that ranges from the St. John River, Canada, to the St. John's River in northeast Florida (Vladykov and Greeley 1963). Although the species was once common in most major East Coast river systems, commercial exploitation and habitat degradation have reduced populations significantly (Kynard 1997; Collins et al. 2000). The shortnose sturgeon has been federally listed as an endangered species since 1967 (National Marine Fisheries Service [NMFS] 1998).

Northern and southern populations of shortnose sturgeon are known to exhibit several important differences in life history; however, southern populations have not been well studied. In southern rivers, shortnose sturgeon mature sooner, spawn earlier in the year, grow faster, and have shorter life spans compared to those in the northern part of the range (Vladykov and Greeley 1963; Heidt and Gilbert 1978; Dadswell 1979). As an amphidromous species, shortnose sturgeon require riverine habitats to complete their life cycle, but they will feed in estuarine and marine habitats during the winter months (Bemis and Kynard 1997). Shortnose sturgeon typically mature at 500-600 mm total length (TL), which is reached by 2-3 years for males and 3-5 years for females in southern populations (Dadswell 1979; Kynard 1997). After maturity, males spawn every 1-2 years; females every 3-5 years (Dadswell 1979). Southern
shortnose sturgeon are estimated to live less than 20 years, compared to 30-67 years for their northern counterparts (Rogers and Weber 1994; Kynard 1997). Spawning occurs from late January (D. Peterson, unpublished data) to March in southern rivers, where shortnose sturgeon migrate to the upstream portion of their population range (Heidt and Gilbert 1978; Bain 1997; Kynard 1997).

Although shortnose sturgeon have been federally protected for more than 40 years, they are frequently captured across their range in commercial fisheries targeting other riverine species (Kynard 1997). Most of this “bycatch” occurs in anchored and drifted gill net fisheries for American shad (*Alosa sapidissima*; Collins et al. 1996; Kynard 1997). Several authors have shown that fishing mortality from bycatch poses an especially serious threat to species with reproductive strategies that depend on late maturation and protracted spawning periodicity (Boreman 1997; Stein et al. 2004; Munro et al. 2007). Despite their long life spans, shortnose sturgeon spawn only once every 2-5 years after reaching maturity (Dadswell 1979), which makes them particularly sensitive to the cumulative losses of reproductive potential resulting from chronic bycatch mortality (Boreman 1997).

Bycatch of shortnose sturgeon in commercial shad fisheries has been well documented (Heidt and Gilbert 1978; Dadswell 1979; Collins et al. 1996; Weber 1996; Kynard 1997; Collins et. al 2000), but population level effects are poorly understood. Previous studies of commercial shad fisheries have shown that shortnose sturgeon bycatch can be significant and Collins et al. (2000) suggest that this bycatch may be among the most serious impediments to the recovery of
southern shortnose sturgeon populations. In South Carolina, previous studies have shown that shad fishermen captured 240 shortnose sturgeon from 1990-92 in the Savannah River and that 97% of those captured were mature adults (TL 560 -1060 mm; Collins et al. 1996). In 1994, the shortnose sturgeon population in the Savannah River was estimated at 1,676 individuals; this level of annual bycatch in this commercial fishery may have resulted in the incidental capture of up to 15% of the entire adult population (NFMS 1998).

Although shortnose sturgeon accidentally captured in commercial shad fisheries must be immediately released, delayed mortality and injury resulting from incidental capture has been identified as a serious threat to populations in several southern rivers (Kynard 1997; Collins et al. 2000). Collins et al. (1996), for example, documented a 16% mortality rate and a 20% injury rate for shortnose sturgeon captured in commercial shad nets in Winyah Bay, SC.

In many Atlantic Coast rivers, spawning runs of American shad largely overlap with those of shortnose sturgeon (Hall et al. 1991; Collins et al. 1996; NMFS 1998). Consequently, adult shortnose sturgeon are particularly vulnerable to incidental capture in commercial shad fisheries because their annual upstream migrations coincide with the peak commercial fishing effort (Collins et al. 2000). Because bycatch is a known problem for recovering shortnose sturgeon populations, NMFS has identified studies of bycatch in commercial fisheries as a research priority as part of the iterative process of identifying and reducing threats to the recovery of sturgeons (NMFS 1998).
In Georgia, the Altamaha River contains the largest population of shortnose sturgeon (~1,800 adults) within the southern portion of the range (Peterson and DeVries 2006). Hence, bycatch of shortnose sturgeon in the Altamaha commercial shad fishery is of particular concern to both state and federal management agencies (NMFS 1998). In the Altamaha River, the commercial shad fishery is open from 1 January to 31 March and fishermen may use both drifted and anchored gill nets, depending on where they operate. Drifted gill nets can be used throughout the river, but their use is largely restricted to estuarine waters because of an abundance of course woody debris above the head of tide. Anchored gill nets can be used upstream of the estuary. Because drifted nets must be tended constantly, the average duration of fish entanglement is typically much lower in drifted nets compared to anchored nets (Collins et al. 1996; Stein et al. 2004). Collins et al. (1996) also noted that catch-per-unit-effort (CPUE) of shortnose sturgeon may be lower in drifted gill nets because they usually do not extend down to the benthos where shortnose sturgeon are typically found. Anchored nets must have a minimum of 11.43-cm stretched mesh with a maximum length of 30.48 m. Nets must be spaced at least 182.88 m apart with one end attached to the shore; this arrangement allows fish to pass unhindered through at least ½ of the river channel. Most gill nets deployed upstream of the estuary in the Altamaha River from 2004-06 were anchored gill nets (D. Peterson, unpublished data).

In southern rivers, both shortnose sturgeon and American shad migrate to upstream spawning sites in southern rivers from December to March (Hall et al.
1991; Collins and Smith 1993; Bahn et al. 2010). Although Georgia’s commercial shad fishery does not open until January, DeVries (2006) documented adult shortnose sturgeon moving upstream in December and continuing their migration through February and early March. Hence, the temporal and spatial overlap of shortnose sturgeon spawning migrations and the commercial shad fishery creates a potential for incidental capture of spawning shortnose sturgeon. Soak time directly affects sturgeon mortality rates in anchored gill net fisheries (Atlantic Sturgeon Status Review Team [ASSRT] 2007). Although commercial fishermen must immediately release any shortnose sturgeon caught, soak time of commercial gear is not regulated. Consequently, most commercial fishermen check their nets only once daily, thereby increasing the potential for injury or death of entangled shortnose sturgeon. Aside from direct mortality caused by long soak times of anchored gill nets, sublethal effects of prolonged entanglement have been documented for shortnose sturgeon (Moser and Ross 1995; Kynard 1997). Previous studies have reported several instances where radio-tagged shortnose sturgeon aborted spawning migrations after capture in anchored gill nets (Moser and Ross 1995; Weber 1996).

Because the effects of sturgeon bycatch have not been well studied, little is known about how Georgia’s commercial shad fisheries may be affecting recovery of shortnose sturgeon throughout the state. The objective of our study was to quantify bycatch of shortnose sturgeon in the anchored gill net commercial shad fishery in the Altamaha River from 2007-2009. Although surveys conducted during the 1980s and 1990s documented mortality of
shortnose sturgeon in Georgia’s shad fisheries, the population level effects were difficult to quantify because shortnose sturgeon abundance estimates were not available (Collins et al. 1996). A recent study by Peterson and DeVries (2006) however, provided new abundance estimates for Altamaha River shortnose sturgeon, providing the key context necessary for quantifying the effects of bycatch in this population. In this study, we report the first quantified estimates of total bycatch and mortality rates of shortnose sturgeon in the Altamaha River commercial shad fishery. The application of these results may provide an important new framework for evaluating current commercial shad fishing regulations in Georgia and on other rivers where shortnose sturgeon populations coexist with commercial shad fisheries.

**Study Site**

The Altamaha River is formed on the coastal plain of Georgia by the confluence of the Ocmulgee and Oconee rivers near Hazlehurst, GA (Figure 2.1). The river flows southeast 215 km to the Atlantic Ocean near Darien, GA. The watershed contains approximately 800 km of unimpounded channel habitat accessible to diadromous fishes including shortnose sturgeon. Because the river drains over one-quarter of the state, channel depths are highly variable depending on seasonal rainfall patterns and hydropower operation on reservoirs in the Ocmulgee and Oconee rivers. The head of tide is typically located between rkm 45-55, depending on discharge. Mean channel depth is typically 50-70 m in width and 2-3 m in depth (Heidt and Gilbert 1978). Depths greater
than 10 m are common in the tidally influenced section of the river. Deep cutbanks (10 m and greater) and channel scours below bridges are found above the head of tide.

Methods

Survey Design

To estimate the number of shortnose sturgeon captured incidentally in the commercial shad fishery, we conducted a standardized fishery assessment of the Altamaha River mainstem from 1 January to 31 March, 2007-09. Based on a priori knowledge of known and suspected shortnose sturgeon spawning locations (Peterson and DeVries 2006), we divided the river into two strata (Figure 2.1). The upper river stratum began at rkm 215 and extended downstream to rkm 184. The lower river stratum began at rkm 184 and extended downstream to rkm 21.

Using a roving creel survey design (Malvestuto 1996), we conducted weekly counts of anchored gill nets by traversing the entire 215 rkm of the study area by boat. In 2007 and 2008, these weekly counts were completed in two consecutive days. In 2009, counts were conducted continuously from upstream to downstream, so that they could be completed in one day. In each year, a running count of shad nets was made by checking each floating net buoy encountered during these counts to confirm that an actively fishing net was present.

For each month of each season, CPUE was obtained using a combination of direct observations of net retrievals and log books from five to seven
commercial fishermen, who represented 25-35\% of fishery participants. The individual fishermen selected to provide this information were chosen based on the river section where they fished and their willingness to participate in the study. Specific locations of their nets were independent of each other and interspersed throughout the study area. Each fisherman was compensated US$500 annually in return for their cooperation in allowing us to observe randomly selected net pulls and for keeping accurate log books of both effort and catch. Direct observations of fishermen were as randomized as possible, but the individual schedules of each fishermen prevented complete randomization of observations. Fishermen were not compensated, however, until accuracy of log books had been verified at the conclusion of each fishing season. Accuracy of log books was verified using two methods: 1) using a paired t-test to compare days when observers were and were not present, and 2) using a paired t-test to identify any significant differences of effort and catch data in log books versus those obtained through direct observations.

Direct observations of catch were conducted at least three times for each participating fishermen during each shad season. During each observation, we followed the fishermen to his nets in a separate boat so that we could record the number of each species captured as the net was retrieved. After all nets had been pulled, we recorded soak times, net dimensions, and mesh sizes. During 2008 and 2009, we also recorded total length (TL) and weight (g) of each shortnose sturgeon that was captured.

Data Analysis
To estimate total annual fishing effort, we first calculated the mean number of nets fished in each stratum for each month of the shad fishing season. Total net-hours was then calculated for each month based on the number of nets counted each week and the total number of fishing hours that the season was open. This included 12 hours for opening and closing days and 24 hours for all other days. Total monthly fishing effort for each stratum was then calculated using the formula:

Total fishing effort (net-hrs) = \sum ((\text{Mean nets observed / mo}) \times (\text{Total fishing hrs / mo}))

Accuracy of log book data from each fisherman was evaluated using a paired t-test (\( \alpha = 0.05 \)) to compare the mean of the differences between days when observers were and were not present. We then used a paired t-test (\( \alpha = 0.05 \)) to compare the mean of the differences between logged and observational data. To perform this test, the total annual number of shortnose sturgeon observed in the catch of each individual fisherman was standardized to the total number of net-hours recorded in his log book to calculate a monthly CPUE for each fisherman. Estimates of total monthly effort and catch were then calculated for each fisherman by supplementing the direct observational data with those from the log books recorded on days when observers were not present. A total monthly CPUE for shortnose sturgeon (SNS) was then estimated for each stratum by using the formula:

\[ \text{CPUE} = \frac{\text{Number SNS observed} + \text{number SNS logged}}{\text{Total net-hrs}} \]
We plotted effort versus catch data to confirm a linear relationship between these variables. We then estimated total monthly bycatch in each stratum by using the formula:

Total estimated monthly bycatch = (Total net-hrs / mo) x (Mean monthly CPUE)

To identify any potential bias of mean CPUE calculations and to estimate bycatch variance, we used bootstrap analysis with replacement as described by Efron and Tibshirani (1994) to resample our original data. Using program SAS (SAS Institute, Cary, NC), we constructed two resample sets (100 and 1,000 bootstrap samples) to compare resampled means and variances to those of the original data. For each month in each year in each stratum, we randomly constructed 100 and 1,000 bootstrap samples containing the same number of observations as the year-month-stratum data from which we were resampling (e.g., from 70 field observations we generated 100 and 1,000 bootstrap resample sets with 70 observations each). We then calculated the mean of each bootstrap sample and used these means to calculate grand means and variances for the resample sets (by year-month-stratum, both 100 and 1,000 bootstrap samples) for comparison with original field data. Standard error estimates generated from the 1,000 bootstrap sample sets were used to calculate 95% confidence intervals for estimated total monthly shortnose sturgeon bycatch.

Results
During each of the three commercial fishing seasons sampled, we conducted a total of 7-12 net counts totaling 1,358-2,328 rkm surveyed annually. We also collected catch data from 192-336 direct observations, and 10,382 – 15,410 net-hours of log book entry data (Table 2.1). From these data, we estimated that the total anchored gill fishery was comprised of 13-20 fishermen annually. Of these participants, 2-4 operated in the upper stratum compared to 11-16 in the lower stratum. Over the three fishing seasons, data collected from log books and direct observations annually accounted for 48% – 66% of all fishing effort in the anchored gill net fishery (Table 2.1).

Weekly effort throughout the river varied from 6 – 35 nets per week during all three years of the study (Figure 2.2). Based on these net counts, we estimated total effort for the entire anchored gill net fishery at 22,689 – 27,405 net-hours annually (Table 2.2). In the upper river, fishing effort peaked in February of each year, but in the lower river, effort was not consistent among months or years (Figure 2.2). In the upper river, monthly effort varied from 495 – 1536 net-hours, compared to 5,712 – 11,700 net-hours in the lower river (Table 2.2). Despite this variability, several spatial and temporal trends in bycatch were evident. Most fishing effort (56%) occurred between rkm 35 -100; however, most of the estimated shortnose sturgeon bycatch (67%) occurred in the upper river. In fact, our estimates showed that more shortnose sturgeon were incidentally captured in the upper river during January 2009 (333 fish) than in all months of all three years combined in the lower river (216 fish; Table 2.2).
Analysis of log book data from all three years showed that catch data recorded on days when observers were present was not significantly different than on days when observers were absent (mean of the differences $\leq 0.006$ SNS/net-hr for all three years; $p > 0.61$ for all three years). Furthermore, total catch of shortnose sturgeon recorded during direct observations (140 fish) was not significantly different from that recorded in fishermen log books (135 fish; $p > 0.42$ for all three years).

Total estimated bycatch varied from a low of 53 shortnose sturgeon in 2008 to a high of 498 shortnose sturgeon in 2009 (Table 2.2). The highest rates of bycatch occurred in the upper river in 2009, when an estimated 387 shortnose sturgeon were incidentally captured. Zero shortnose sturgeon were captured in the upper river during March of all three years of the study. In 2008 and 2009, bycatch in the lower river peaked in February (36 and 74 fish, respectively), and then declined in March (Table 2.2). In 2007, however, more shortnose sturgeon were captured in the lower river in January (22 fish) than in February or March (Table 2.2).

During months when shortnose sturgeon were incidentally captured in the upper river, CPUE over the same period in the lower river was always lower (Figure 2.3). For example, in January 2009, CPUE in the upper river was 0.5007 SNS/net-hr, compared to only 0.0015 SNS/net-hr in the lower river (Figure 2.3). During February 2007 and 2009, CPUE in the upper river was also higher (0.0126 and 0.0512 SNS/net-hr, respectively) than during the same period in the lower river (0.0019 and 0.0110 SNS/net-hr, respectively; Figure 2.3).
2008 and 2009, CPUE in the lower river was lowest in January, followed by an increase of over 100% in February, and then a decline in March (Figure 2.3).

Bootstrap results of both the 100 and 1,000 resample sets showed that the observed mean CPUE values for our study were unbiased (Table 2.3). The associated standard errors for the randomized bootstrap sample sets were smaller than those of the estimated mean CPUE for both strata, indicating that the variance estimates of mean CPUE in both strata were also accurate (Table 3).

Except for one juvenile fish captured in the upper river during January 2009, all shortnose sturgeon we observed during 2008 – 09 were adults and measured ≥590 mm TL. Most fish appeared to be in good condition and swam away after release; however, we were unable to assess any sublethal or post-release effects of incidental capture. Only four of the 172 (2.3%) shortnose sturgeon captured in commercial gill nets were dead upon net retrieval (Table 2.2).

Discussion

Although shortnose sturgeon were captured during all three years of the study, a key finding of this study was that bycatch varied by as much as 900% across years. During the 2007 and 2008 seasons, fewer than 40 shortnose sturgeon were observed in the commercial catch, but in 2009, we recorded 105 captures, which yielded an expanded estimate of 498 captures over the entire three month fishery. Because of annual variability in habitat conditions, and the
protracted spawning periodicity of shortnose sturgeon, we caution against future researchers forming conclusions about sturgeon from short-term data. The results of this study demonstrate that a roving survey is a feasible means of assessing annual bycatch and mortality of shortnose sturgeon in commercial shad fisheries. Consequently, we suggest that the methods presented in this study be used as a template for similar assessments of other fisheries where shortnose sturgeon bycatch may occur.

The Altamaha River is thought to have the largest shortnose sturgeon population among southern rivers (Peterson and DeVries 2006); however, adult abundance is low compared to that of northern river systems. Throughout the study, all but one fish observed in commercial nets were adult (≥590 mm TL). A recent study by Peterson and DeVries (2006) showed the Altamaha population to contain 1,500-2,000 adults. Our results from 2009 show that 19-40 percent of the entire adult population was incidentally captured in the commercial shad fishery. Given the spawning periodicity of shortnose sturgeon in southern rivers (females every 3-5 years; males every 1-2 years), we estimated that 37 - 60 percent (470; 95% CI 374-568) of the spawning run was captured in 2009. Although the observed mortality rate of 2.3% recorded in this study was lower than the 16% previously observed by Collins et al. (1996), studies of sub-lethal and post-release effects of bycatch are completely lacking. Because incidental capture of spawning adults has been shown to negatively affect spawning behavior (Moser and Ross 1995; Weber 1996), bycatch can have indirect population level effects.
The highest bycatch rates observed in this study occurred in the upper river strata during January. Although there were never more than five fishermen operating in this stratum at any one time, many of their nets were fished in known spawning areas of shortnose sturgeon. During January 2009, we observed several net retrievals in this reach in which 4-16 shortnose sturgeon were captured in a single net. In total, 36 adult shortnose sturgeon were recorded in the upper river during January and February 2009, and many of the males were running ripe. In contrast, sturgeon were not captured in the upper river during March in any year, suggesting that the spawning period was probably limited to a four-to six-week interval that lasted from mid-January to late-February.

In all three years of the study, few shortnose sturgeon were captured in the lower river during January. A previous telemetry study by Peterson and DeVries (2006) suggests that spawning shortnose sturgeon have already reached their spawning grounds by the start of the commercial fishing season while non-spawners remain in the estuary. Although many shortnose sturgeon were captured in the lower river during 2009, CPUE of shortnose sturgeon in the lower 184 rkm was only 0.0015 SNS/net-hour compared to 0.5007 SNS/net-hour in the upper river during the same period. These findings suggest that spawning adult were highly vulnerable to incidental capture in the upper stratum of the river.

Reducing bycatch of shortnose sturgeon in commercial fisheries is a critical component of recovering populations throughout the Atlantic coast. Further studies are needed in southern rivers, including the Altamaha, to quantify
both direct (mortality) and indirect (sub-lethal and post-release) population-level
effects of bycatch on shortnose sturgeon populations. Although several potential
management strategies already exist to minimize bycatch, the results of this
study suggest that river-specific research and monitoring programs are needed
to provide quantified data on the spatial and temporal variation in shortnose
sturgeon movements for implementation of an effective adaptive fisheries
management plan. For example, Collins et al. (2000) suggested the
establishment of riverine and estuarine reserves that are completely closed to
commercial gill net fisheries. Although closure of critical habitats may or may not
be an important component of protecting shortnose sturgeon spawning habitat,
our results suggest that on the Altamaha River, delaying the opening of
commercial shad fishing in the upper river stratum until 1 March, would almost
completely eliminate bycatch of migrating shortnose sturgeon with only a minimal
(5-15%) affect to total shad landings (Bahn et al. 2010). Regardless of which
specific management actions are used, an adaptive approach that incorporates
real-time monitoring of commercial bycatch may be the only practical means of
adequately protecting shortnose populations exposed to commercial gill netting
operations. Although complete closure of shad fisheries is probably
unnecessary, the annual variability of shortnose sturgeon spawning runs (and
hence sturgeon bycatch) as well as commercial fishing behavior will preclude a
"one size fits all" management approach. Consequently, future efforts to
minimize shortnose sturgeon bycatch while maintaining the economic and social
benefits provided by commercial fisheries will require close cooperation among federal and state management agencies as well as commercial fishermen.
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Fi

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Table 2.1. Number of net counts, direct observations, logged net-hours, and estimated percent of total anchored gill net fishery observed by year from Altamaha River shortnose sturgeon bycatch study, 2007-09.

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of net counts</th>
<th>Number of direct observations</th>
<th>Logged net hours</th>
<th>Percent of fishery Observed</th>
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<td>336</td>
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<tr>
<td>2008</td>
<td>11</td>
<td>252</td>
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<tr>
<td>2009</td>
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<td>10,382</td>
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</tr>
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<td>Month</td>
<td>Number of SNS captured</td>
<td>CPUE</td>
<td>95% CI</td>
</tr>
<tr>
<td>------</td>
<td>-------</td>
<td>------------------------</td>
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<tr>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>*</td>
<td>*</td>
<td>*</td>
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<tr>
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<td>± 0.0000</td>
</tr>
<tr>
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<td>0.0000</td>
<td>± 0.0000</td>
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<td>2007</td>
<td>Jan</td>
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<tr>
<td></td>
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<td>14</td>
<td>0.0037</td>
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Table 2.3. Results of bootstrap analysis of observed mean CPUE by strata by month by year for both 100 and 1,000 resample sets and associated standard errors (SE). Standard errors from the 1,000 resample sets were used to calculate 95% confidence intervals for mean estimated shortnose sturgeon bycatch. * = No data available. — = No analysis results because observed CPUE was zero.

**Upper River**

<table>
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<tr>
<th>Year</th>
<th>Month</th>
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<th>1,000 bootstrap</th>
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<td>*</td>
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**Lower River**

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Figure 2.1. Map of Georgia with a close-up of the section where the Altamaha River, including the locations of commercial fishermen observed during the study, is enlarged. ● = Six locations and river kilometer of fishermen surveyed in each year of the study. The line downstream of rkm 203 is the U.S. 1 Bridge (rmk 184), which demarcates the lower and upper river strata used during this study.
Figure 2.2. Mean number of anchored gill nets with associated 95% confidence intervals observed in the Altamaha River, GA gillnet fishery, by strata by month and year from 2007 – 09. J = January, F = February, M = March.
Figure 2.3. Mean CPUE of shortnose sturgeon with associated 95% confidence intervals in the Altamaha River, GA by strata by month and year from 2007 – 09.

$J = \text{January, } F = \text{February, } M = \text{March, } ^* = \text{No data}$
CHAPTER 3
CONCLUSION

Although shortnose sturgeon were captured during all three years of the study, a key finding of this study was that bycatch varied by as much as 900% across years. During the 2007 and 2008 seasons, fewer than 40 shortnose sturgeon were observed in the commercial catch, but in 2009, we recorded 105 captures, which yielded an expanded estimate of 498 captures over the entire three month fishery. Because of annual variability in habitat conditions, and the protracted spawning periodicity of shortnose sturgeon, we caution against future researchers forming conclusions about sturgeon from short-term data. The results of this study demonstrate that a roving survey is a feasible means of assessing annual bycatch and mortality of shortnose sturgeon in commercial shad fisheries. Consequently, we suggest that the methods presented in this study be used as a template for similar assessments of other fisheries where shortnose sturgeon bycatch may occur.

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184 km of the river was only 0.0015 SNS/net-hour compared to 0.5007 SNS/net-hour in the upper river during the same period. These findings suggest that spawning adult shortnose sturgeon are highly vulnerable to incidental capture in the upper 30 km of the Altamaha River. We estimated that 470 (95% CI 374-568) adult shortnose sturgeon were captured in January and February of 2009, which suggests that 37 - 60 percent of the spawning run was captured. The observed mortality rate of 2.3% is lower than the 16% previously observed by Collins et al. (1996) in southern shad fisheries. However, studies on sub-lethal and post-release effects of bycatch are lacking. Because incidental capture of spawning adults has been shown to negatively affect spawning behavior (Moser and Ross 1995; Weber 1996), bycatch has indirect population level effects.

Reducing bycatch of shortnose sturgeon in commercial fisheries is a critical component of recovering populations throughout the Atlantic coast. Further studies are needed in southern rivers, including the Altamaha, to quantify both direct (mortality) and indirect (sub-lethal and post-release) population level effects of bycatch on shortnose sturgeon populations. Although several potential management strategies already exist to minimize bycatch, the results of this study suggest that river-specific research and monitoring programs are needed to provide quantified data on the spatial and temporal variation in shortnose sturgeon movements for implementation of an effective adaptive fisheries management plan. For example, Collins et al. (2000) suggested the establishment of riverine and estuarine reserves that are completely closed to commercial gill net fisheries. Although closure of critical habitats may or may not
be an important component of protecting shortnose sturgeon spawning habitat, our results suggest that on the Altamaha River, delaying the opening of commercial shad fishing in the upper river stratum until 1 March would almost completely eliminate bycatch of migrating shortnose sturgeon with only a minimal (5-15%) reduction of total shad landings (Bahn et al. 2010). Although complete closure of shad fisheries is probably unnecessary, the annual variability of shortnose sturgeon spawning runs and commercial fishing behavior will preclude a “one size fits all” management approach. Consequently, future efforts to minimize shortnose sturgeon bycatch while maintaining the economic and social benefits provided by commercial fisheries will require close cooperation among federal and state management agencies as well as commercial fishermen.
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