INVESTIGATING GEORGIA'S SHARK NURSERIES: EVALUATION OF SAMPLING GEAR, HABITAT USE AND A SOURCE OF SUB-ADULT MORTALITY

by

CAROLYN NILES BELCHER

(Under the Direction of Cecil A. Jennings)

ABSTRACT

Many shark species along the Atlantic coast of the United States have been fished to unsustainable population levels over the past 30 years. There is a direct relationship between the numbers of adults and young in a population for most shark species, but data about the immature portion of stock is scarce. Neonate and small juvenile sharks use near shore waters and inshore embayments as nursery areas where they are protected from predators and prey are abundant. However, neonate sharks are susceptible to human influences on habitat as well as increased rates of fishing mortality associated with recreational and commercial fisheries. In this dissertation, I present the results of work that examined: 1) potential sources of bias that could affect longline estimates of abundance estimates for common shark species; 2) the utility of a fishery-independent trawl survey for assessing the distribution and abundance of sub-adult sharks; 3) the relative importance of mesohabitat characteristics in defining habitat use for common species; and 4) the effects of the shrimp trawl fishery on sub-adult sharks. My findings demonstrate that bait type can bias longline catch rates and species selection. My examination of gear efficacy revealed that although longline and trawl surveys provide similar information, the trawl provides the distinct advantage of being able to sample offshore waters and currently is the only gear that captures neonate bonnethead sharks. Results from the mesohabitat evaluation indicate that bonnethead and sandbar sharks do have unique water chemistry preferences; however, mesohabitat characteristics better explain the absence of these species from sampling areas. Finally, my investigation of the effects of commercial shrimp trawls reveal that although sub-adult sharks are captured in trawls, the current management regime for this fishery may be already be sufficiently conservative to offer moderate protection from fishing mortality. Sub-adult sharks in Georgia's estuaries are apex predators that play a critical part in maintaining the health of the ecosystem. Protecting shark nursery areas is one mechanism to rebuild the severely depleted stocks of sharks and a means to ensure the continued health of Georgia's coastal ecosystems.

INDEX WORDS: Shark nurseries, Sub-adult sharks, Essential fish habitat, Mesohabitat, Sampling bias, Gear comparison, Bycatch, Longline, Trawl, Georgia estuaries

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# DEDICATION

*- To Robert and my mother: two people who have given me much love and moral support -*

"*In wildness is the preservation of the world*"

- Henry David Thoreau, *Walking* (1862)

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*"That which we persist in doing becomes easier, not that the task itself has become easier, but that our ability to perform it has improved."*
*- Ralph Waldo Emerson*

If I have learned anything throughout this process, it is the importance of self-confidence and personal growth. Completing a PhD is more than just reaching the top rung of an educational ladder; it provided me with an opportunity for self-reflection and affirmation of my professional goals. I'd like to thank two people, Jim Lanier and Deborah Riner, who provided me with the tools to evaluate myself and to reach my goals.

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# CHAPTER 1

# BACKGROUND AND CHAPTER ORGANIZATION

Sharks are cartilaginous fish of the subclass Elasmobranchii (Castro 1983; Compagno 1984). Fossil records indicate that sharks have been in existence since the Devonian period, which occurred 400 million years ago; modern groups, which include 350 extant species, have been in existence since the Cretaceous period, 135 to 65 million years ago (Castro 1983). Part of their evolutionary success lies with their reproductive adaptations, which separate them from other fishes. In general, fish reproduction is characterized by the production of large numbers of eggs that are externally fertilized. Most shark species, however, produce small numbers of fully formed young, which are the product of internal fertilization (Castro 1983). Other biological characteristics of sharks include slow growth, late sexual maturity, and long life span (Camhi 1998; Castro 1983). This life history strategy, which has allowed sharks to dominate the oceans for millions of years, also makes them extremely vulnerable to overfishing.

The current U. S. Atlantic shark fishery developed relatively quickly in the late 1970s as market demand increased for shark meat, fins, and cartilage (NMFS 2008). Directed and incidental fisheries continued to expand well into the 1980s, with peak commercial landings reported in 1989 (NMFS 2008). In 1989, the Atlantic Fishery Management Councils asked the Secretary of Commerce to develop a fishery management plan for sharks because of concerns that increased fishing mortality was leading to overfishing (NMFS 2008). The National Marine Fisheries Service (NMFS) developed the first fishery management plan for sharks in 1993. This management plan included 39 species of sharks, which were placed into three management groups (large coastal, small coastal, and pelagic) based on fishery characteristics rather than biological/ecological factors (NMFS 1993). The original plan was developed primarily to prevent overfishing; however, by the time the plan was implemented, the large coastal group was already considered to be overfished, and the other two categories were considered fully utilized (Camhi 1998).

Over the past two decades, many populations of shark species have been fished to dangerously low numbers (Camhi 1998). Although many management actions were formulated to reduce fishing pressure on the adult stock, scientists have identified the need to understand how fishing affects juvenile sharks, especially since the relationship between recruitment and adult stock size is direct (Carlson and Brusher 1999; Holden 1974; Helfman 2007).

Because of the highly migratory nature of many shark species, complementary regulations between state and federal waters are needed to manage shark stocks, especially as state regulations for sharks currently vary along the Atlantic coast. In 2008, the Atlantic States Marine Fisheries Commission produced an interstate shark management plan that complemented the recently implemented federal shark regulations as well as provided consistency in shark management among states. The importance of state shark regulations is amplified also by the importance of many state waters that act as essential fish habitat and nursery grounds for a variety of shark species (Castro 1993; McCandless et al. 2007).

In 1998, the Cooperative Atlantic States Shark Pupping and Nursery ground Survey (COASTSPAN) was formed to investigate shark nursery grounds along the east coast of the United States (Pratt et al. 1999). Cooperators included the NMFS Apex Predators Program and state agencies and universities from North Carolina, South Carolina, Georgia, and Florida. Scientists with the Apex Predators Program were responsible for surveying Delaware Bay's sandbar shark nursery (Pratt et al. 1999). In 2007, American Fisheries Society published the proceedings of a symposium focusing on shark nurseries from Massachusetts to Texas. This volume, edited by McCandless et al. (2007) provides an overview of contemporary research conducted on shark nurseries, and includes manuscripts discussing distributional patterns, seasonality, and relative abundance of sub-adult sharks.

Prior to McCandless et al. (2007), there were very few publications that focused on shark nursery grounds in the south Atlantic and the Gulf of Mexico. Multi-species studies were conducted in North Carolina (Thorpe et al. 2004), South Carolina (Castro 1993), and along the east (Snelson and Williams 1981) and west (Carlson and Brusher 1999; Bethea et al. 2004) coasts of Florida. Further, there have been studies of nursery areas for sandbar sharks (*Carcharhinus plumbeus*) (Carlson 1999), blacktip sharks (*Carcharhinus limbatus*) (Huepel and Hueter 2002; Heupel and Simpfendorfer 2002), and bull sharks (*Carcharhinus leucas*) (Simpfendorfer et al. 2005) on the west coast of Florida. These works will be discussed, as appropriate, in specific chapters in the dissertation.

Information on sub-adult sharks in Georgia waters has become available only in the past decade. Although recreational and commercial bycatch data indicate that some sharks use Georgia's estuaries and near shore waters as nursery grounds, directed studies for sharks had not been conducted prior to 1997. Gurshin (2007) documented sub-adults from four species in the Sapelo Island National Estuarine Research Reserve. Atlantic sharpnose shark, blacktip shark, and finetooth shark, used the estuarine system as primary (i.e., neonates present) and secondary (i.e., juveniles present) nursery grounds, whereas bonnethead sharks used the area as a secondary nursery.

In this dissertation, I present information from four separate studies designed to provide new information about different aspects of current methods for determining the abundance and habitat use of sub-adult sharks in Georgia's marine waters. Additionally, I will examine a fishery-dependent source of sub-adult shark mortality. In Chapter 2, I evaluate potential biases (environmental and bait) associated with use of the bottom-set longline to capture sub-adult sharks. In Chapter 3, I determine if trawl gear can be used to sample neonate and juvenile sharks, and if direct comparisons in catch can be made between trawl and longline indices. In Chapter 4, I examine the relationship between mesohabitat characteristics and the presence/absence of shark species. In Chapter 5, I identify shark species commonly caught in commercial shrimp trawls and evaluate possible trawl characteristics (e.g., tow time, tow speed, net type) that could have an effect on the numbers of sharks caught. Chapter 6 summarizes the key findings and implications of each chapter and provides recommendations for future research.

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# CHAPTER 2

## Potential Gear Bias Associated with Hand-retrieved Longline Catches of Sub-Adult Sharks in Georgia Estuaries[1]

[1] Belcher, C. N. and C. A. Jennings. Submitted to *North American Journal of Fisheries Management.*

## INTRODUCTION

During the past three decades, many shark populations have undergone dramatic declines in abundance (NMFS 1993; Stevens et al. 2000). Since the implementation of the first fishery management plan for sharks by the National Marine Fisheries Service (NMFS) in 1993, there has been an acute need for better estimates of shark abundance. Because of certain life history traits (e.g., offshore/inshore migrations, segregation by sex) and the highly migratory nature of many shark species, especially during late juvenile and adult stages, fishery-independent surveys used to produce estimates of abundance can be costly and produce highly variable indices of abundance over time (Rago 2005). Shark reproduction is generally characterized by the production of low numbers of precocious offspring; this strategy supports a more direct relationship between adult abundance and the number of offspring (Carlson and Brusher 1999). Many shark nursery areas occur in nearshore and estuarine areas and are used for discrete time periods (e.g., season) over multiple years (Springer 1967; Castro 1993; McCandless et al. 2007). The strong relationship between abundances of adults and offspring and the restricted use of nurseries suggest that fishery-independent sampling can be a cost-effective strategy for estimating the abundance for sub-adult sharks. If successful, such sampling could improve the estimates of overall stock size.

Sharks can be captured with a variety of fishing gears; however, longlines and gillnets are the main gears used to harvest sharks along the Atlantic coast of the United States (Castro 1983; Rago 2005). Both gear types have been used in fishery-independent studies to provide estimates of relative abundance for shark species in the

Gulf of Mexico (Carlson and Brusher 1999) and along the east coast of the United States (Musick et al. 1993; USDOC 1997).

In the mid-Atlantic states, which are characterized by low tidal amplitudes and slow currents, gillnets frequently are used to sample sub-adult sharks and can be fished for long periods of time. Although hand-retrieved, bottom-set longlines are used in some of the more northern areas, they are reserved for use in deep channels or areas of high-velocity currents or high boat traffic (USDOC 1997). In the south Atlantic states, gillnet use is more restricted than in northern areas because of constraints associated with a large tide amplitude (>2m), high current velocity, and gear fouling. Georgia has relied on the hand-retrieved longline as the primary gear for sampling sub-adult sharks because the gear can be fished with minimal limitations.

Longlines are passive gear and catches are influenced by both gear selectivity and efficiency (Murphy and Willis 1996). Several studies have examined potential sources of bias affecting longline catch rates of sharks. Branstetter and Musick (1993) found that catch rates of multiple shark species increased without a large increase in effort when monofilament gangions are used in place of traditional rope/steel gangions (i.e., Yankee gear). Schwartz (1984) found that higher longline catches for blacknose sharks (*Carcharhinus acronotus*) occur during morning ebb tides and tended to be influenced by depth. Medved and Marshall (1981) examined the effects of time of day, depth fished, tidal stage, and tidal velocity on hook and line catches of sub-adult sandbar sharks (*C. plumbeus*). They found higher catch rates at night, and although depth was not a factor during night fishing events; during daytime events, higher catch rates were associated with fishing on the bottom. Although hook and line and longlines differ in effort and fishing practices (e.g., hooks are often re-baited), they share many of the same selectivity issues.

Longline selectivity and efficiency can be affected by many factors including, but not limited to, bait type, soak time, seasonality, and timing of sampling events (Murphy and Willis 1996; Rago 2005). The timing of sampling events can affect gear efficiency because abiotic conditions and animal behavior can be affected by weather, lunar, or tidal patterns (Stoner 2004). The effects of abiotic factors on fishing efficiency and gear selectivity are unknown for longline gear. Therefore, the objectives of this study were to evaluate the effects of bait type, moon phase, and tide phase on the selectivity and efficiency of longlines targeting sub-adult sharks in Georgia estuaries.

## MATERIALS AND METHODS

### Study Area

Georgia's coastline is approximately 161 km (100 miles) long, extending from the St. Marys River in the south, which is the boundary between GA and FL, to the Savannah River in the north, which is the boundary between GA and SC. The outer coastline is comprised of thirteen barrier islands that form the openings to nine estuaries, which are interconnected by a maze of tidal creeks and rivers. Many of these creeks and rivers are navigable and are part of the Intra-Coastal Waterway. Mean water depth is approximately 9 m, with tidal amplitudes averaging 2.1 m (Johnson et al. 1974). Eight of the nine estuaries were sampled from April 15 through September 30, 2001-2003 (Figure 2-1). Doboy, Sapelo, St. Catherines, and Ossabaw systems were sampled in 2001; Wassaw and Cumberland were sampled in 2002; and St. Andrew and St. Simons were sampled in 2003.

**Sampling Methodology**

Longline sampling was conducted under the Cooperative Atlantic States Shark Pupping and Nursery Grounds project's (COASTSPAN) protocol established by the National Marine Fisheries Service's Apex Predator Investigation (USDOC 1997). In accordance with the COASTPAN protocol, stations were sampled during daylight hours with a hand-retrieved longline. The longline was referred to as a "pup line" and was similar in design to the old style Yankee longline gear (i.e., rope and steel gangions clipped to a rope mainline), but on a much smaller scale. The gear was bottom-set and secured via standard 4.1 kg Danforth® anchors at both ends. Each end of the mainline was marked with a fluorescent buoy (31 kg buoyancy) rating. The longline consisted of 305 m of 6.4 mm braided mainline and 50 removable gangions, each comprised of 12/0 Mustad® circle hooks with depressed barbs, 50 cm of 1.6 mm stainless steel cable, 50 cm of 6.4 mm braided nylon, and a longline snap. Gangions were attached to the main line at 4.5 - 6.1 m intervals.

Initially, the longline was allowed to fish for one hour. The 1-hr set time maximized the catch as very few recovered sets had hooks with remaining bait (less than 10% of hooks). However, during June 2001, soak time was reduced to 30 minutes because of high mortalities in the smaller shark species. The shorter set time reduced mortality and did not appear to affect catch rates, as the number of baited hooks recovered after 30 minutes remained minimal (less than 10%).

Estuarine sampling areas were divided into sound sites (closest to the mouth) and creek/river sites in the lower reaches adjacent to the estuary. Typically, two sound sites and two river sites were sampled per day, and each system was sampled two consecutive days each month. Ideally, eight longline sets were made in each estuarine system during each month.

Commercial-grade squid (*Loligo sp*.) and spot (*Leiostomus xanthurus)* were used to bait the longlines. Squid was the only bait used during the moon and tide phase portion of the study. During the bait comparison study, 25 hooks were baited with spot and 25 were baited with squid. The order in which the bait was placed on the line (i.e., squid on the first 25 hooks, followed by the 25 fish hooks) was reversed between sets.

To identify the effects of lunar phase, sampling occurred in conjunction with the four main lunar phases: new, first quarter, full, and last quarter. Two of three days considered to be representative for a given phase (i.e., the day before, the day of, and the day after), were sampled each month. All estuaries were sampled during each moon phase over the course of the season. Tide phase (e.g., flood tide, slack tide, and ebb tide) was not specifically targeted within a lunar phase because of the unpredictable time associated with set recovery and processing of catch data. As a result, tidal stage was assigned to longline sets *a posteriori.*

**Fish Sampling**

Both targeted and bycatch species collected at each sampling site were identified to species. As required in the COASTSPAN protocol, all sharks were sexed, measured for both fork and total lengths (cm FL and TL), weighed (kg), and characteristics of the umbilical scar were recorded. Sharks were classified as neonates or juveniles based on the presence of an umbilical scar and the degree of healing. Umbilical scars that are open or partially healed (i.e., scar is black in color but not "open" or a gray line is visible) are found on age-0 or neonate sharks (USDOC 1997). Well-healed scars are found on age-1 or later aged juveniles (USDOC 1997). Species- and sex-specific length-at-maturities presented in Castro (1983) were used to distinguish larger juveniles from adults.

All species captured were handled to insure maximum survival once returned to the water. Because of the slow speed associated with line retrieval, all fishes captured were left on their gangions, and moved to a "stringer" line on the off side of the boat where they were allowed to swim along side the vessel until they were processed. This method worked well for keeping fish alive and eliminated the need for a large live well. The hook was removed promptly and with minimal trauma to the fish. When necessary, difficult-to-remove hooks were cut with wire cutters and removed from the fish's mouth. In the case of large sharks (i.e., greater than 1.2m TL) that were too big to bring on the boat, the leader was cut as close to the terminal end of the line as possible. All sharks capable of swimming were tagged with National Marine Fisheries Service's rototags (similar to sheep ear tags) on the first dorsal prior to release. Sharks that were moribund or lethargic were not tagged; however, resuscitation attempts were made before they were returned to the water.

Catch per unit of effort (CPUE) values for the aggregate shark catch and for each species represented by 15 or more individuals were calculated and reported as the number of individuals per 50 hooks (for the moon and tide phase analysis) or as the number of individuals per 25 hooks (for the bait comparison analysis).

### Data analysis

**Moon and Tide Phase.** Data collected during 2001 and 2002 were used to evaluate the effects of lunar and tide phases on sub-adult shark catch rates. Data were examined for normality prior to conducting analyses. Normality was evaluated by examining skewness and kurtosis values (Mertler and Vannatta 2005); however, none of the species-specific or aggregate CPUEs were normally distributed. Given the large degree of positive skew associated with each of the CPUE values and the large number of zero values, the data appeared to fit a negative binomial distribution. Consequently an inverse hyperbolic sine transformation was used to correct the fit. Unfortunately, the transformation was unable to correct for non-normality. In many situations a nonparametric form of the intended analysis can be used to analyze non-normal data. In situations where an analogous nonparametric form does not exist, rank transformations can be applied to the data and the transformed values are then used in the parametric analysis (Conover and Iman 1981). Therefore, rank transformations were applied to all calculated CPUE values before further analyses were conducted.

Because tide phase was assigned *a posteriori*, unbalanced two-way analyses of variance (ANOVA) were used to evaluate the effects of moon and tidal phase on ranked total CPUE and species-specific CPUEs for the most abundant species. If an ANOVA indicated significant differences for the main effects, a Student-Newman-Keuls' (SNK) multiple-range test was used to identify the differences among the treatments. The SNK multiple-range test was chosen because it has higher power and is slightly less conservative than Tukey's multiple comparison test, which is another commonly used multiple comparison method (Zar 1999). If the ANOVA found only a significant interaction term, a one-way analysis of variance was used to determine which combinations of moon and tide phase produced higher catch rates. A total of twelve combinations (three tide phases combined with four moon phases) were compared.

**Bait Type.** Data collected during 2003 were used to evaluate how bait type affected catch rates. Because both bait types were used during each longline set, a paired t-test was used to compare catch rates (CPUEs) between bait types. A multinomial chi-square analysis was used to evaluate the dependence of species composition on bait type (Zar 1999). Mean fork lengths of sub-adult sharks were compared using a two-sample *t*-test between bait types for all species combined and for the most abundant species caught. Although a statistical difference in fork length between bait types could indicate an ontogenetic shift in diet for sharks, because of the amount of overlap in sizes for large neonates and small juveniles, a Chi-square analysis of life stage (i.e., neonate versus juvenile) and bait preferences also was applied to confirm a shift between life stages.

Because of the high degree of variability associated with the catch data and the exploratory nature of the study, a significance level of 0.10 was used to determine the significance of the effects. All analyses were performed using SAS version 9.1 (SAS Institute 2002).

RESULTS

## Moon and Tide Phase

A total of 420 sub-adult sharks from nine species were captured during 147 of the 212 sets. The four most abundant shark species, accounting for 96.0% of the total catch, were the Atlantic sharpnose shark (*Rhizoprionodon terranovae*), bonnethead (*Sphyrna tiburo*), blacktip shark (*Carcharhinus limbatus*) and sandbar shark (Table 2-1). Although capture rates for all species were not very high, Atlantic sharpnose and bonnethead sharks were more likely to be encountered than blacktip or sandbar sharks (Table 2-1). The total number of sharks captured per set ranged from 0 to 11. The other species caught but not commonly represented in the longline catches were scalloped hammerhead (*S. lewini*), finetooth (*C. isodon*), spinner (*C. brevipinna*), bull (*C. leucas*), and lemon (*Negaprion brevirostris*) sharks (Table 2-1).

Moon and tide phases did not have significant effects on CPUEs for all shark species combined or for three of the four most common species (Figure 2-2 and Table 2-2). A significant model was found for blacktip sharks ($p$ = 0.087); however, CPUEs for blacktip sharks were not directly influenced by either lunar or tidal phases, instead both factors interacted significantly ($p$ = 0.038) to affect the catch of blacktip sharks. Because the interaction cannot be analyzed via a multiple comparison procedure, a second level of analysis was conducted. The results of a one-way ANOVA indicated a significant difference among the moon and tide phase combinations ($p$ = 0.0589); however, the results of the SNK test failed to detect differences between any pair of mean ranks.

**Bait Type**

A total of 177 sub-adult sharks from seven species were captured during 52 of 80 sets. The three most abundant shark species, which accounted for 93.8% of the total catch, were again Atlantic sharpnose, bonnethead, and sandbar sharks (Table 2-3). Overall catch rates were not very high; however, Atlantic sharpnose were more likely to be caught than bonnetheads or sandbar sharks (Table 2-3). The total number of sharks captured per set ranged from 0 to 10. The other species caught but not commonly represented were blacktip, scalloped hammerhead, finetooth, and bull sharks (Table 2-3).

Species composition differed significantly between bait types ($\chi^2$=21.93, d.f.=6, *p*=0.0012; Table 2-3). A total of 70 sharks from six species were caught on hooks baited with spot, whereas 107 sharks from five species were captured on hooks baited with squid (Table 2-3). Four species (Atlantic sharpnose, sandbar, blacktip, and bull sharks) were caught on both bait types. Atlantic sharpnose sharks occurred almost equally between baits, with a slightly higher catch rate on hooks baited with squid (Figure 2-3). Both blacktip and sandbar sharks were captured more frequently on hooks baited with squid, whereas bull sharks were captured for frequently on hooks baited with spot. Bonnetheads were caught exclusively on squid; whereas, finetooth and scalloped hammerhead sharks were only caught on hooks baited with spot (Figure 2-3).

Overall catch rates differed between bait types (t-value=-3.35, d.f. = 79, *p* = 0.0012). Hooks baited with squid had an average CPUE (mean = 1.72, S.E. = 0.22) that was almost twice that of hooks baited with spot (mean = 0.94, S.E. = 0.15). Mean sizes (FL) of Atlantic sharpnose sharks differed between bait types (t-value = 3.52, d.f. = 64, $p$ = 0.0008); sharks captured on hooks baited with spot were longer (average = 43.3 cm, S.E. = 2.4 cm) than sharks caught on squid (average = 34.6 cm, S.E. = 0.73 cm) (Figure 2-4). A relationship between life stage and bait type was found for Atlantic sharpnose sharks ($\chi^2$= 6.89, d.f. = 1, $p$ = 0.0087). The ratio of neonates to juveniles captured on spot was 1:1.2, indicating a slightly higher capture rate of juveniles; whereas, the same ratio was 2.3:1 for squid, which indicated that neonates were twice as likely to be caught on hooks baited with squid.

Average sizes of sandbar sharks did not differ significantly between bait types (t-value = -0.21, d.f. = 26, $p$ = 0.8350; Figure 2-4). Further, bait preference was independent of life stage for neonate and juvenile sandbar sharks ($\chi^2$=0.02 d.f.= 1, p = 0.6359).

## DISCUSSION

Generally, the results of this study indicated that catch rates of sub-adult sharks in Georgia are not directly influenced by either tide or lunar phase; however, blacktip sharks may be the possible exception. Although the analysis of variance indicated a significant difference among the 12 combinations of moon and tide phase, the results from the multiple comparison test did not support this conclusion. According to Zar (1999) this is not a common occurrence, but reflects the higher power of the ANOVA as compared to the multiple comparison procedure, which is more prone to Type II errors. Additionally, Zar (1999) indicates repeating the experiment with a larger sample size would result in a more capable multiple comparison test.

Because of Georgia's large tidal amplitude (averaging 2.1m) and the high degree of mixing in the water column of most estuaries, other factors such as predator avoidance and prey availability may combine with both tidal and lunar cycles to affect the feeding habits of sub-adult sharks in Georgia's estuaries. Although most sharks are opportunistic feeders, they tend to have crepuscular feeding habits; thus, the timing of sampling during daylight hours also may limit catches. Medved and Marshall (1981) found hook and line catch rates of sub-adult sandbar sharks were higher at night.

Although strict adherence to standardized methods is considered ideal for all surveys (Murphy and Willis 1996; Carlson 1999), localized changes in the protocol may be necessary when sampling efforts are widespread. For example, researchers may change the bait type used in the study because the availability of commercial baits or common prey species may not be the same between areas.

Results from this study indicated that Atlantic sharpnose sharks do not have a strong preference for either bait type; however, they did exhibit a potential ontogenetic shift as neonates dominated the squid catch; whereas, juveniles dominated the fish catch. Diet analyses conducted in the Atlantic Ocean and the Gulf of Mexico indicate that both squid and spot are naturally occurring prey items for Atlantic sharpnose sharks (Gelsleichter et al. 1999, Hoffmayer and Parsons 2003, Bethea et al. 2004). Atlantic sharpnose sharks are classified as generalist species because of the high diversity of prey species and the large number of stomachs that contained multiple prey types (Hoffmayer and Parsons 2003). Both mean size and life-stage analyses by bait type supported an ontogenetic shift in diet for Atlantic sharpnose sharks. Hoffmayer and Parsons (2003) found a similar result through dietary analysis, which indicates that sharpnose sharks tended to shift from crustaceans and mollusks to teleosts as the sharks increased in size. The same study also documented a large degree of dietary overlap occurred between juveniles and adults.

Bonnetheads are the second most common species of shark found in Georgia's estuaries. This pattern is evident in the catches on hooks baited with squid; however, bonnetheads were conspicuously absent on hooks baited with spot. Studies of the diet of bonnethead sharks indicate that preferred prey species for this species tend to be crustaceans or mollusks (Castro 1983, Compagno 1984). Cortes et al. (1996) suggests that bonnethead sharks are specialists, with occasional habitat- or season-dependent shifts in diet. Bethea et al. (2007) documented geographical and ontogenetic shifts in food preference for bonnetheads in the Gulf of Mexico. Earlier life stages were found to consume a larger amount of seagrasses along with crustaceans, whereas the adults did not consume plant matter (Bethea et al. 2007).

The results of this study indicate that sandbar sharks exhibited a strong preference for hooks baited with squid compared to hooks baited with spot. Sandbar sharks are opportunistic feeders that feed on numerous crustaceans, mollusks, and small fishes (Castro 1983, Medved and Marshall 1981, Medved et al. 1985, Stillwell and Kohler 1993). Squid is not a strongly preferred bait for sub-adult sandbar sharks; however, they seem to prefer crustaceans over bony fishes (Castro 1983, Medved and Marshall 1981, Medved et al. 1985, Stillwell and Kohler 1993).

Although the current study did not document an ontogenetic shift in the bait preference of sandbar sharks, Stillwell and Kohler (1993) found that young sharks shift from a primary diet of blue crabs (*Callinectes sapidus*) to fish as they grew. This apparent discrepancy could be related to differences in the average size (FL) of juveniles caught, 69 cm in this study and 123 cm in Stillwell and Kohler's (1993) work. Ellis and Musick (2007) also noted an ontogenetic shift for sandbar sharks in the lower Chesapeake Bay and Virginia coastal waters; however, they also noted that sandbar sharks tended to be more generalized in their predation habits as geographically separated groups showed different prey preferences.

## CONCLUSIONS

Traditionally, hook-and-line fishers have targeted certain times of day, tide stages, or lunar phases to optimize their catch. Lunar and tidal phases are known to affect feeding activity, which is linked to prey availability and detectability or predator avoidance for many fishes (Wootton 1998). Abiotic factors also are affected by lunar and tidal cycles, and these can indirectly affect feeding behavior as fishes have to overcome interference associated with turbidity, water level, and currents (Stoner 2004). Because the current sampling protocol suggests that sampling occur for three to seven consecutive days each month and that each sampling event "be as evenly spaced as possible" (USDOC 1997), knowing if timing within a monthly cycle influences catch rates would be beneficial for maximizing catch rates and the ability to make sound inferences based on these data.

The current sampling protocol dictates sampling events occur at evenly spaced intervals between months. The main issue with sampling in this manner is that sampling events would occur during the same lunar phase and tidal cycle each month within a year. If catch rates were influenced by these two factors, this protocol could lead to biased annual indices of relative abundance for sub-adult shark species, especially if annual sampling events began on different lunar phases. The results of this study indicate that tide and moon phase do not have significant effects on the on the individual catch rates of sub-adult sharks or the overall catch rates of sharks encountered in Georgia waters, with the possible exception for blacktip sharks. As such, the current sampling protocol should not introduce a source of bias associated with either of these two factors.

However, the results of this study did indicate that bait choice can have a significant effect on the overall catch rate and species composition of sub-adult sharks captured by the gear. The effects of bait type as a source of bias will be dependent on the goals of a given study. If the goal is to assess a suite of shark species, a universally-appealing bait such as squid should be selected. If the goal is to collect information on a single species, preliminary research on local dietary preferences should be conducted. The possibility of ontogenetic shifts also needs to be considered if more than one life stage is to be sampled.

Although any single bait may not allow for relatively large or uniform catch rates for all species, it should provide information on relative abundance for most. For abundant species, care should be taken to ensure the selected bait adequately represents the focal life stage(s) before the data are used to produce indices of abundance.

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Table 2-1. Relative frequencies and encounter rates by species for sub-adult sharks captured during longline sets in Georgia's estuaries, 2001-2002. Encounter rate is calculated as the number of sets that caught at least one individual of a given species divided by the total number of sets (n=212).

| Species | Total Number Captured | Number of positive sets | Encounter Rate (%) |
|---|---|---|---|
| Atlantic sharpnose (*Rhizoprionodon terraenovae*) | 307 | 115 | 54.25 |
| Bonnethead (*Sphyrna tiburo*) | 63 | 42 | 19.81 |
| Blacktip (*C. limbatus*) | 17 | 16 | 7.55 |
| Sandbar (*C. plumbeus*) | 16 | 16 | 7.55 |
| Scalloped hammerhead (*Sphyrna lewini*) | 8 | 7 | 3.30 |
| Finetooth (*C. isodon*) | 5 | 4 | 1.89 |
| Spinner (*Carcharhinus brevipinna*) | 2 | 2 | 0.94 |
| Bull (*C. leucas*) | 1 | 1 | 0.47 |
| Lemon (*Negaprion brevirostris*) | 1 | 1 | 0.47 |
| Overall | | 147 | 69.34 |

Table 2-2. Analysis of variance results examining the effects of moon and tide phase on overall and species-specific hand-retrieved longline catch rates of sub-adult sharks collected from Georgia's estuaries during 2001-2002. ** -Denotes statistical significance at $\alpha$ = 0.10.

| Species | ANOVA Overall Model Fit p-value | Effect | Effect p-value |
|---|---|---|---|
| Atlantic Sharpnose | 0.5955 | Moon | 0.3911 |
| | | Tide | 0.0558 |
| | | Moon x Tide | 0.9949 |
| Bonnethead | 0.3073 | Moon | 0.2933 |
| | | Tide | 0.2670 |
| | | Moon x Tide | 0.3568 |
| Blacktip | 0.0874 ** | Moon | 0.4983 |
| | | Tide | 0.5172 |
| | | Moon x Tide | 0.0382 ** |
| Sandbar | 0.2279 | Moon | 0.7634 |
| | | Tide | 0.3575 |
| | | Moon x Tide | 0.3043 |
| All Species Combined | 0.6244 | Moon | 0.4792 |
| | | Tide | 0.1870 |
| | | Moon x Tide | 0.8804 |

Table 2-3. Encounter rates for sub-adult sharks, by species, caught during bait study longline sets in Georgia's estuaries during 2003. Encounter rate is calculated as the number of sets that encountered at least one individual of a given species divided by the total number of sets (n=80).

| | Species | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Atlantic sharpnose | | Sandbar | | Bonnethead | | Blacktip | | Bull | | Scalloped Hammerhead | | Finetooth | | All Species Combined | |
| Bait Type | NPS | ER (%) | NPS | ER (%) | NPS | ER (%) | NPS | ER (%) | NPS | ER (%) | NPS | ER (%) | NPS | ER (%) | NPS | ER (%) |
| Squid | 27 | 33.75 | 11 | 13.75 | 16 | 20.00 | 5 | 6.25 | 1 | 1.25 | 0 | 0.00 | 0 | 0.00 | 44 | 55.00 |
| Spot | 30 | 37.50 | 7 | 8.75 | 0 | 0.00 | 1 | 1.25 | 2 | 2.50 | 1 | 1.25 | 1 | 1.25 | 36 | 45.00 |
| Both Baits Combined | 41 | 51.25 | 14 | 17.50 | 16 | 20.00 | 6 | 7.50 | 2 | 2.50 | 1 | 1.25 | 1 | 1.25 | 52 | 65.00 |

NPS = Number of positive sets
ER = Encounter rate

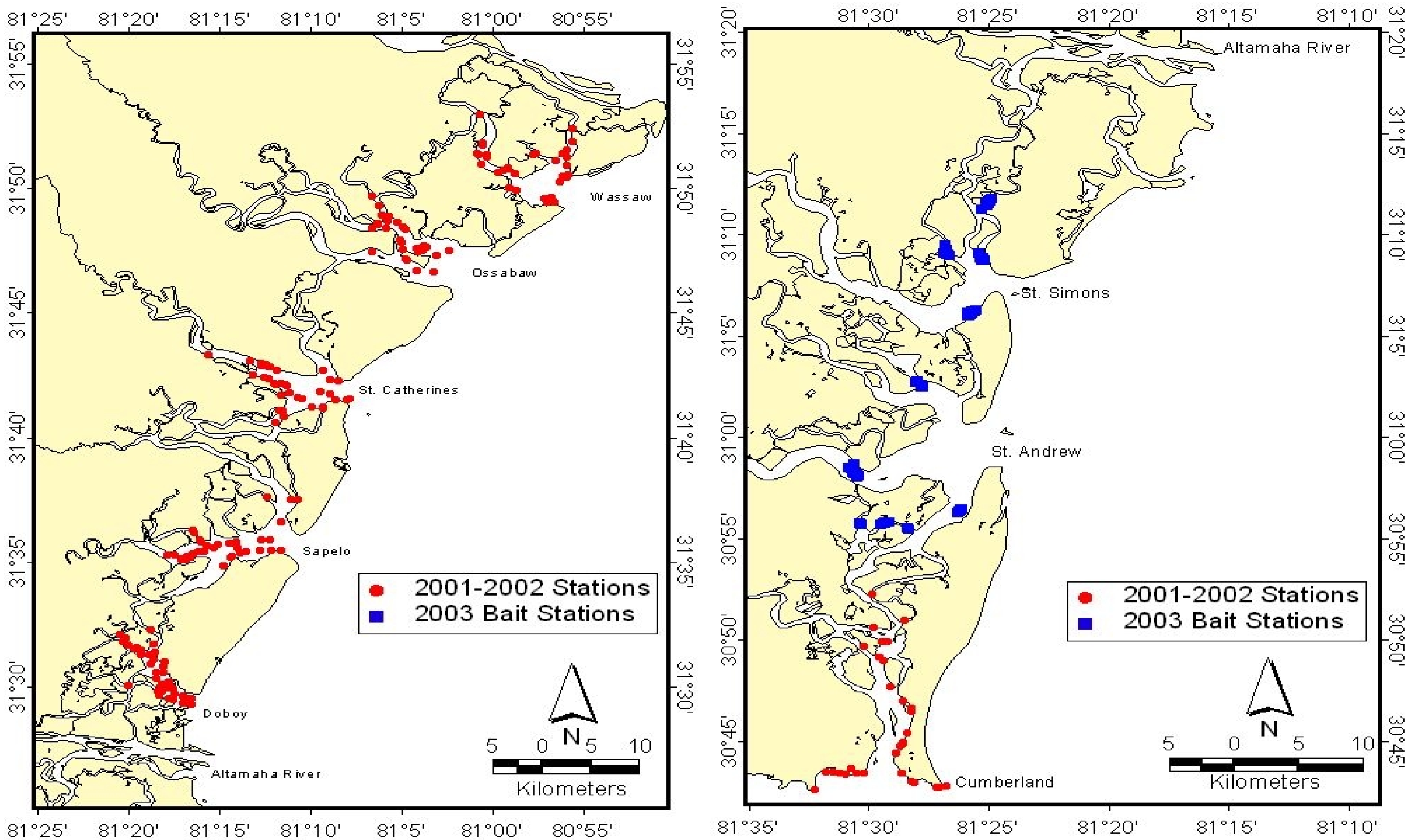
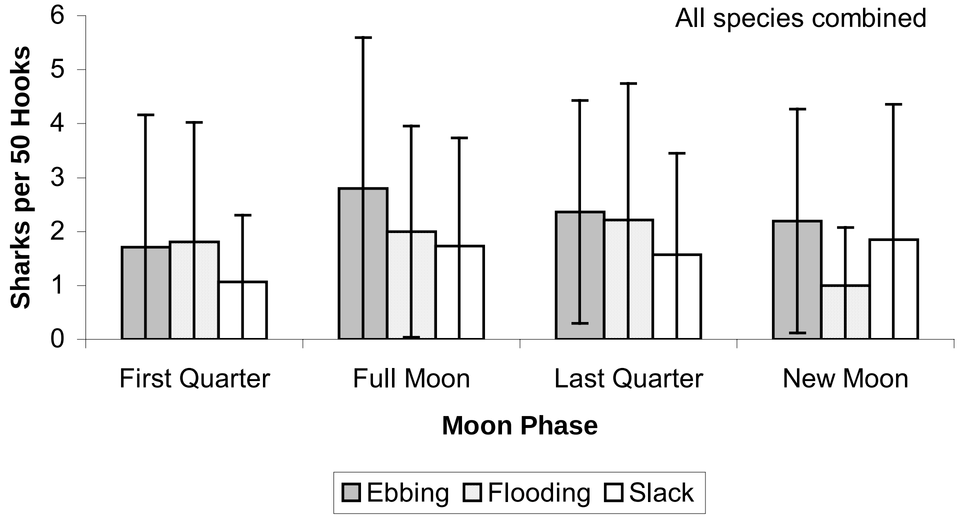



Figure 2-1. Map of stations where hand-retrieved longlines were fished in Georgia's estuaries during 2001-2003.



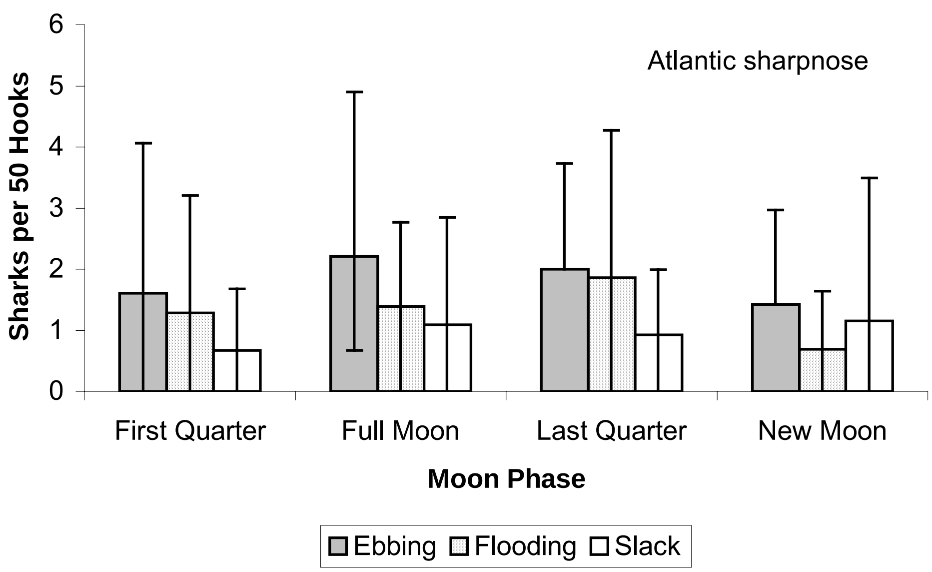
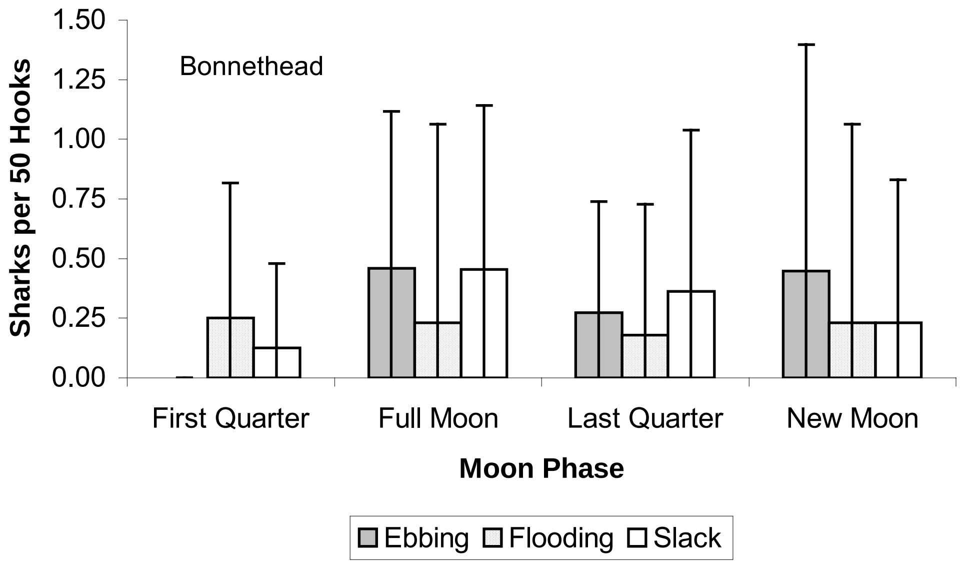




Figure 2-2. Average catch-rates (overall and species-specific) and 95% confidence intervals of hand-retrieved longline sets for sub-adult sharks captured in Georgia's estuaries during 2001-2002 by moon and tide phase. ** - Denotes statistical significance at $\alpha = 0.10$.



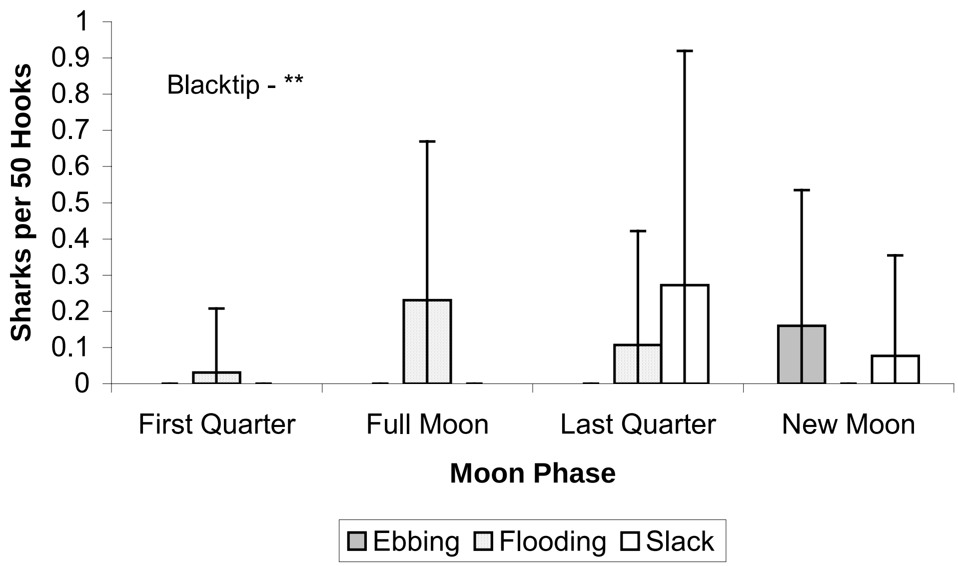




Figure 2-2. Continued.

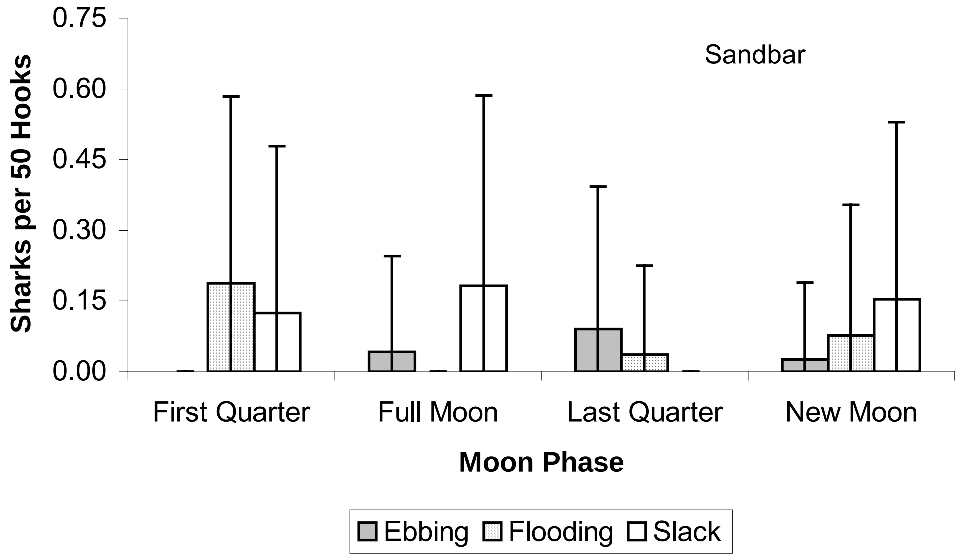



Figure 2-2. Continued.

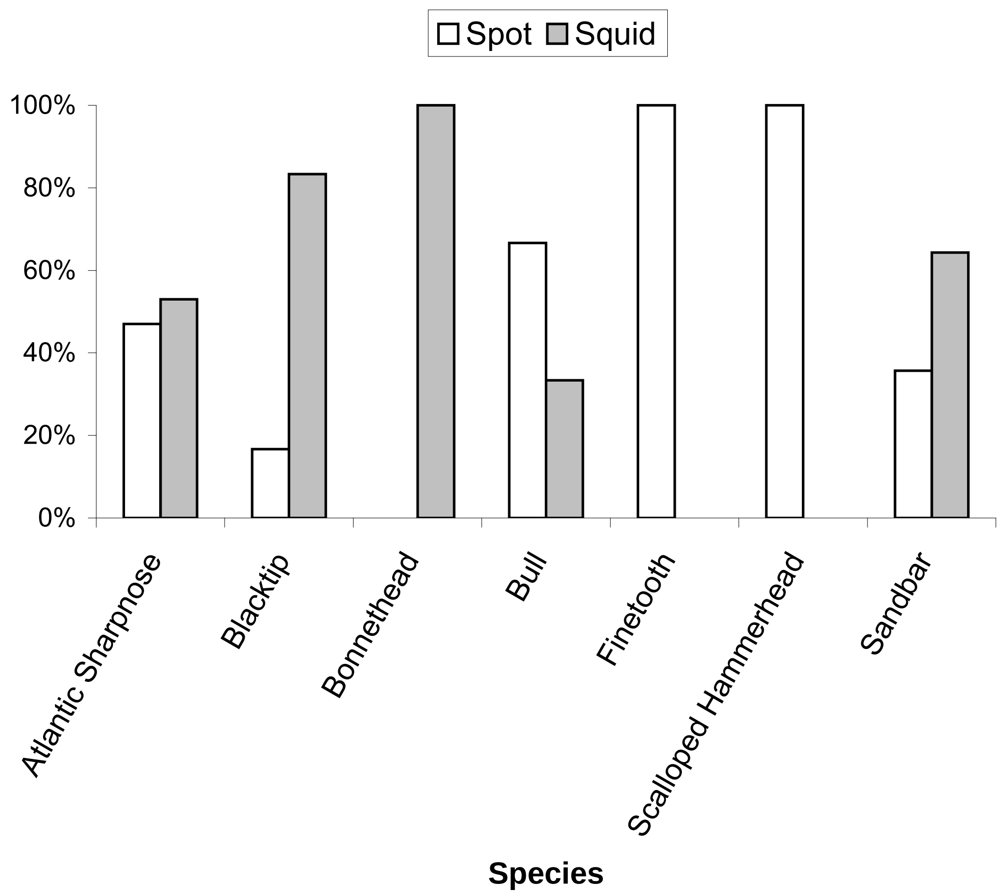
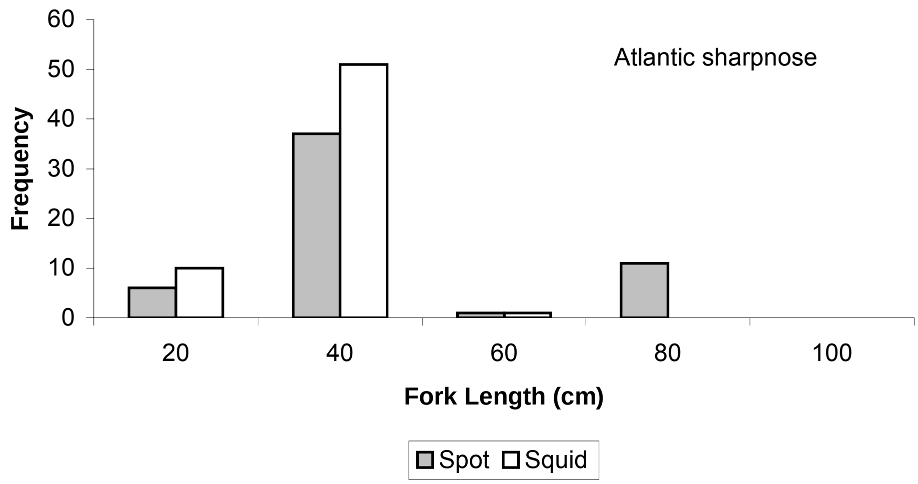



Figure 2-3. Percentage of total catch, by species, of sub-adult sharks captured on one of two bait types during hand-retrieved longline sets in Georgia estuaries during 2003.



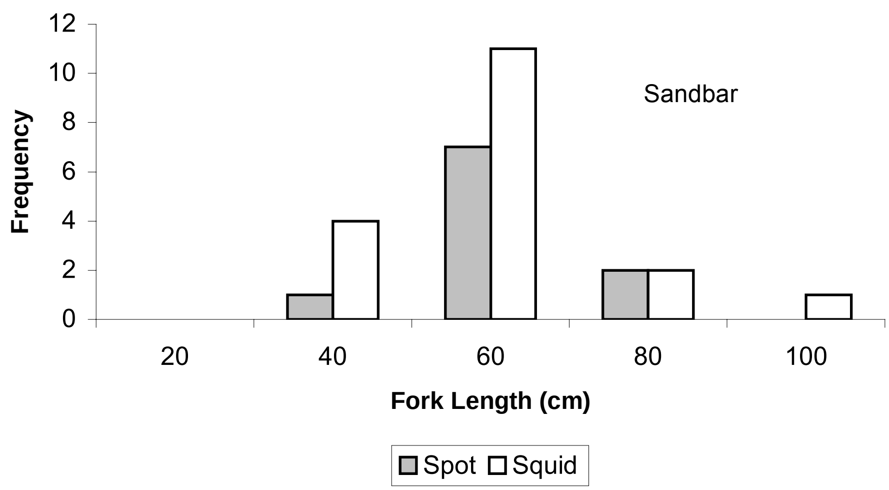




Figure 2-4. Length frequency distributions of sub-adult sharks, by species and bait type, caught during hand-retrieved longline sets in Georgia's estuaries during 2003.

# CHAPTER 3

# USE OF A FISHERY-INDEPENDENT TRAWL SURVEY TO EVALUATE DISTRIBUTION PATTERNS OF SUB-ADULT SHARKS IN GEORGIA[1]

[1] Belcher, C. N. and C. A. Jennings. Submitted to *Marine and Coastal Fisheries*.

## INTRODUCTION

Sharks are extremely vulnerable to overfishing because of their unique life histories that are characterized by low fecundity, slow growth rates, and late maturity (Castro 1983). Because of these traits, once shark populations are reduced to low numbers, it could take decades for some species to recover (Anderson 1990). In 1993, when the first fishery management plan for sharks was published, reported declines for many species were up to 75% from the 1970's to the mid 1980's (Carlson and Brusher 1999). The 1993 Fishery Management Plan for Sharks stressed the importance of better monitoring of shark stocks, as well as the need for improved abundance estimates for inclusion in future assessments (National Marine Fisheries Service 1993).

Accurate stock assessments for commercial species are dependent on both fishery-independent and fishery-dependent data. Fishery-dependent data provide information on the exploited segment of a population; however, these data do not provide managers with a representative sample of the population as a whole. By contrast, fishery-independent data are based on standardized sampling methods and examine the population as a whole (Rago 2005) and provide a more representative sample of the stock being assessed.

Prior to 1993, stock assessments for many shark species relied on fishery-dependent indices (Carlson and Brusher 1999). Currently, there are limited fishery-independent surveys being conducted on shark stocks in the northwest Atlantic. Three surveys currently monitor shark abundance in the Gulf of Mexico and along the U. S. Atlantic coast (Carlson and Brusher 1999); these surveys are conducted in areas where older juveniles and adults congregate, generally in waters greater than 10 meters deep (Carlson and Brusher 1999).

For many species, neonate and younger juvenile sharks occupy distinct habitats from the older juveniles and adults, especially during the summer months (Branstetter 1990). Fishery-dependent data are lacking for the sub-adult segment of the population as these life stages are seldom encountered in the commercial catches. Unlike many teleost species, the relationship between recruitment and adult stock size is direct (Carlson and Brusher 1999; Holden 1974; Helfman 2007). The importance of studying these life stages is two-fold: (1) to provide more comprehensive assessments of shark populations than are currently available, and (2) to provide information on trends in recruitment and abundance of sub-adult sharks in coastal waters.

Presently, there are only a few programs in the northwest Atlantic Ocean and the Gulf of Mexico that have fishery-independent surveys that provide relative indices of abundance for sub-adult sharks. Carlson and Brusher (1999) present potential indices of abundance for multiple species generated from fishery-independent gillnet and longline sets made in the northeast Gulf of Mexico. Musick et al. (1998) used longlines in the Chesapeake Bay to assess abundance of juvenile sandbar sharks. The Cooperative Atlantic States Shark Pupping and Nursery Grounds (COASTSPAN) survey was established in 1998 as a cooperative program between the National Marine Fisheries Service and state agencies along the east coast of the United States to assess coastal areas as shark nursery grounds and to develop sampling methodologies to be used for producing fishery-independent indices of abundance for sub-adult sharks. Under the COASTSPAN protocol, two gears (i.e., hand-retrieved longlines and gillnets) are being used to sample sub-adult sharks  In Georgia, the COASTSPAN project uses a hand-retrieved longline, with effort focused in Georgia's estuaries and inshore waters.

Gillnets and longlines are considered passive fishing gears (Murphy and Willis 1996).  If these gears are fished with a standardized protocol, they can be used to produce measures of relative abundance for a variety of species; however, because they are dependent on fish behavior (e.g., taking bait off hooks on longlines) or morphology (e.g., fins and spines becoming entangled in gill and trammel nets), they can be more selective than other gear types (Murphy and Willis 1996).

Active fishing methods include fishing gears that require sustained movement to capture the target species (Murphy and Willis 1996).  Some gears (e.g., seines) capture fish by encircling them, whereas others (e.g., trawls and dredges) actively "sweep" an area and overtake animals in their path.  One key advantage associated with active fishing gear is that an estimate of fish density/area can be calculated for each tow.  In contrast, the area sampled by stationary gear is more difficult to compute because the size of the area sampled is influenced by fish behavior, environmental factors, and a feeding response (Rago 2005; Murphy and Willis 1996).

Although trawls are not traditionally used to target large sharks (Rago 2005), they frequently encounter small sharks as bycatch (Castro 1983; Camhi 1998).  Georgia's Department of Natural Resources' Coastal Resources Division (GADNR CRD) has a standardized bottom trawl survey that began in 1978 and samples Georgia's nearshore and estuarine waters.  Because the survey is standardized and sampling occurred monthly, the trawl survey is being considered as a potential fishery-independent survey for sub-adult sharks, especially since the bycatch could provide potential insight about offshore abundances of sharks, which are not currently sampled with longlines.

The purposes of this study were to: 1) determine the utility of the bottom trawl survey for evaluating the spatial distribution of sub-adult sharks in Georgia's nearshore and estuarine waters; 2) determine if the bottom trawl and hand-retrieved longline catches show similar seasonal trends; and 3) compare the efficiency, and selectivity of the two gears for capturing sub-adult sharks.

## MATERIALS AND METHODS

*Trawl Survey---*

GADNR CRD has used a stratified, fixed-station sampling design since the late 1970's to conduct monthly trawl sampling on board the *R/V Anna*, an 18.3 m trawler. Sampling effort has been focused in Georgia's inshore and nearshore waters, with strata defined by sound system and area. Six of Georgia's nine estuaries were sampled. From north to south, they are Wassaw, Ossabaw, Sapelo, St. Simons, St. Andrew and Cumberland. Three areas-- creek/river, sound, and offshore -- were identified within each sound system. Two stations within each area were sampled. A total of 36 stations was sampled each month, coastwide (Figure 3-1). Shark bycatch was quantified from trawls that occurred during the 2003 pupping season, which generally occurs in Georgia waters from mid-April through the end of September.

Each trawl used a single-net otter trawl, outfitted with a 12.2 m flat net with 4.8 cm stretched-mesh webbing used in both the body and the bag of the net. For standardization purposes, sampling was scheduled during the first two weeks of the month and on neap tides when possible. Tow speeds were standardized, depending on the direction of the tow. Tows made against the tide were maintained at a speed of 2.0 knots, whereas those made with the tide were maintained at 2.5 knots. Tow time was constant at 15 minutes for each station.

*Longline Survey---*

Longline sampling, conducted under the COASTSPAN protocol established by the National Marine Fisheries Service's Apex Predator Investigation (USDOC 1997), occurred from mid-April through the end of September 2003. The longline, which was bottom-set and retrieved by hand, was secured to the bottom via standard 4.1 kg Danforth® multi-purpose anchors, with ends marked with orange A-2 Polyform® fluorescent buoys. The longline consisted of 305 m of 6.4 mm braided mainline and 50 removable gangions comprised of 12/0 Mustad® circle hooks with depressed barbs, 50 cm of 1.6 mm stainless steel cable, 50 cm of 6.4 mm braided nylon, and a longline snap. Gangions were attached to the main line at 4.5 - 6.1 m increments. One half of the 50 hooks were baited with squid (*Loligo sp.*), with the remaining 25 hooks baited with spot (*Leiostomus xanthurus*), a local baitfish.

Eight of the 36 stations sampled by the *R/V Anna* were sampled with the longline gear. These eight stations were from the inshore sectors (i.e., creek/river and sound) of St. Simons and St. Andrew sounds (Figure 3-1). Stations were visited twice monthly (total effort = 16 longline sets). The offshore stations were not sampled because of safety constraints associated with the sampling vessel. Longline sampling generally occurred in the last two weeks of each month because concurrent sampling with both gears was not possible.

*Shark sampling from shrimp trawl bycatch ---*

All sharks encountered as bycatch during trawl stations were identified to species, sexed, measured for both fork and total lengths (FL and TL in cm, respectively), weighed (kg), and characteristics of the umbilical scar were recorded. Sharks were classified as neonates or juveniles based on the presence of an umbilical scar and the degree of healing (USDOC 1997). Species- and sex-specific length-at-maturities presented in Castro (1983) were used to distinguish juveniles from adults.

All sharks caught in trawl samples were returned to the water once the pertinent data were recorded. Unfortunately, because of the height of the vessel from the water, assessing the release condition of most sharks was difficult. Limited space on the boat did not allow for the use of a live well; however, all sharks < 50 cm TL were placed in an aerated 5-gallon bucket until they could be processed. Sharks > 50 cm TL were processed immediately, tagged on the first dorsal fin with a numerically referenced plastic roto-type tag (i.e., same type of tag used for sheep ears) for individual identification, and returned to the water.

*Shark sampling with longlines ---*

All targeted and bycatch species encountered on the longline gear were handled carefully to insure maximum survival once returned to the water. Because of the slow speed associated with line retrieval, all fishes captured were left on their gangions and moved to a “stringer” line on the off side of the boat where they were allowed to swim along-side the vessel. This method worked well for keeping fish alive and eliminated the need for a large live well. Hooks were removed promptly and with minimal trauma to the fishes. When necessary, hooks that could not be easily removed (e.g., embedded in the jaw) were either cut with wire cutters and removed from the fish’s mouth; or in the case of large sharks (i.e., > 1.2 m TL) that were too big to bring on the boat, the leader was cut as close as possible to the hook. All sharks capable of swimming were tagged prior to release in the same manner described in the trawl section. Sharks that were moribund or lethargic were not tagged; however, attempts were made to resuscitate these animals before they were released.

*Catch per unit of effort ---*

Although catch per unit of effort (CPUE) can be calculated for each gear as the number of sharks caught per unit of time, both surveys use different fishing times. Although standardizing both CPUEs to an hour may seem feasible, converting these values to equal time units assumes that catch would be a linear function of fishing time. This assumption may be probable for the trawl because it continues to fish as time increases; however, the assumption may not be probable for the longline because the gear continues to fish only as long as bait remains on the hooks. Observations made during the COASTSPAN project indicate that most bait on the longline (more than 90%) is gone after 30 minutes.

Because the existence of a linear relationship between trawl catches and tow time has not been confirmed, trawl CPUEs cannot be expressed in terms of 30 minutes.

Since both surveys are standardized, CPUEs are presented as the number of individuals per sampling event, calculated for the aggregate shark catch and for individual species represented by 15 or more individuals.

*Statistical Analyses* ---

**Trawl Catch Characteristics.** Catch rates and average fork lengths for abundant species and the aggregate catch associated with trawl stations were evaluated for normality by examining associated skewness and kurtosis values prior to conducting analyses (Mertler and Vannatta 2005). None of the species-specific or aggregate CPUEs or fork lengths were normally distributed. Because the catch data exhibited a negative binomial distribution, an inverse hyperbolic sine transform was applied to the catch data (Zar 1999). Because the fork lengths exhibited a substantial positive skew, a base-10 logarithmic transform was applied to those data (Mertler and Vannatta 2005). The transformations did not normalize either the length or CPUE data; therefore, the Kruskal-Wallis test was used to compare both the mean CPUEs and the mean lengths for the aggregate catch and for the commonly occurring species among areas for the trawl data (Hollander and Wolfe 1973; Zar 1999). If significant differences were found among the areas, Dunn's multiple comparison test was used to separate significant means (Zar 1999). Both analyses were conducted with Excel 2000 software (Microsoft Corporation 1999).

Multinomial Chi-square analyses (Zar 1999) were used to determine if the overall species composition, and the life stage compositions for the aggregate catch and the most abundant species differed among areas. Chi-square analyses were conducted with SAS version 9.1 (SAS Institute 2002).

Because of limited sample sizes produced by the two standardized survey protocols, the high degree of variability associated with the data, and the exploratory nature of the study, an $\alpha$ level of 0.10 was used to evaluate the significance of all the analyses performed.

**Between Gear Comparisons.** As a means of controlling variation, only stations that were sampled by both gears were included in these analyses. Catch rates and fork lengths for the aggregate catch and the most abundant species were evaluated for normality by examining skewness and kurtosis values prior to analysis. Both sets of data were non-normal and transformations were not successful in normalizing the data. As a result, these data were analyzed with nonparametric or analogous parametric methods.

Because the catch data were not normally distributed, parametric ANCOVAs could not be used on the raw data to determine if the longline and trawls detected similar seasonal trends of abundance for the commonly occurring species and the aggregate catch. Although a nonparametric rank analysis of covariance was developed by Quade (1967), Conover and Iman (1982) demonstrated the robustness of using a parametric general linear model on rank transformed data.

One of the key assumptions of ANCOVA is the existence of a linear relationship between the dependent variable (i.e., abundance) and the covariate (i.e., seasonal variable) (Mertler and Vannatta 2005). If abundance was plotted against a temporal variable (i.e., month), catch rates over the course of the season tended to indicate a nonlinear trend (i.e, peak catches occur in July). The presence and absence of neonate and juvenile sharks in coastal waters has been correlated with water temperature in many studies (McCandless et al. 2007). Therefore, water temperature was used as a seasonal surrogate for month, as the abundance of sharks appears to increase with increasing temperature; thus resulting in a linear trend between the two variables.

An ANCOVA was conducted by using the SAS GLM procedure and the rank transforms of the catch rates and water temperatures to evaluate if both gears determine the same seasonal abundance patterns. An $\alpha=0.10$ was used to determine significance.

Additional analyses were conducted to determine the similarity of basic measures of efficiency and selectivity between the two gears. Efficiency was evaluated by comparing CPUEs between the two gears for the aggregate catch and the most abundant species. A nonparametric Wilcoxon rank sum test was applied in all cases (Hollander and Wolfe 1973).

Selectivity of the two gears was evaluated by examining differences in average size, life stage characteristics, and species composition of the sharks in the catch. Average fork lengths were analyzed for the aggregate catch and for the most abundant species. Wilcoxon rank sum tests (Hollander and Wolfe 1973) were used to compare the mean fork lengths of the aggregate catch and the most abundant species caught by both gears. Overall species composition and life stage characteristics for the overall catch and the most abundant species were analyzed with multinomial chi-square analyses (Zar 1999). Wilcoxon rank sum tests and chi-square analyses were conducted with SAS version 9.1 (SAS Institute Inc. 2002) and were evaluated at $\alpha$=0.10.

RESULTS

*Trawl Catch Characteristics---*

A total of 234 sub-adult sharks from six species was captured during 85 of 216 trawls. The two most abundant shark species, which accounted for 96.6% of the total shark bycatch, were the Atlantic sharpnose shark (*Rhizoprionodon terranovae*) and bonnethead (*Sphyrna tiburo*) (Table 3-1). The total number of sharks captured per sampling event ranged from 0 to 12 (mean = 1.1, s.d. = 2.2). Other species captured in trawls were blacktip shark (*Carcharhinus limbatus)*, scalloped hammerhead shark (*Sphyrna lewini*), sandbar shark *(C. plumbeus*), and blacknose shark (*C. acronotus)* (Table 3-1). Because of low capture numbers, these species were combined into a single group (i.e., "other" species) for inclusion in the overall species analyses.

Trawl catch rates for sub-adult sharks among areas were not different for the aggregate catch or for Atlantic sharpnose shark (Table 3-2). The catch rates for bonnethead sharks differed among areas; catches in the offshore (mean = 0.14, s.d. = 0.48) were significantly lower than those found in the inshore areas (sound: mean = 0.43, s.d. = 1.06; creek/river: mean = 0.47, s.d. = 1.26).

Average fork lengths of sharks did not differ among areas for the aggregate catch and Atlantic sharpnose shark (Table 3-2). The average fork lengths differed among areas for bonnethead sharks, with the larger bonnetheads occurring in the offshore waters. Average sizes of bonnethead sharks were 46.4 cm FL in the offshore (s.d. =

14.9), 41.3 cm in the sound (s.d. = 11.9) and 37.1 cm in the creek/river areas (s.d. = 6.0).

Life stage was independent of sampling area for the Atlantic sharpnose ($\chi^2_{0.10,\,2}$ =1.05, p=0.59) and bonnethead sharks ($\chi^2_{0.10,\,2}$ =0.20, *p*=0.99). The ratio of juveniles to neonates for Atlantic sharpnose sharks was consistent among areas at 1:3. Bonnetheads also had a consistent ratio of juveniles to neonates among areas with a ratio of 10:1. Life stage differed among areas for the aggregate catch ($\chi^2_{0.10,\,2}$ =10.66, *p*=0.005). Neonates occurred with the same frequency as juveniles in the sound (1:1 ratio), whereas juveniles dominated the creeks (2:1), and neonates dominated the offshore (2:1).

Overall species composition in trawl catches varied among areas ($\chi^2_{0.10,\,4}$ =20.57, *p*=0.0004). General trends for total catch indicated equal frequencies of occurrence between the creek and offshore sectors, with higher frequencies in the sound (Table 3-3). Atlantic sharpnose sharks were the dominant species in the sound and offshore sectors, whereas bonnetheads were the dominant species in the creeks (Table 3-3). When “other” species were captured in any numbers, they were more likely to be in the sounds and offshore waters (Table 3-3).

Between Gear Comparisons---

A total of 193 sub-adult sharks from seven species was captured during 57 of 96 longline sets, whereas 52 sub-adults from four species were captured at trawl stations (Table 3-4). All species captured at trawl stations also were encountered at longline stations.

Four species, Atlantic sharpnose, sandbar, bonnethead, and blacktip sharks, accounted for 97.4% of the total longline catch. Two species, the Atlantic sharpnose shark and bonnethead, accounted for 96.2% of the total catch in the trawls. The catch rate of bonnetheads was higher in trawls than on longlines; however, catch rates for "other" species in the study were higher on longlines compared to the trawls. The total number of sub-adult sharks captured per sampling event ranged from 0 to 9 for the longline and from 0 to 12 for the trawl; the average catch for each gear was 2.0 (s.d. = 2.3) and 1.1 (s.d. = 2.2), respectively. Blacktip and scalloped hammerhead sharks were captured by both gears; however, neither occurred with great frequency. Two species captured solely by longline and with low frequency were the finetooth shark (*C. isodon*) and the bull shark (*C. leucas*) (Table 3-4).

The significant interaction terms in the ANCOVA results indicated that the trawl and longline gear sampled the aggregate of sub-adult sharks and Atlantic sharpnose sharks differently (Table 3-5; Figure 3-2). The lack of statistical significance for the interaction term associated with bonnetheads indicated that the two gears exhibited trends that were not significantly different (Table 3-5; Figure 3-2). However, further examination of the results indicates that water temperature may be a poor indicator of abundance for sub-adult bonnetheads and that the abundance did not differ between the two gears, as neither main effect was significant (Table 3-5). The total catch for all species ($Z$ = -2.73, $p$ = 0.0071) and for Atlantic sharpnose shark (Z = -2.38, $p$=0.02) differed significantly between gears; the longline caught more sharks per sampling event than the trawls (Figure 3-3). Catch rates for bonnetheads did not differ between gears ($Z$ = 0.96, $p$ = 0.34).

Average sizes of sharks differed significantly between gears for Atlantic sharpnose shark ($Z = -4.35$, $p < 0.0001$), bonnetheads ($Z = -4.01$, $p = 0.0002$), and the aggregate catch ($Z = -5.06$, $p < 0.0001$). The average size of the aggregate catch (mean = 45.0 cm FL, s. d. = 15.6) and the average sizes of Atlantic sharpnose sharks (mean = 38.4 cm FL, s. d. = 13.3) and bonnetheads (mean = 51.9 cm FL, s. d. = 13.5) captured on the longline were larger than those caught during trawls (aggregate catch: mean = 33.5 cm FL, s. d. = 7.2; Atlantic sharpnose shark: mean = 30.3 cm FL, s. d. = 4.8; Bonnetheads: mean= 36.3, s. d. = 7.6). In general, the size distributions associated with each gear type exhibited either a dome-shaped size selectivity (trawl-caught sharks) or a positively skewed size selectivity (longline-caught sharks) (Figure 3-4).

The proportions of neonate and juvenile bonnethead sharks differed between gears ($\chi^2_{0.10,\,1} = 6.75$, $p = 0.009$). Both gears encountered more juveniles than neonates; however, the longline only encountered juveniles, whereas the ratio of juveniles to neonates was 3.6:1 for the trawl.

Species composition was dependent on gear type ($\chi^2_{0.10,\,2} = 25.82$, $p < 0.0001$). Atlantic sharpnose shark was the dominant species captured by both gears, bonnethead was the second most abundant species in the trawl gear, and the “other” shark species occurred more frequently during longline sets (Table 3-6).

## DISCUSSION

*Utility of Bottom-Trawl Gear for Sampling Sub-adult sharks--*

The results of this study indicate that bottom trawls could provide useful information for assessing the sub-adult portion of both the Atlantic sharpnose and bonnethead shark populations in Georgia and perhaps similar southeastern U. S. waters. Although six species were captured during trawls, Atlantic sharpnose and bonnethead sharks dominated the catch. The catch rates and average sizes of the aggregate shark catch did not differ among areas, indicating that area use by neonates and juveniles did not vary significantly.

The lack of differences in average size of the aggregate catch of sub-adult sharks among areas probably reflects gear selectivity and not the true size of sub-adults in those areas. Size selectivity for many teleost species caught with nets occurs for small and large fish because the smaller ones can pass through the net and larger fish swim faster than the net (Murphy and Willis 1996; Rago 2005). Neonates of some shark species may be more accurately sampled by trawl gear because the mesh size is too small for them to pass through. Further, many small species (e.g., Atlantic sharpnose and bonnethead sharks) may be incapable of swimming faster than the net is pulled. The majority of sub-adults encountered during trawls were < 45 cm FL (Figure 3-4). Other shark species such as the blacktip and sandbar that are common to Georgia waters are born at sizes larger than 45 cm (Castro 1983; Compagno 1984) and may be capable of swimming faster than the net is pulled.

Sub-adult Atlantic sharpnose sharks are the most abundant shark found in Georgia's inshore and nearshore waters. Studies in the Duplin River National Estuarine Research Reserve, GA (Gurshin 2007) and in South Carolina estuaries (Ulrich et al. 2007) have also shown similar patterns in abundance for this species. The results of our study suggest that Atlantic sharpnose do not have a specific nursery area. Many investigators have reported on the assumed importance of inshore bays, lagoons, and estuaries as key nursery areas for sharks (Castro 1993; McCandless et al. 2007; Snelson and Williams 1981; Simpfendorfer and Milward 1993). The suggested advantages of these areas are protection from predators, and abundant food sources (Branstetter 1990; Castro 1993; Simpfendorfer and Milward 1993). Other studies have suggested that species requirements for nurseries may be limited by water depth and habitat type (Springer 1967; Parsons 1983). If Georgia's estuaries and inshore waters provided protection from predators, one would expect to find the average size of sharks caught inshore to be smaller than those caught offshore, and a higher ratio of neonates to juveniles. Our results for Atlantic sharpnose sharks do not support this assumption. Instead, our results seem to support Heupel et al.'s (2007) assertion that the benefits of a nursery area may be limited for species (such as the Atlantic sharpnose) that have a productive life history (i.e., rapid growth, early maturity, annual reproduction), and high rates of population growth.

The results for average size and catch rates of bonnetheads captured in the trawl support distributional patterns observed by Heupel et al. (2006) and Ulrich et al. (2007). The offshore area is used by larger sized individuals, but with low frequency, indicating this species tends to utilize inshore waters more frequently than the offshore. The results of this study also suggest that bonnethead sharks may have specialized nursery areas. For example, juvenile bonnethead sharks > 60 cm TL and adult bonnethead sharks in Pine Island Sound, FL are resident in the estuary and seem not to undergo long-distance coastal migrations (Heupel et al. 2006). Additionally, Ulrich et al. (2007) found similar overlap in the habitat use for adult and juvenile stages; however, neonate bonnetheads were conspicuously absent, even though pregnant females had been encountered in April and early May. Such habitat use patterns suggest that pupping might occur in inshore waters. Assuming Georgia's bonnethead shark populations exhibit similar residency patterns, the low frequency of encounters with neonate bonnethead sharks leads one to conclude that the young of the year do congregate in areas different from the juveniles and adults. Whether the lack of neonates in Georgia's estuaries is a function of the sampling gear or their occurrence in areas separate from the rest of the population is unknown.

The proportion of neonates to juveniles for the aggregate catch varied among areas. Contrary to hypotheses about shark nurseries, the current study documented that the higher ratio of neonates occurred offshore rather than in the creeks and sounds. If one assumes that inshore areas provided a high degree of protection from predation for most species, then the numbers of neonates would be higher in the inshore areas. However, the contradiction appears to be a function of species distribution and the ratio of neonates to juveniles for the dominant species. The most abundant species in the creeks was the bonnethead shark, which was represented predominantly by juveniles. The most abundant species in the offshore was the Atlantic sharpnose shark, which was represented mostly by neonates. In evaluating multi-species nursery areas, the neonate to juvenile ratio needs to be assessed at the species level as distributional patterns also affect these ratios.

*Gear Comparisons---*

Published studies that evaluated the efficiency of various gears for capturing sharks are scarce. The available literature includes an examination of longlines and gillnets for providing an index of abundance for coastal species of juvenile sharks in the northeast Gulf of Mexico (Carlson and Brusher 1999), the selectivity of commercial gillnets for catching small coastal sharks (Carlson and Cortes 2003), and the effects of gangion type (i.e., rope/steel vs. monofilament) on catch rates (Branstetter and Musick 1993). Although trawls are not generally used to sample sharks (Rago 2005), the large incidental catch of sub-adult sharks in this gear lead to an evaluation of its potential use for sampling this portion of the population. This study examined the utility and compared the relative efficiency and selectivity of trawls to the commonly used longline gear.

Comparisons between the trawl and longline gears indicate that each sampled the population of sub-adult sharks differently. Species diversity of the longline catch was higher than the diversity of the trawl catch. The species (e.g., sandbar, blacktip and bull sharks) that occurred with lower frequency or were absent from trawl catches are born at larger sizes than either the Atlantic sharpnose shark or the bonnethead shark, which were commonly caught in the trawls. Sandbar, blacktip and bull sharks are larger than 45 cm TL at birth (Castro 1983). Thus, the lack of these species in the trawl catches supports the premise that larger-sized species are able to avoid the net (Rago 2005).

Although the aggregate catch rate and the catch rate for Atlantic sharpnose sharks were higher on the longline than in trawls, determining the true magnitude of difference between the two gears is difficult because the two gears do not represent similar efforts. Although both gears are fished essentially along the estuarine or sound bottom, longlines have the advantage of attracting sharks to the gear; therefore, sharks that are high in the water column also are susceptible to the gear. The trawl can only capture those fish that are directly in its path, which limits its catch to those organisms that do not swim higher than the trawl extends above the bottom.

Catch rates for bonnethead sharks did not differ between the two gears. Although higher catch rates would be expected for longlines, the lower catch rates compared to trawls may be related to the choice of the bait used during this study. Bonnethead shark diets are largely comprised of crustaceans and mollusks (Castro 1983, Compagno 1984). Because half of the hooks on each set were baited with fish, bonnethead sharks may have been underrepresented in longline catches. This lack of efficiency for the longline was also documented by Ulrich et al. (2007), as the majority of bonnetheads captured during their study were caught with gillnets and not on hooks baited with teloests. Results presented in Chapter 2 of this dissertation documented that sub-adult bonnethead sharks were not caught on hooks baited with spot (*Leiostomus xanthurus*).

Although evidence exists for differences in selectivities between the two gears, the exact reasons for some of the key differences are unknown. Size selectivity of the longlines and trawls used in this study was evident as the average size of sub-adult sharks at both the species and aggregate level differed between the two gears. Larger sharks were captured on the longline whereas smaller sharks were caught in trawls. The smaller mean size for sharks captured in the trawl suggests that either neonates are encountered more frequently during trawls or that they are not attracted to the baits used during longline sets. The results of this study indicate that this assumption is only supported for bonnethead sharks. The results of the aggregate catch and Atlantic sharpnose life stage analyses indicate that equal ratios of neonates and juveniles are present in the catch of the two gears. All sharks that lack the umbilical evidence to classify them as a neonate and are smaller than the currently published size-at–maturity for a given species were classified as juveniles; therefore, the juvenile classification encompasses a wide range of age classes. Although the trawl encounters the same proportion of juveniles as the longline, the trawl may catch mostly young (i.e., small) juveniles, whereas the bait on the longline appeals to a broader range of ages. Only the trawl gear captured bonnethead shark neonates, which is probably a function of feeding ecology for this particular species and/or life stage.

## CONCLUSIONS

Current fishery-independent surveys for sharks use passive gears to provide indices of abundance for both the exploited adult segment of the population and the unexploited sub-adult portion. Generally, trawls are not used to assess shark populations because of their large size, fast swimming speeds, pelagic behavior, and low encounter rates (Rago 2005). Additionally, use of active gear tends to be costly as larger vessels, mechanized retrieval and larger crews are needed (Murphy and Willis 1996). Although a targeted effort with active gears may be cost prohibitive for sharks, bycatch information from surveys employing active gear could prove to be a valid source for ancillary data and trends in abundance for smaller shark species, such as Atlantic sharpnose and bonnethead sharks.

Sub-adult sharks are a common bycatch in shrimp trawls, especially during summer months when they frequent shallow areas in coastal waters. Although not all shark species are susceptible to the gear, some species, such as Atlantic sharpnose and bonnethead sharks, occur often enough that data collected from trawls could be useful in developing indices of abundance for neonates and small juveniles of both species.

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Table 3-1. Frequencies and encounter rates, by species, for sub-adult sharks captured during standardized trawls in Georgia's estuaries during 2003. Encounter rate is calculated as the number of sets that encountered at least one individual of a given species divided by the total number of sets (n=216).

| Species | Total Number Captured | Number of Positive Stations | Encounter Rate (%) |
|---|---|---|---|
| Atlantic sharpnose | 151 | 61 | 28 |
| Bonnethead | 75 | 42 | 19 |
| Blacktip | 3 | 3 | 1 |
| Scalloped hammerhead | 2 | 2 | 1 |
| Sandbar | 2 | 1 | <1 |
| Blacknose | 1 | 1 | <1 |
| Overall | 234 | 85 | 39 |

Table 3-2. Results of Kruskal-Wallis test of differences in catch rates and fork lengths among sampling areas for aggregate and species-specific catches of sub-adult sharks collected during 2003 (Degrees of freedom = 3; *-Denotes significant differences among areas at $p<0.05$).

| Species | Calculated $\chi 2$ |
|---|---|
| Atlantic Sharpnose | |
| CPUE | 1.36 |
| Fork Length (cm) | 0.67 |
| Bonnethead | |
| CPUE | 6.43 * |
| Fork Length (cm) | 7.04 * |
| All Species Combined | |
| CPUE | 1.04 |
| Fork Length (cm) | 3.88 |

Table 3-3. Contingency table examining the relationship between species composition of sub-adult sharks and trawl sampling areas in Georgia's estuaries during 2003.

| | | | Species | | | |
|---|---|---|---|---|---|---|
| | | | Atlantic Sharpnose | Bonnethead | Other | Total |
| Area | Creek/River | Frequency<br>Row % | 29<br>45.31 | 34<br>53.13 | 1<br>1.56 | 64 |
| | Sound | Frequency<br>Row % | 75<br>68.18 | 31<br>28.18 | 4<br>3.64 | 110 |
| | Offshore | Frequency<br>Row % | 47<br>78.33 | 10<br>16.67 | 3<br>5.00 | 60 |
| | | Total | 151 | 75 | 8 | 234 |

Table 3-4. Encounter rates and total number captured (in parentheses) for sub-adult sharks, by species, caught at inshore trawl and hand-retrieved longline stations of St. Andrew and St. Simons estuaries during 2003. Encounter rate is calculated as the number of sets that encountered at least one individual of a given species divided by the total number of sets (trawl: n=48; longline n=96).

| Species | Number of Positive Sets | | Encounter Rate (%) | |
|---|---|---|---|---|
| | Longline | Trawl | Longline | Trawl |
| Atlantic sharpnose | 42 (122) | 12 (27) | 44 | 25 |
| Sandbar | 15 (30) | 0 (0) | 16 | 0 |
| Bonnethead | 19 (28) | 13 (23) | 20 | 27 |
| Blacktip | 8 (8) | 1 (1) | 8 | 2 |
| Bull | 2 (3) | 0 (0) | 2 | 0 |
| Scalloped hammerhead | 1 (1) | 1 (1) | 1 | 2 |
| Finetooth | 1 (1) | 0 (0) | 1 | 0 |
| Overall | 57 (193) | 20 (52) | 59 | 42 |

Table 3-5. Results of analysis of covariance tests used to evaluate the similarity of seasonal trends in abundance between the longline and trawl for aggregate and species-specific transformed catches of sub-adult sharks collected in St. Simons and St. Andrew estuaries during 2003 as explained by water temperature. †- Denotes assumption of homogeneous slopes is not valid.

Atlantic sharpnose

| Source | Type III Sum of Squares | Degrees of Freedom | Mean Square | F | p-value |
|---|---|---|---|---|---|
| Model | 50810.15 | 3 | 16936.72 | 17.37 | <0.0001 |
| Water Temperature | 32885.64 | 1 | 32885.64 | 33.72 | <0.0001 |
| Gear Type | 436.61 | 1 | 436.61 | 0.45 | 0.5046 |
| Water Temperature x Gear Type | 7515.49 | 1 | 7515.49 | 7.71 | 0.0063† |
| Error | 136543.85 | 140 | 975.31 | | |
| Corrected Total | 187354.00 | 143 | | | |

Bonnethead

| Source | Type III Sum of Squares | Degrees of Freedom | Mean Square | F | p-value |
|---|---|---|---|---|---|
| Model | 3548.43 | 3 | 1182.81 | 1.30 | 0.2770 |
| Water Temperature | 2408.29 | 1 | 2408.29 | 2.65 | 0.1060 |
| Gear Type | 533.05 | 1 | 533.05 | 0.59 | 0.4454 |
| Water Temperature x Gear Type | 167.26 | 1 | 167.26 | 0.18 | 0.6688 |
| Error | 127403.57 | 140 | 910.03 | | |
| Corrected Total | 130952.00 | 143 | | | |

All Species Combined

| Source | Type III Sum of Squares | Degrees of Freedom | Mean Square | F | p-value |
|---|---|---|---|---|---|
| Model | 68131.47 | 3 | 22710.49 | 20.62 | <0.0001 |
| Water Temperature | 41269.75 | 1 | 41269.75 | 37.48 | <0.0001 |
| Gear Type | 634.98 | 1 | 634.98 | 0.58 | 0.4489 |
| Water Temperature x Gear Type | 11195.26 | 1 | 11195.26 | 10.17 | 0.0018† |
| Error | 154165.53 | 140 | 1101.18 | | |
| Corrected Total | 222297.00 | 143 | | | |

Table 3-6. Contingency table examining the relationship between gear type and species composition of sub-adult sharks captured in Georgia's estuaries during 2003.

| | | | Species | | | |
|---|---|---|---|---|---|---|
| | | | Atlantic Sharpnose | Bonnethead | Other | Total |
| Gear | Longline | Frequency<br>Row % | 122<br>63.21 | 28<br>14.51 | 43<br>22.28 | 193 |
| | Trawl | Frequency<br>Row % | 27<br>51.92 | 23<br>44.23 | 2<br>3.84 | 52 |
| | | Total | 149 | 51 | 45 | 245 |

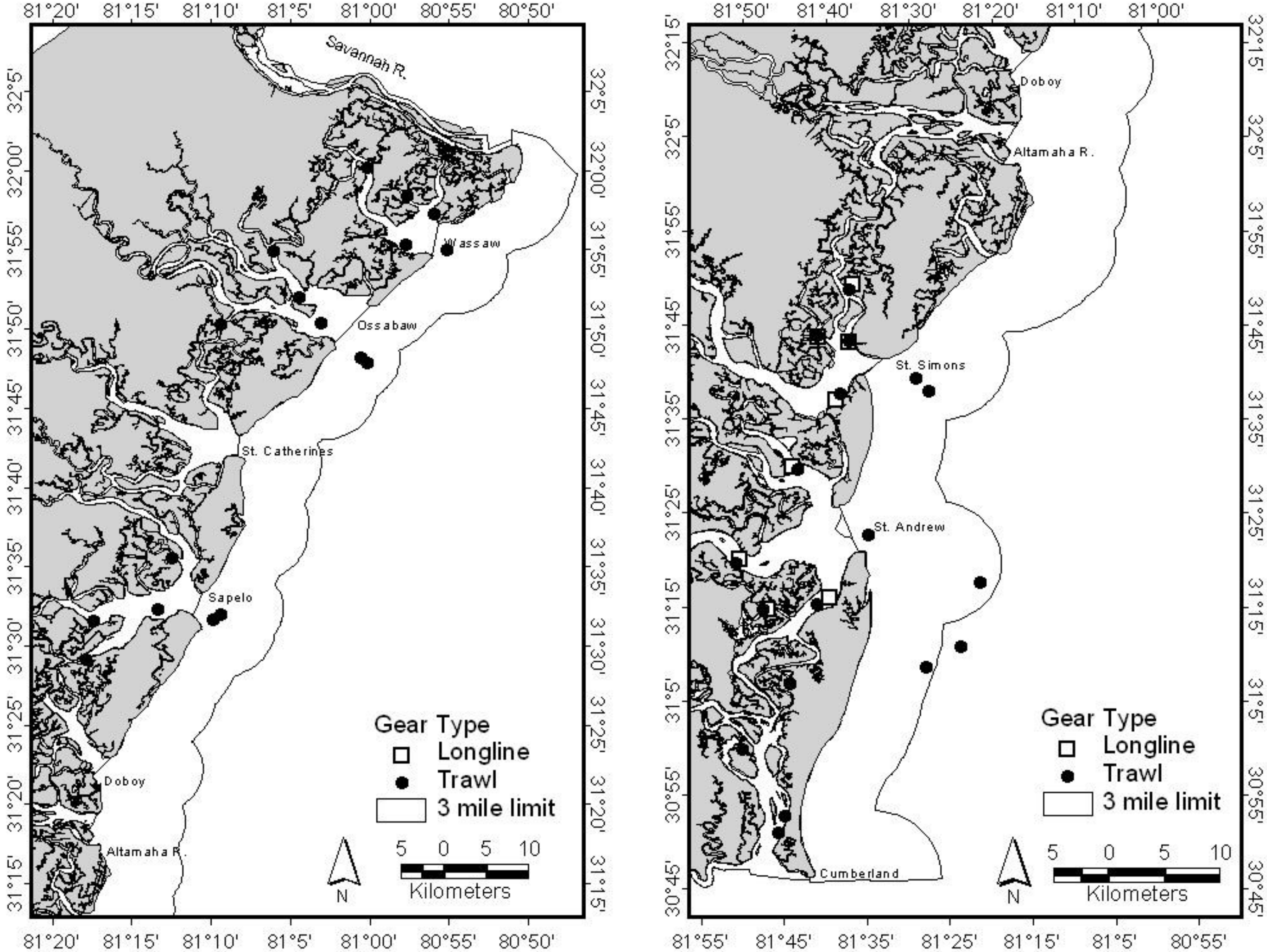
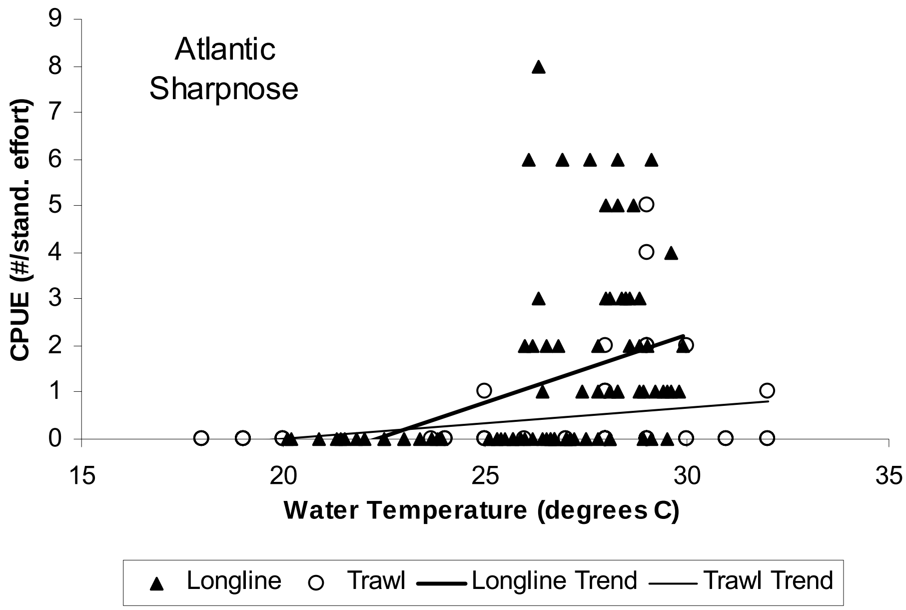



Figure 3-1. Map of trawl (filled circles) and hand-retrieved longline (open squares) stations fished in Georgia's estuaries during 2003.



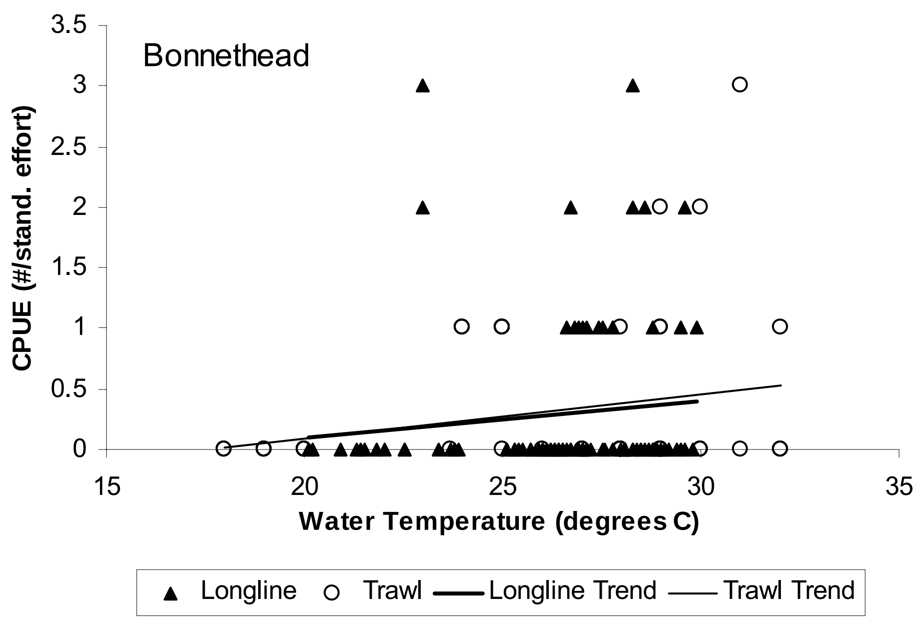




Figure 3-2. Seasonal trends (as a function of water temperature) in standardized catch rates of sub-adult sharks by species and gear type caught in Georgia's estuaries during 2003.

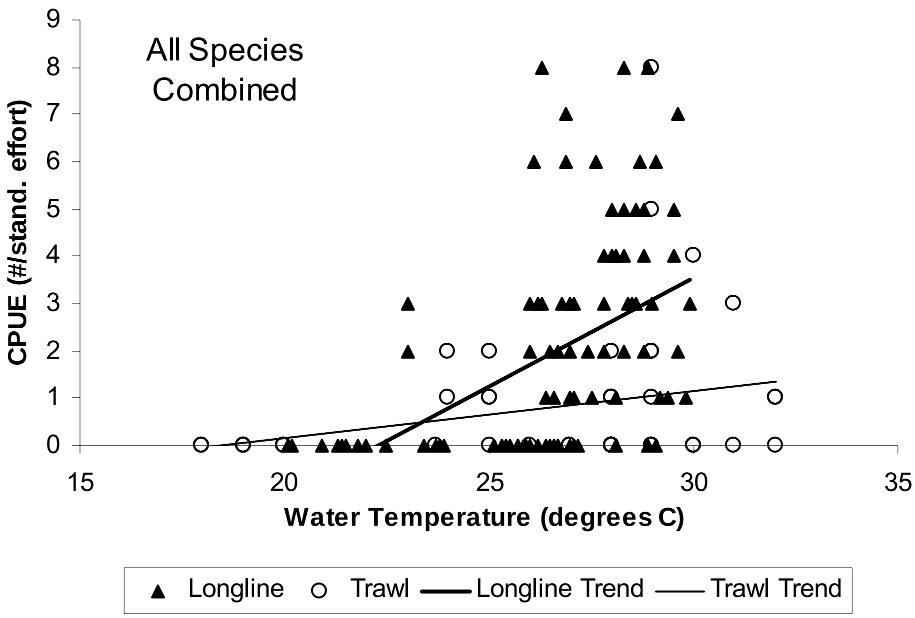



Figure 3-2. Continued.

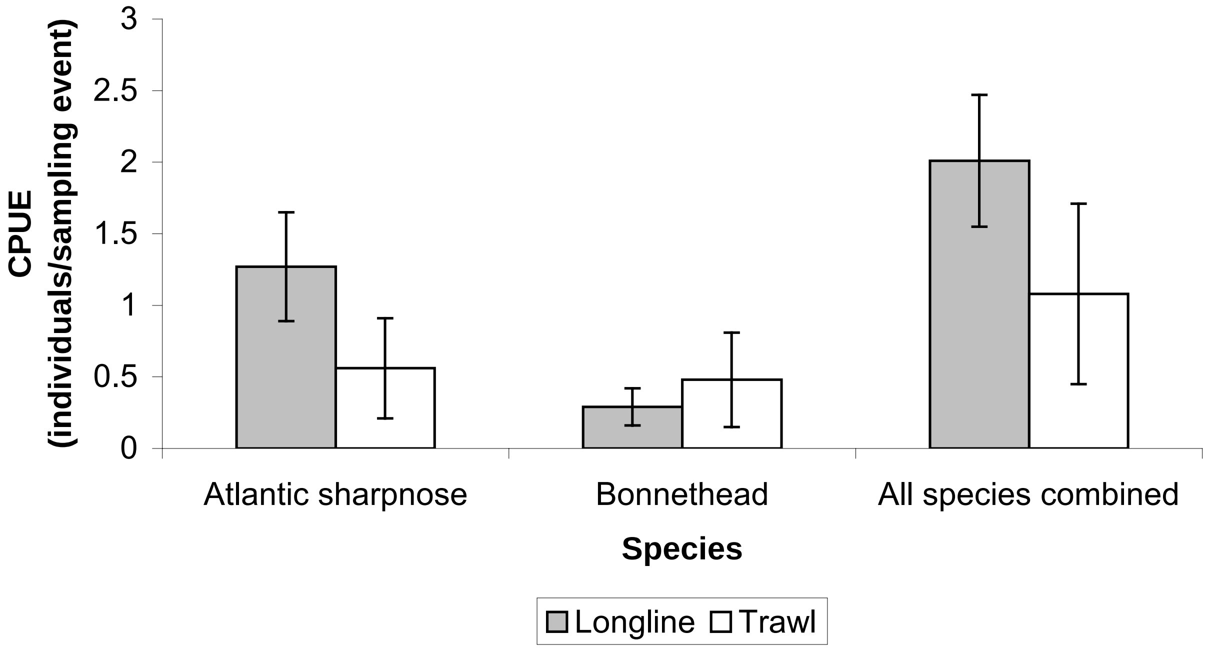
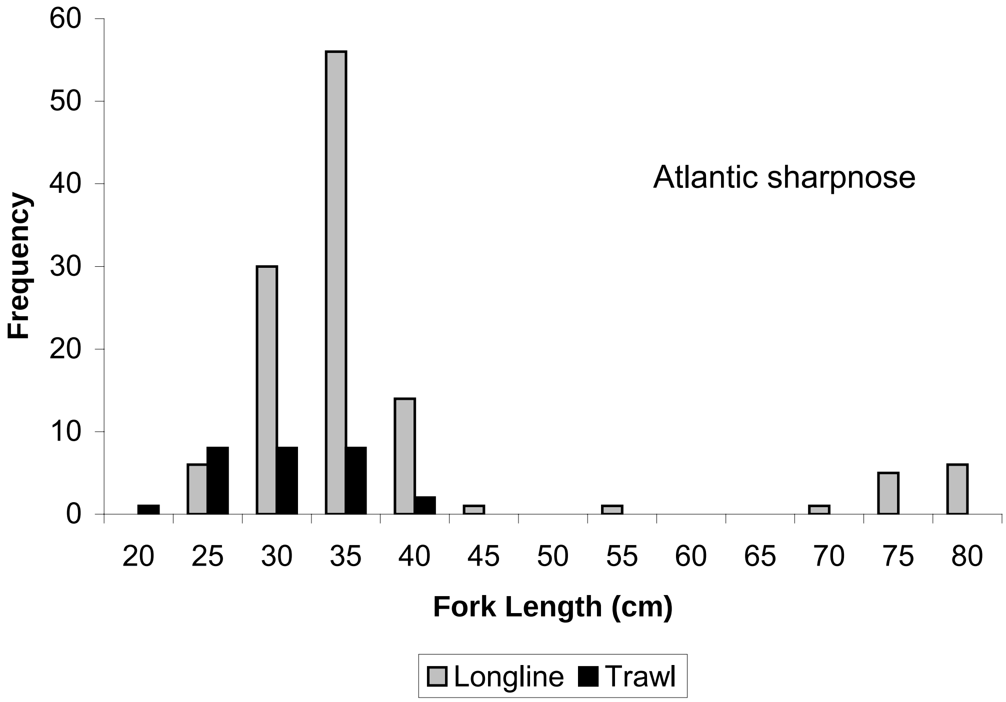



Figure 3-3. Mean catch rates by gear for sub-adult shark species encountered in Georgia estuaries during 2003. Vertical bars represent 95% confidence intervals.



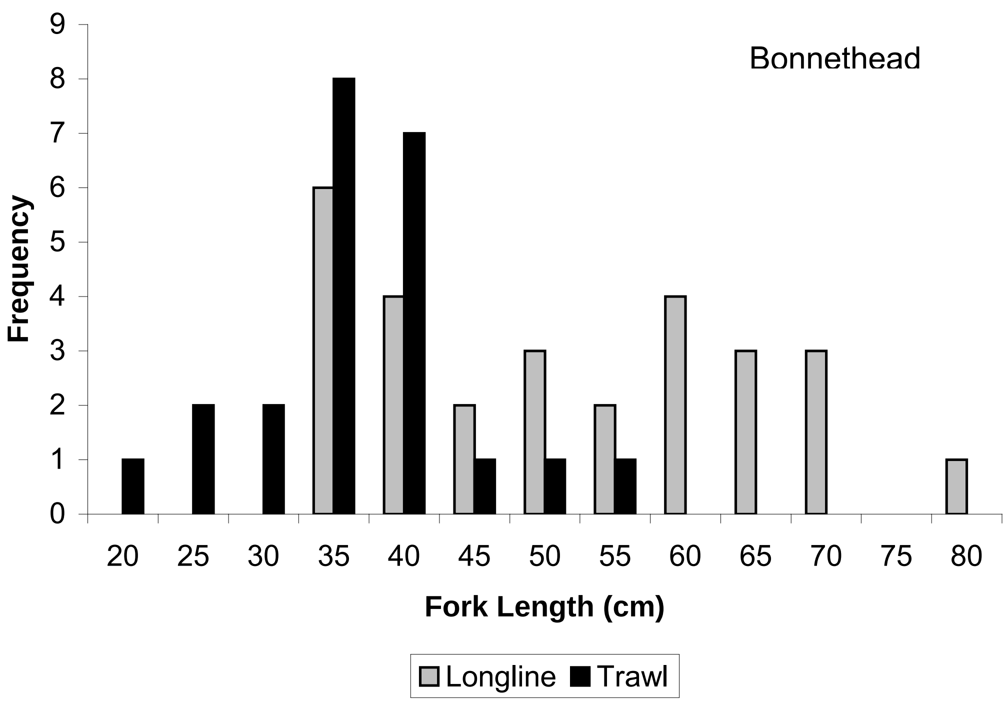




Figure 3-4. Length frequency distributions of sub-adult sharks by species and gear type caught in Georgia's estuaries during 2003.

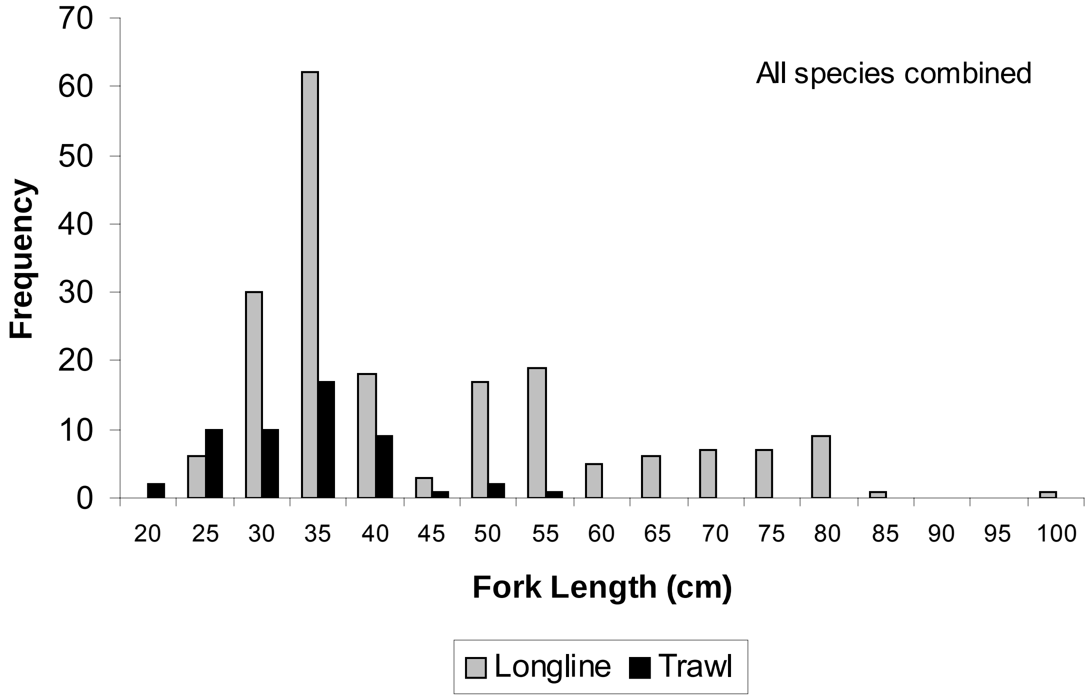



Figure 3-4. Continued.

# CHAPTER 4

## Utility of Mesohabitat Features for Determining Habitat Associations of Sub-adult Sharks in Georgia's Estuaries[1]

[1] Belcher, C. N. and C. A. Jennings. To be submitted to *Environmental Biology of Fishes.*

INTRODUCTION

The 1996 reauthorization of the Magnuson-Stevens Fishery Conservation and Management Act (MSA) through the Sustainable Fisheries Act required that all regional fishery management councils account for Essential Fish Habitat (EFH) for all species with fishery management plans (FMPs) (NMFS 1997). The definition put forth in the MSA identifies EFH as “those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity” (NMFS 2002). This requirement applies to all fisheries that fall under federal management in the Exclusive Economic Zone (EEZ; designated as the offshore zone from 3-200 nm). State waters (0-3 nm offshore) do not fall under the requirement; however, EFH for some federally managed species occur within state waters.

Although highly migratory species such as tunas, swordfish, billfishes and sharks (Appendix 1) are not managed by the councils, they are managed directly by the United States’ Secretary of the Department of Commerce (i.e., the governing agency for the National Marine Fisheries Service). As such, fishery management plans for these fisheries are required to provide information on EFH. Many coastal shark species captured in commercial operations in the EEZ have nursery grounds inside of state waters, however, very little is known about these areas.

Along the east coast of the United States and the Gulf of Mexico, nurseries have been documented in shallow bays, estuaries, and lagoon systems for a number of shark species. Multi-species nurseries have been reported off the South Carolina coast (Castro 1993; McCandless et al. 2007), in Florida’s Indian River Lagoon (Snelson and Williams 1981) and in the Gulf of Mexico (Carlson and Brusher 1999; McCandless et al.

2007). Single species nurseries that have received some intensive study include: the lemon shark nursery in the Bahamas (Morrissey and Gruber 1993), sandbar shark nurseries in areas such as the Gulf of Mexico (Carlson 1999), Chesapeake Bay (Conrath and Musick 2007; Grubbs and Musick, 2007), and Delaware Bay (Merson and Pratt 2001; Rechisky and Wetherbee 2003), the blacktip shark nursery near Tampa Bay, FL (Heupel and Heuter 2002), and the Atlantic sharpnose shark nursery in the Gulf of Mexico (Parsons and Hoffmayer 2005). To date, much of this work has focused on identifying spatial and temporal aspects of the nurseries as well as occurrence and distribution of various species.

The use of nursery areas by many shark species is influenced by both biotic and abiotic factors; however, current studies suggest biotic factors, specifically food abundance and predator avoidance, are the primary reasons for nursery use (Branstetter 1990; Castro 1993; Heupel and Heuter 2002; Simpfendorfer and Milward 1993). Although abiotic factors may have a limiting effect on nursery use, they are potentially useful for defining the physical boundaries for some nurseries (Simpfendorfer et al. 2005; Grubbs and Musick 2007). As the presence of anthropogenic factors associated with water use and coastal development increases, knowing what abiotic factors influence the distribution of fish species is becoming increasingly important.

Although the importance of certain abiotic factors (e.g., water temperature, salinity, and dissolved oxygen) has been inferred in some studies of sub-adult sharks, very few have quantitatively assessed the effects of these factors on the presence or abundance of shark species. Salinity affects the presence and number of neonate bull sharks in estuaries in southwest Florida (Simpfendorfer et al. 2005) and juvenile sandbar sharks in the Cheaspeake Bay (Grubbs and Musick 2007). Temperature affects the occurrence and number of juvenile sandbar sharks in the bays along the east shore of Virginia (Conrath and Musick 2007) and in the northeastern Gulf of Mexico (Carlson 1999), as well the presence of juvenile blacktip sharks on the west coast of Florida (Heupel and Heuter 2002) and juvenile lemon sharks in the Bahamas (Morrisey and Gruber 1993). Depth affects the distribution of both juvenile lemon sharks (Morrisey and Gruber 1993) and juvenile sandbar sharks (Grubbs and Musick 2007; Rechisky and Wetherbee 2003). Dissolved oxygen levels affect the distribution of juvenile sandbar sharks along the eastern shore of Virginia (Conrath and Musick 2007). The purpose of this study was to determine if environmental variables, specifically salinity, water temperature, dissolved oxygen, current speed, water depth, and turbidity can be used to define the habitats used by sub-adult sharks in Georgia's estuaries.

## MATERIALS AND METHODS

### *Study Area*

Georgia's coastline is approximately 161 km (100 miles) long and extends from the St. Marys River in the south (dividing GA and FL) to the Savannah River in the north (dividing GA and SC). The outer coastline is comprised of eight barrier islands that separate the mainland from the Atlantic Ocean (Johnson et al. 1974). The openings between the islands form the entrances to nine estuaries. The nine estuaries are interconnected by a maze of tidal creeks and rivers, many of which are navigable and are part of the Intra-Coastal Waterway (Figure 4-1).

Six of the nine estuaries were studied from April 15 through September 30 during 2001 and 2002. Doboy, Sapelo, St. Catherines, and Ossabaw systems were sampled in 2001; Wassaw and Cumberland were sampled in 2002. Each sound system was sampled two days during each month, with four sets made each day. Sampling areas in all estuaries were divided into sound sites (closest to the mouth) and creek/river sites in the lower reaches adjacent to the estuary. Typically, two sound sites and two river sites were sampled per day. Any deviations from this protocol were because of inclement weather.

### *Sampling Methodology*

Longline sampling was conducted under the COASTSPAN protocol established by the Apex Predator Investigation (USDOC 1997). Stations were sampled during daylight hours with a hand-retrieved longline, which consisted of 305 m of 6.4 mm braided mainline and 50 gangions. Each gangion was comprised of a longline snap attached to 50 cm of 6.4 mm braided nylon connected to 50 cm of 1.6 mm stainless steel cable with a 12/0 Mustad® circle hook with depressed barb at the end. Hooks were baited with pieces of squid, and gangions were attached to the main line at 4.5 - 6.1 m increments. The gear was set along the bottom and secured via standard Danforth® multi-purpose anchors (4.1 kg) at both ends. The mainline was marked with two fluorescent buoys (30.9 kg buoyancy rating), attached to each anchor. The longline was deployed and recovered as described in Chapter 2. Soak times varied from one hour in the first year to 30 minutes in the second year. The change in soak time was in response to increased mortality of smaller shark species (e.g., Atlantic sharpnose sharks) during the second year.

*Fish Sampling*

All sharks and bycatch collected at each sampling site were identified to species. All fishes captured were removed from the hook and returned to the water as quickly as possible to ensure maximum survival. Resuscitation was attempted on any fish exhibiting a high degree of lethargy prior to release. All sharks were sexed, measured for both fork and total lengths (FL and TL in cm, respectively), weighed (kg), and umbilical scar characteristics were recorded. All sharks capable of swimming were tagged prior to release. Sharks larger than 45 cm but smaller than 100 cm TL were tagged on the first dorsal with a National Marine Fisheries Service juvenile rototag, whereas individuals ≥100 cm TL were tagged on the dorsal surface behind the first dorsal with a National Marine Fisheries Service M-type harpoon tag prior to release.

Sharks were classified as neonates or juveniles based on the presence of an umbilical scar and the degree of healing. Umbilical sites that are open or partially healed (i.e., black or gray line is visible) are found on age-0 or neonate sharks. Well-healed scars are found on age-1 or older juveniles. Species- and sex-specific length-at-maturities presented in Castro (1983) were used to distinguish juveniles from adults. Catch data for the total and species-specific catches were highly skewed and exhibited a negative binomial distribution; therefore, catches were coded as binomial variables representing presence or absence.

*Environmental Data*

Georgia's estuaries are classified as well-mixed estuaries that demonstrate homogeneous measures of water quality between the surface and bottom of the water column (Verity et al. 2006). Five environmental variables were measured at the beginning of each set. Dissolved oxygen (mg/L), water temperature ($^{o}$C), and salinity (ppt) were measured within 1 m of the surface with a YSI® 85 meter. Current velocity (measured in ft/s; converted to m/s) also was measured within 1 m of the surface with a Marsh-McBirney® model 511 current meter. Turbidity (NTU) was measured with a Lamotte® series 2020 handheld turbidity meter. Turbidity was measured for samples collected with a Van Dorn bottle within 1 m of the bottom. Water depth (measured in ft; converted to m) was measured at the beginning and end of each set with a fathometer and a stern-mounted transducer. The average depth was calculated for use in the analyses.

Environmental data were evaluated for normality, linearity, homogeneity of variance and multicollinearity. Normality was evaluated by examining skewness and kurtosis values for each variable. When both values fell between ±1, the assumption of normality was supported (Mertler and Vannatta 2005). Linearity was evaluated qualitatively using bivariate scatterplots wherein if the shape of the cloud of data points differed from elliptical, the relationship was determined to lack linearity (Mertler and Vannatta 2005). Data transformations were applied to those variables that were non-normal or exhibited nonlinear relationships with the remaining variables. Once the data were corrected for normality and linearity, they were examined for homogeneity of variance. In the multivariate setting, homogeneity of variance is evaluated via Box's M test for equality of variance-covariance matrices (Mertler and Vannatta 2005). In the case of the canonical correlation analysis, multicollinearity was examined via the computation of the squared multiple correlation for each individual environmental variable with the remaining environmental variables. If the value is close to 1, the variable is considered strongly related to the others, thus indicating multicollinearity and redundant information among the variables (Mertler and Vannatta 2005).

Turbidity was the only environmental variable whose values were not normally distributed; these data were transformed by taking the square root of the value to correct for a moderately positive skew (Mertler and Vannatta 2005). Bivariate plots for each of the pairings of the environmental variables in the model, including the transformed turbidity, indicated that linearity was present among the variables. The assumptions of homogeneity of variance and absence of mutlicollinearity were supported. Mahalanobis distances for environmental data were calculated for all longline sets prior to analysis to determine the presence of multivariate outliers (Tabachnick and Fidell 1996). Multivariate outliers were not detected.

Two multivariate analyses were used to analyze the data from this study. Canonical correlation analysis was used to describe the association between the water chemistry, depth and current velocity and the presence/absence of common shark species. Canonical correlation analysis is akin to multiple regression analysis, except that more than one dependent variable is predicted (Tabachnick and Fidell 1996). Canonical variates, similar to those produced in principal component analysis, are produced for each dataset, with the additional caveat that the resulting variates are strongly correlated with each other (Manly 2005). Canonical redundancy analysis also was applied to determine how much variance the canonical variates from the environmental set extract from the species presence/absence set.

Discriminant analyses were conducted for each individual species included in the canonical correlation analysis to determine how well water chemistry, depth and current speed determine the presence of each of those species. An additional discriminant analysis was conducted to determine if the environmental variables could be used to determine the presence of sub-adult sharks in general. The significant discriminant functions were cross-validated to determine the adequacy of the functions for correctly classifying the sample data (Tabachnick and Fidell 1996). Analyses were conducted with SAS 9.1 (SAS Institute 2002) and were evaluated at $\alpha = 0.05$. Variable importance in the canonical correlation analysis and the discriminant analyses was evaluated by examining the corresponding correlations within the resulting functions. Based on criteria presented in Tabachnick and Fidell (1996), only variables with correlations above 0.45 were considered significant and were included as predictor variables for each function.

## RESULTS

A total of 415 sub-adult sharks representing nine species was captured during 231 longline sets (Table 4-1). The four most abundant species, which represented a combined 96.1% of the total number caught, were Atlantic sharpnose shark *(Rhizoprionodon terranovae)*, bonnethead shark *(Sphyrna tiburo)*, blacktip shark *(Carcharhinus limbatus)* and sandbar shark *(C. plumbeus)* (Table 4-1). Atlantic sharpnose shark was the most frequently captured species and was caught at approximately 52% of the sampling sites. The other three species were captured at less than 20% of the sites (Table 4-1). The total number of sub-adults caught per site ranged from 0 to 16 (mean = 2, SD = 2.2) and the number of species captured per site ranged from 0 to 4 (mean = 1, SD = 0.84). Because of low capture rates (<5% of total catch; Table 4-1) the additional species encountered (i.e., scalloped hammerhead shark (*S. lewini*), lemon shark (*Negaprion brevirostris)*, finetooth shark *(C. isodon)*, bull shark *(C. leucas)*, and spinner shark *(C. brevipinna)*) were not included in the canonical correlation analysis; however, they were included in the discriminant analysis examining the effects of the environmental variables on the presence or absence on the aggregate catch of sub-adult sharks. The mean values and 95% confidence intervals for each of the environmental variables are presented in Table 4-2.

*Canonical Correlation Analysis*---

The canonical correlation analysis of the four most common species and environmental variables indicated that 87.6% of the variance was explained by the first two canonical correlations (Table 4-3). Although significant, neither of the two canonical correlations represented a substantial relationship between the pairs. The percent of variation explained between the first pair of variates was 18.71%, with 13.27% explained between the second pair of variates (Table 4-3).

The first canonical variate calculated for the species data was positively correlated with the presence of bonnethead sharks and negatively correlated with the presence of sandbar sharks (Table 4-4). The first canonical variate calculated for the environmental data was negatively correlated with depth (Table 4-4). Taken as a pair, these variates indicated that the presence of bonnethead sharks correlates negatively with water depth, suggesting bonnetheads are found in shallower waters. The same pair of variates indicated sandbar sharks are positively correlated with water depth, suggesting that they are present in deeper waters. The second canonical variate calculated for the species data was positively correlated with the presence of both bonnethead and sandbar sharks (Table 4-4). The second canonical variate calculated for the environmental data was positively correlated with salinity and negatively correlated with dissolved oxygen levels (Table 4-4). This pair of variates indicates the presence of both bonnethead and sandbar sharks is positively correlated with salinity and negatively correlated with dissolved oxygen levels. These results suggest that those stations where both sandbar and bonnethead sharks occur are influenced by higher salinity and lower dissolved oxygen levels. The results of the redundancy analysis indicated that the two environmental variates account for only 8.3% of the total variation in the species presence dataset.

Discriminant Analyses ---

Five independent discriminant analyses were performed with the environmental variables as predictors of presence and absence for the four commonly encountered species and for the aggregate catch of sub-adult sharks. Two of the five analyses yielded significant discriminant functions. Similar to the results of the canonical correlation analysis, the presence of sandbar sharks ($\Lambda = 0.842$, $\chi^2_{(6,\, n = 153)} = 25.374$, $p < 0.0001$) and bonnethead sharks ($\Lambda = 0.852$, $\chi^2_{(6,\, n = 153)} = 23.772$, $p = 0.001$) were correlated with environmental variables; whereas, the presence of sub-adult sharks ($\Lambda =$

0.923, $\chi^2_{(6, n = 153)}$ = 11.813, p = 0.066), Atlantic sharpnose sharks ($\Lambda$ = 0.947, $\chi^2_{(6, n = 153)}$ = 8.113, p = 0.230) and blacktip sharks ($\Lambda$ = 0.969, $\chi^2_{(6, n = 153)}$ = 4.634, p = 0.592) were independent of the environmental variables examined.

The discriminant function generated for the presence of sub-adult bonnethead sharks accounted for 14.82% of the function variance. Standardized function coefficients and correlation coefficients indicated that transformed turbidity and salinity were most associated with the presence of this species (Table 4-5). Stations where bonnethead sharks were present had lower turbidities (mean = 16.3 NTU) and higher salinities (mean = 32.03 ppt) than stations where they were absent (mean turbidity = 24.7 NTU and mean salinity = 30.9 ppt). Original classification results showed that 96.7% of the stations where bonnethead sharks were absent were correctly classified, whereas only 15.6% of the stations where bonnethead sharks were present were correctly classified. For the overall sample, 79.7% of presence/absence determinations were correctly classified. Cross-validation derived similar accuracy for the overall sample, with a correct classification rate of 79.1%.

The discriminant function generated for the presence of sub-adult sandbar sharks accounted for 15.76% of the function variance. Standardized function coefficients and correlation coefficients indicated that transformed turbidity, depth, and dissolved oxygen were most associated with the function (Table 4-5). Stations where sandbar sharks were present had higher turbidities (mean = 34.2 NTU), were deeper (mean = 7.28 m), and had lower dissolved oxygen levels (4.34 mg/L) than stations where they were absent (mean turbidity = 21.6 NTU, mean depth = 5.33 m, and mean dissolved oxygen = 4.95 mg/L). Original classification results showed that 100% of the stations where sandbars were absent were correctly classified, whereas only 12.5% of the stations where sandbar sharks were present were correctly classified. For the overall sample, 90.8% were correctly classified. Cross-validation derived similar accuracy for the overall sample, with a correct classification rate of 88.9%.

## DISCUSSION

Canonical correlation analysis provided a synoptic view of the suite of shark species that utilize Georgia's estuaries and what environmental variables affect that assemblage. Only bonnethead and sandbar sharks were affected by environmental variables. Generally, the two species were separated by depth preference, with sandbar sharks found in deeper water than the bonnethead sharks; however, when the two species co-occurred, they were found in areas characterized by higher salinity and lower dissolved oxygen levels. In Georgia's estuaries, bonnethead sharks occurred commonly in small marsh creeks or feeder creeks that are surrounded by marsh grass, or along the shallows where they can be seen feeding on low tide, whereas sandbar sharks frequented larger creeks and the open areas of the lower sound.

Similar patterns of habitat use for bonnethead sharks and sandbar sharks have been reported in other areas. For example, bonnethead sharks frequented shallow water areas near seagrass beds in Charlotte Harbor, FL (Heupel et al. 2006). Heupel et al. (2006) also documented that bonnethead sharks tend to be localized residents within an estuary; however, attachment to specific sites within a given estuary was not observed. Further catch rates of both neonate and small juvenile sandbars found along the eastern shore of Virginia were correlated with sites located farther from the inlet and with warmer temperatures and lower dissolved oxygen levels (Conrath and Musick 2007). In another example, neonate and juvenile sandbars in Chesapeake Bay were most abundant in areas of salinity greater than 20.5 g/L and in depths greater than 5.5m (Grubbs and Musick 2007).

The results of the canonical correlation analysis also suggest that neither Atlantic sharpnose shark nor blacktip shark presence was influenced by any of the environmental variables investigated. Similar results were found for immature Atlantic sharpnose sharks in the Gulf of Mexico (Parsons and Hoffmayer 2005) and juvenile blacktip sharks on the west coast of Florida (Heupel and Hueter 2002). Heupel and Heuter (2002) also suggested that water temperature could be a migratory cue for blacktip sharks, indicating that temperature acts more on a temporal scale than a spatial one.

Although the canonical correlation was able to account for some of the variability in presence and absence of shark species found in Georgia's estuaries, the amount of variation explained was minimal at best. Redundancy analysis indicated that less than 10% of the variation in the species set was explained by the environmental variables examined during this study.

Whereas the discriminant analysis is a special case of the canonical correlation analysis (Tabachnick and Fidell 1996), it allows for a species-specific examination of how the environmental data affect an individual species, minus any interspecies relationships. Additionally, the discriminant analysis was able to examine the effects of habitat variables on the presence/absence of sub-adult sharks in general.

The results of the discriminant analyses applied to the presence/absence data of the four common species support the general conclusions of the canonical correlation analysis and provide insight into the relative importance of those environmental variables for each species. Although salinity, average water depth and dissolved oxygen were able to define how two co-existent species partition habitat use, the influence of these variables at the species level differs. With the species interactions removed, average depth and dissolved oxygen defined the presence of sandbar sharks; whereas, salinity defined the presence of bonnethead sharks. Areas where sandbar sharks were present had deeper depth and lower dissolved oxygen. Similar results were found in Grubbs and Musick (2007) and Conrath and Musick (2007). Salinities were higher in areas where bonnethead sharks occurred. Generalized habitat use for bonnethead sharks suggests that they use shallow coastal areas and estuaries (Castro 1983; Compagno 1984), which are areas characterized by high salinities.

Turbidity, though not identified in the canonical correlation analysis, was an additional environmental variable that was correlated with the presence of both sandbar and bonnethead sharks. Sandbar sharks were present in areas with higher turbidity, whereas bonnethead sharks were found in areas of lower turbidity. Because of Georgia’s high tide amplitude, the estuaries usually are well mixed (Johnson et al. 1974). Why these species exhibit their respective turbidity preferences is unknown, but it could be a function of more general habitat preferences. Sandbar sharks are found over sandy or muddy bottoms in the mouths of river systems and bays (Campagno 1984), whereas bonnethead sharks have been documented frequenting shallow waters, sometimes in conjunction with seagrass beds (Heupel et al. 2006).

The results of the discriminant analysis for the aggregation of shark species (inclusive of all encountered species) indicated that the environmental variables examined during this study do not have a strong influence on the presence of sub-adult sharks. This result is useful and important when trying to determine the potential physical boundaries for a multi-species nursery. If overall species presence was affected by variables with a largely spatial component (e.g., salinity or depth), then defining species specific nursery areas would be lead to improved definition of essential fish habitats (e.g., nursery area), as was demonstrated for sandbar sharks in Chesapeake Bay (Grubbs and Musick 2007) and for bull sharks off the western coast of Florida (Simpfendorfer et al. 2005).

Although mesohabitat features may be too fine a scale for analyzing habitat associations for sub-adult sharks, examination of macrohabitat may provide stronger associations for habitat use. Other studies have found relationships between specific macrohabitat types and life history stages for a variety of shark species. For example, older juveniles and adults frequented around seagrass beds in a Florida estuary (Heupel et al. 2006). Similarly, small juvenile nurse sharks used coral patch reefs on the edge of a lagoon, channel edges, and mangrove roots as shelter in the Dry Tortugas; larger juveniles and adults preferred octocoral (i.e., soft corals composed of polyps that have eight tentacles) hard bottom areas, which have more exposure to waves and currents than the other habitats (Pratt and Carrier 2007). Lemon sharks in the Bahamas prefer shallow waters over rocky or sandy substrate, possibly to avoid predators (Morrissey and Gruber 1993). Georgia has very few unique habitat types in its inshore waters, yet there are many hydrologic and geologic characteristics that could provide similar forms of refuge/protection. Future research should include the identification of macrohabitat features (e.g., intertidal oyster reefs, in channel and off channel sites, bank characteristics, across-creek gradient) either through empirical methods or through the use of GIS analyses.

Biotic factors such as predator avoidance and prey availability may have a stronger effect than abiotic factors on the presence and abundance of sub-adult sharks (Branstetter 1990; Castro 1993; Simpfendorfer and Milward 1993). Other studies that have examined the effects of abiotic factors on the presence and abundance of sub-adult sharks have concluded that biotic factors have a stronger effect than environmental ones (Conrath and Musick 2007; Heupel and Heuter 2002). Further research is needed to understand how prey density and the presence of predators, specifically larger sharks, affect habitat use for sub-adult sharks.

## CONCLUSIONS

Mesohabitat characteristics were not good indicators of the habitat used by sub-adult sharks found in Georgia’s estuaries. Although they do provide an indication of where sub-adult sharks are not found, other factors could have a stronger influence than water quality in determining where these fishes were found. Given that many species of shark are apex predators and highly migratory in nature, habitat preferences may not be as critical as the need to find food or avoid predators for these fishes. However, the addition of empirical data or GIS analyses on existing datasets is needed to determine if macrohabitat features (e.g., hydrographic and geological features, bottom type, bottom relief) could provide better explanations of habitat use.

The difficulty experienced defining EFH for sharks in Georgia estuaries suggest that shark nurseries, especially multi-species nurseries, may be better managed as Habitat Areas of Particular Concern (HAPC). HAPCs are subsets of EFH and are areas that serve extremely important ecological functions or are especially vulnerable to degradation (NMFS 2002). This designation can be based on one or more of the following criteria: importance of the ecological function provided by the area, extent to which the area is sensitive to human induced environmental degradation, rarity of a particular habitat type, whether, and to what extent, development activities are, or will be, stressing to the habitat (NMFS 2002). HAPC designation is used as means to prioritize conservation efforts and does not provide additional protection or restriction on a given area (NMFs 2002). Both Chesapeake Bay and Delaware Bay have been designated HAPCs for sandbar sharks, as they are considered the primary nursery grounds for this species (Conrath and Musick 2007). Georgia's estuaries fits the HAPC criteria because they provide an important ecological role for at least four species of shark and because of the potential negative effects to these areas caused by human activities, including dredging of shipping channels and waterways, as well as coastal development.

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Table 4-1. Numbers, frequencies of occurrence and encounter rates for sub-adult shark species captured on longlines in Georgia's estuaries during April through September 2001 and 2002.

| Species | Number Caught | Percent of total catch | Encounter rate* (%) |
|---|---|---|---|
| Atlantic sharpnose | | | |
| *Rhizoprionodon terraenovae* | 305 | 73.49 | 52.4 |
| Bonnethead | | | |
| *Sphyrna tiburo* | 62 | 14.81 | 18.2 |
| Blacktip | | | |
| *Carcharhinus limbatus* | 16 | 3.88 | 6.5 |
| Sandbar | | | |
| *C. plumbeus* | 16 | 3.88 | 6.9 |
| Scalloped Hammerhead | | | |
| *S. lewini* | 7 | 1.70 | 2.6 |
| Finetooth | | | |
| *C. isodon* | 5 | 1.21 | 1.7 |
| Spinner | | | |
| *C. brevipinna* | 2 | 0.49 | 0.9 |
| Bull | | | |
| *C. leucas* | 1 | 0.24 | 0.4 |
| Lemon | | | |
| *Negaprion brevirostris* | 1 | 0.24 | 0.4 |
| Overall | | | 66.7 |

* - Calculated as the number of positive stations divided by the total number of stations sampled (n = 231).

Table 4-2. Mean values and 95% confidence intervals for environmental variables measured at sites where sub-adult sharks were collected.

| Species | | Salinity (ppt) | Water Temperature (degrees C) | Dissolved Oxygen (mg/l) | Turbidity (NTU) | Current Speed (m/s) | Depth (m) |
|---|---|---|---|---|---|---|---|
| Atlantic sharpnose shark | Mean | 31.21 | 28.39 | 4.93 | 21.1 | 0.27 | 5.4 |
| | 95% LCL | 25.73 | 25.01 | 3.70 | 0.7 | 0.00 | 1.6 |
| | 95% UCL | 36.69 | 31.76 | 6.16 | 69.3 | 0.62 | 9.1 |
| Bonnethead | Mean | 32.03 | 28.76 | 4.77 | 16.3 | 0.24 | 5.2 |
| | 95% LCL | 28.43 | 26.57 | 3.61 | 2.5 | 0.00 | 1.2 |
| | 95% UCL | 35.63 | 30.95 | 5.93 | 42.1 | 0.49 | 9.2 |
| Blacktip shark | Mean | 30.70 | 29.10 | 4.82 | 25.7 | 0.28 | 5.9 |
| | 95% LCL | 27.85 | 27.54 | 3.56 | 3.0 | 0.00 | 0.5 |
| | 95% UCL | 33.55 | 30.66 | 6.07 | 70.6 | 0.69 | 11.4 |
| Sandbar shark | Mean | 30.09 | 28.73 | 4.34 | 34.2 | 0.30 | 7.3 |
| | 95% LCL | 24.70 | 25.50 | 3.16 | 3.0 | 0.00 | 3.7 |
| | 95% UCL | 35.49 | 31.95 | 5.53 | 99.5 | 0.64 | 10.8 |
| All species | Mean | 31.23 | 28.45 | 4.84 | 22.3 | 0.27 | 5.6 |
| | 95% LCL | 26.10 | 25.29 | 3.56 | 1.4 | 0.00 | 1.6 |
| | 95% UCL | 36.36 | 31.62 | 6.12 | 67.9 | 0.63 | 9.6 |

Table 4-3. Canonical variate results and significance associated with the canonicial correlation analysis conducted to examine the relationship between sub-adult shark species and their corresponding environmental variables in Georgia estuaries.

| Canonical Variate | Eigenvalue | Proportion | Cumulative | Squared Canonical Correlation | Significance (p-value) |
|---|---|---|---|---|---|
| 1 | 0.2301 | 0.5258 | 0.526 | 0.1871 | <0.0001 |
| 2 | 0.1531 | 0.3499 | 0.876 | 0.1327 | 0.0179 |
| 3 | 0.0531 | 0.1214 | 0.997 | 0.0505 | 0.4566 |
| 4 | 0.0012 | 0.0029 | 1.000 | 0.0012 | 0.9803 |

Table 4-4. Factor loadings, amount of explained variance and redundancy values for the canonical variates examining the relationship between shark species (sub-adults) and associated environmental variables in Georgia estuaries. Bolded values indicate variables that were considered for interpretation based on a ±0.45 cutoff.

| | | First Canonical Variate | | Second Canonical Variate | | |
|---|---|---|---|---|---|---|
| | | Correlation | Coefficient | Correlation | | Coefficient |
| *Species Set* | | | | | | |
| Atlantic sharpnose shark | | 0.271 | 0.542 | 0.044 | | 0.087 |
| Bonnethead shark | | **0.585** | 1.434 | **0.770** | | 1.886 |
| Blacktip shark | | 0.021 | 0.087 | 0.241 | | 1.020 |
| Sandbar shark | | **-0.684** | -2.228 | **0.682** | | 2.223 |
| | Percent of variance | 0.285 | | 0.225 | Total = | 0.510 |
| | Redundancy | 0.053 | | 0.030 | Total = | 0.083 |
| *Environmental Set* | | | | | | |
| Salinity (ppt) | | 0.425 | 0.173 | **0.477** | | 0.195 |
| Water temperature (°C) | | 0.437 | 0.243 | 0.354 | | 0.197 |
| Dissolved Oxygen (mg/l) | | 0.173 | 0.261 | **-0.668** | | -1.010 |
| Average Depth (m) | | **-0.559** | -0.299 | 0.355 | | 0.190 |
| Current Speed (m/s) | | -0.046 | -0.238 | -0.269 | | -1.389 |
| Transformed Turbidity | | 0.229 | -0.227 | -0.192 | | -0.104 |
| | Percent of variance | 0.223 | | 0.212 | Total = | 0.434 |
| | Redundancy | 0.042 | | 0.028 | Total = | 0.070 |
| Canonical correlation | | 0.433 | | 0.364 | | |

Table 4-5. Discriminant function factor loadings associated with significant relationships between presence data and environmental variables for sub-adult sharks in Georgia's estuaries. Bolded values indicate variables included for interpretation.

| | Correlation Coefficients with Discriminant Function | Standardized Function Coefficients |
|---|---|---|
| Current Speed | 0.277 | 0.183 |
| Average Depth | 0.214 | 0.216 |
| Salinity | **-0.454** | -0.736 |
| Dissolved Oxygen | 0.222 | 0.546 |
| Turbidity | **0.503** | 0.555 |
| Water Temperature | -0.439 | -0.384 |

(b) Bonnethead shark

| | Correlation Coefficients with Discriminant Function | Standardized Function Coefficients |
|---|---|---|
| Current Speed | 0.053 | -0.148 |
| Average Depth | **0.779** | 0.688 |
| Salinity | -0.344 | -0.096 |
| Dissolved Oxygen | **-0.683** | -0.524 |
| Turbidity | **0.471** | 0.255 |
| Water Temperature | 0.263 | -0.148 |

(c) Sandbar shark

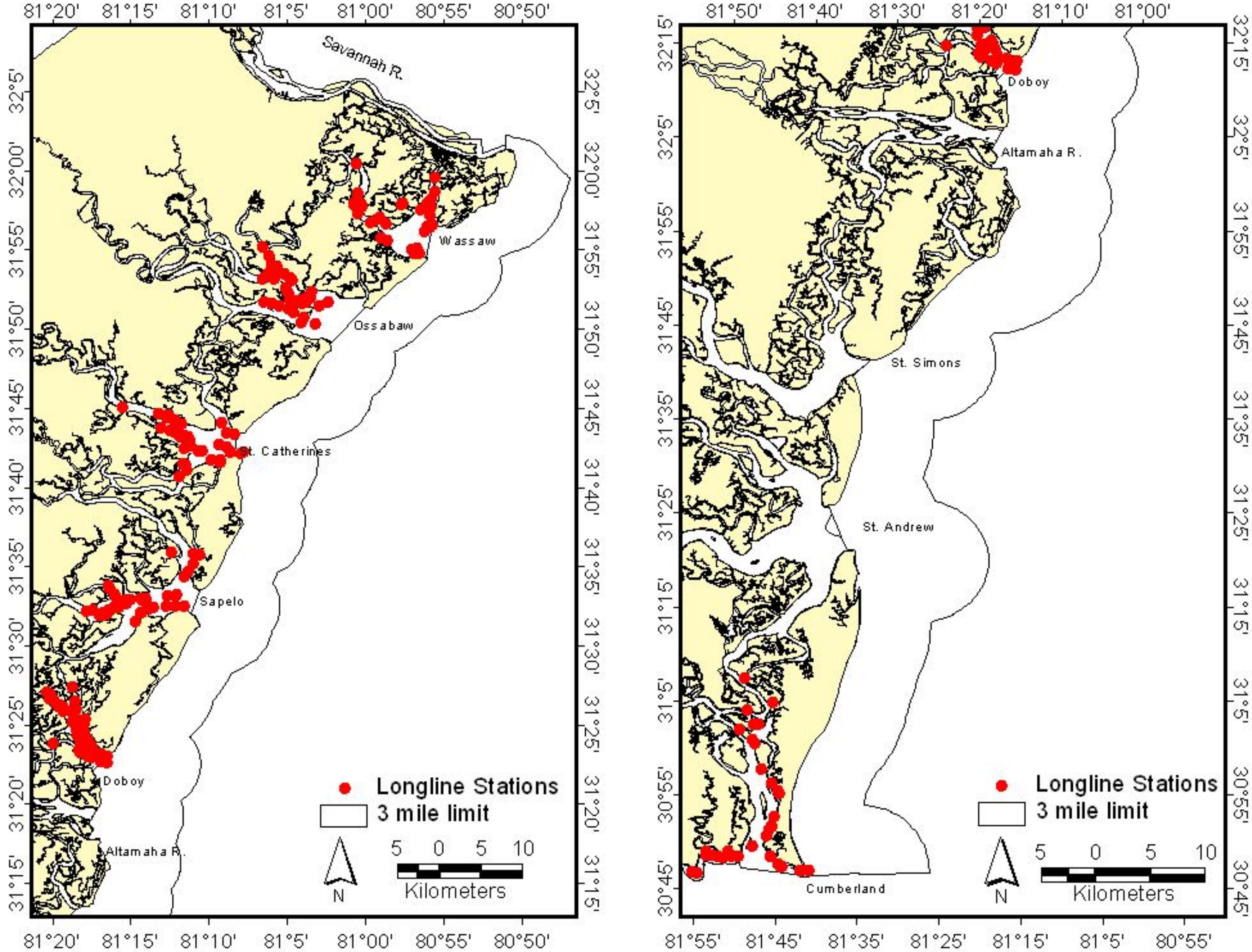


Figure 4-1. Map of study area and longline stations fished in Georgia's estuaries during 2001-2002.

# CHAPTER 5

## Identification and evaluation of sub-adult shark bycatch in Georgia's commercial trawl fisheries[1]

[1] Belcher, C. N. and C. A. Jennings. To be submitted to *Marine and Freshwater Research*.

INTRODUCTION

Bycatch associated with commercial fisheries in the United States has become a growing concern for fisheries management since the 1980s (Alverson et al. 1994). The 2007 Magnuson-Stevens Fishery Conservation Act defines by-catch as ”fish which are harvested in a fishery, but which are not sold or kept for personal use, and includes economic discards and regulatory discards” (NMFS 2007). However, the general public and many conservation groups consider bycatch a source of unnecessary mortality of vulnerable resources or endangered species such as marine mammals (e.g., dolphins in the tuna seine fishery) and sea turtles (e.g., in the shrimp trawl and pelagic longline fisheries) (Alverson et al. 1994).

In the southeastern Atlantic off the U. S. and in the Gulf of Mexico, the shrimp trawl fishery has the highest ratio of bycatch-to-target species, with 10.30 kg of bycatch to 1 kg of shrimp in the Gulf and 8.00 kg of bycatch to 1 kg of shrimp in the southeast (Alverson et al. 1994). Since the late 1980’s, bycatch has become a key management issue facing this fishery (Diamond 2003). In 1989, the National Marine Fisheries Service (NMFS) required trawlers in the South Atlantic and the Gulf of Mexico to use Turtle Excluder Devices (TEDs) to reduce associated mortalities of sea turtles encountered during fishing operations. Bycatch Reduction Devices (BRDs) were required in the late 1990s by NMFS to reduce the amount of finfish bycatch, more specifically overfished species such as red snapper (*Lutjanus campechanus)* in the Gulf of Mexico (GMFMC 1997), and weakfish (*Cynoscion regalis*) and Spanish mackerel (*Scomberomorus maculatus*) in the southeastern U.S (SAFMC 1996).

Sharks are particularly vulnerable to overfishing because of their K-selected life history traits (Stevens et al. 2000). Most shark species demonstrate slow growth and late sexual maturity, produce few offspring, have long life spans, and exhibit a close relationship between the size of the adult breeding stock and the number of recruits produced (Camhi 1998; Stevens et al. 2000). Some of the U.S. populations of sharks have declined by as much as 85% since the late 1970's (Camhi 1998). Generally, these declines are attributed to directed fishing pressure from commercial and recreational fisheries, which have been managed under a federal fisheries management plan since 1993 (NMFS 1993); however, indirect effects from other fisheries that encounter sharks as bycatch also play a role (Barker and Schluessel 2005).

Georgia is one of few U.S. states that do not have a directed commercial fishery for sharks in their coastal waters, as gillnets and longlines are not considered lawful gears in Georgia's marine waters (OCGA § 27-4-113). Recreational fisheries encounter sharks quite frequently during the summer months, which corresponds with the height of the pupping season for many species of sharks (C. Belcher, unpublished data). Recreational catches of sharks in Georgia are managed by species groupings, as well as with size and catch limits (GADNR Board Rule 391-2-4-.04). Much of the recreational fishing effort occurs in Georgia's inshore and nearshore waters, which are areas used as nursery areas by a variety of shark species (Gurshin 1997; C. Belcher, unpublished data). Minimum size limits in the recreational fishery help reduce the effects of mortality for sub-adult sharks. Incidental catch in the commercial shrimp trawl fishery has been identified as a large source of sub-adult shark mortality (Camhi 1998; Shepherd and Myers 2005).

Georgia's penaeid shrimp fishery is the most economically important fishery in the state and ranks second in weight behind the blue crab (*Callinectes sapidus*) fishery (Califf 2007). The fishery operates in state and federal waters throughout much of the year; however, in state marine waters the trawl fishery is restricted to those waters outside of the sound/beach boundary (Belcher and Jennings 2004). In this paper, I describe the temporal distribution and catch composition of sharks taken as bycatch in the Georgia shrimp trawl fishery. I also examine the effects of net type, TEDs and BRDs on the number of sharks captured, as well as the effects of tow time and tow speed on the capture rates of sharks. Based on my results and an assessment of current regulations applied to the shrimp trawl fishery, I suggest potential management approaches that could help reduce the amount of shark bycatch, with minimal effects to the fishery.

## MATERIALS AND METHODS

Bycatch data were collected monthly during the shrimp trawling season in Georgia's state waters and adjacent federal waters. All months except February and March were sampled between April 1995 and March 1998. The commercial shrimp trawl season generally occurs in state waters from mid-May to the end of December; however, the season opening has occurred as late as the end of June (Page 2008). The Georgia Department of Natural Resources (GADNR) can extend the season through the end of February, if shrimp size and quantity remain sufficient (Belcher and Jennings 2004). Federal waters are open year-round to commercial shrimp trawling, which allows for continued fishing once state waters are closed (Belcher and Jennings 2004).

Bycatch information was recorded by observers on board commercial shrimp trawlers fishing in both state and federal waters. Initially, sampling was focused coastwide; however, reduced cooperation from some trawler captains during the latter portion of the study limited sampling to waters off the central part of Georgia coast (Figure 5-1).

The commercial shrimp trawlers that participated during this project were characterized by the following: vessel lengths from 9.8 to 26.7 m, and engine size ranging from 240 to 1,000 horsepower. Net size, measured by the length of the headrope, ranged from 10.6 to 22.4 m. Mesh size of the codend of the trawl was 41 mm stretched mesh. Tow speeds ranged from 1.5 to 4.5 knots, and either 2 or 4 (mode = 4) nets were towed. All commercial trawlers used turtle excluder devices (TEDs) in their nets as mandated by the National Marine Fisheries Service; however, bycatch reduction devices (BRDs) were not mandated until late 1996. As a result, some of the trawls sampled were not configured with BRDs.

Three types of nets (i.e., flat, mongoose, and triple wing) are commonly used in the commercial shrimp trawl fishery. Nets were characterized by the presence of “bibs” (i.e., an extension in the middle of the leading edge of the net; Harrington et al. 1988). A flat net has been used by the shrimp fishery since the early 1900’s and is characterized by the absence of a bib (Harrington et al. 1988). This net type was used in 17% of the trawls observed during this study. The mongoose net has a single bib on the upper part of the net and is the most commonly used net in the southeastern U. S.

(Harrington et al. 1988). The mongoose net was used in 77% of the trawls observed during this study. The triple wing is similar to the mongoose net, but has an additional tongue on the bottom edge of the net (Harrington et al. 1988). The triple wing nets comprised 6% of the trawls sampled.

TEDs used by the commercial trawl fishery during this study were either hard grids or a large ramp of soft mesh. There were two types of hard TEDs, both of which excluded turtles downward or under the net, but differed in the angle of the bars. The Georgia Jumper has an oval face with straight bars, whereas the Super Shooter has an oval face with angled bars. More of the boats in the study were fitted with the two hard TEDs compared to the soft TED. The Super Shooter was the most common (74% of observed trawls) followed by the GA Jumper (19%). All nets observed were configured with TEDs; however, BRDs were not required during the first year of the study. Nets configured without BRDs represented 56% of the trawls observed. BRDs were categorized by both design and dimension. A large mesh funnel BRD placed behind the TED was present in 8% of the trawls sampled. A fish eye design was present in 36% of the trawls; the most common sizes were the 12” x 5” fish eye (17%) and the 9” x 4.5” NC diamond fish eye (13%).

Onboard bycatch data collection was conducted under the Shrimp Trawl Bycatch Characterization Sampling Protocol (NMFS 1992), which was designed to characterize the complete species composition of bycatch associated with the shrimp trawl fishery. Data recorded for each trip included: vessel information (e.g., length, horsepower, gross tonnage), economics associated with vessel operation (e.g., variable costs, wages), gear specifications (e.g., TED type, BRD type), as well as catch characteristics from each tow. General information collected for each tow included beginning and ending location (latitude and longitude), depth, tow duration, and vessel speed.

Prior to each trip, a random number table was used to determine which net would be sampled during a given tow. The outside port net was designated Net 1 and the outside starboard as Net 4. If a boat had only two nets, only the values of 2 (port net) and 3 (starboard net) were used to determine which net was sampled. Generally, larger vessels were equipped with a smaller “try-net”, which is located in front of the main nets. The try-net was used to determine if an area was producing enough shrimp to continue the effort with the larger nets or if the tow should be terminated and relocated. If the random net to be sampled was located behind the try-net, another net was randomly selected to avoid bias associated with the try-net. Only main nets were used for bycatch characterization.

Once the catch from the net to be sampled was emptied onto the deck and the shrimp were removed, the bycatch was mixed with a shovel to homogenize the composition. A 12-kg sample for each hour towed was sampled from the mixed bycatch for characterization. For example, if the total tow time was 2.3 hours, a 28-kg sample would be selected for processing. The sample was processed by separating it into its respective species groupings, obtaining a species group weight, and counting the number of individuals in the group. If more than 30 individuals were in a group, they were mixed (to ensure randomness) and 30 individuals were selected for length measurements. Lengths of finfish were reported in cm TL.

Catch Per Unit Effort (CPUE) was calculated as the estimated number of sharks captured per net per hour towed. The total number of sharks captured per net was calculated with the recommended expansion outlined in NMFS (1992), which used the following equation:

$$\textit{Sharks per Net} = \#\,\textit{Sharks in Sample} \bullet \frac{\textit{Total Net Weight}}{\textit{Total Sample Weight}} \qquad (1)$$

Where, total net weight is the weight of the total catch in the sampled net; sample weight is the weight of the complete sample. Number of sharks per net (1) divided by the number of hours towed provided an estimate of the number of sharks caught per net per hour. CPUEs were calculated for the aggregate shark catch and for individual species represented by 15 or more individuals.

Catch rates for abundant species and the aggregate catch were evaluated for normality by examining associated skewness and kurtosis values prior to conducting analyses (Mertler and Vannatta 2005). Species-specific and aggregate CPUEs exhibited non-normal distributions. To correct substantial positive skews, a $\log_{10}$ transform was applied to the catch data (Mertler and Vannata 2005). The transform did normalize the data, but the variance of the data remained heterogeneous. Parametric tests on rank transformed data can be useful as analogs for nonparametric tests (Conover and Iman 1981). Accordingly, catch rate data were rank transformed prior to analysis.

Monthly catch rates for the aggregate and species-specific shark catch were compared using a one-way analysis of variance applied to the rank transformed data. If significant differences in catch existed among months, a Student-Newman-Keuls (SNK) multiple comparison test was used to determine where significant differences occurred. The SNK test was chosen over the other multiple comparison tests because it is neither liberal nor conservative relative to its associated power and Type I error rate (Dowdy and Wearden 1983).

Net type, TED type, and BRD type could have an effect on catch rates of sharks. Three nets types, 3 TED types, and 5 BRD types were in use on the vessels observed during this study. A three-factor analysis of variance could not be used to analyze the joint effects of the three devices on shark catch rates, specifically because of the large number of empty cells. Fifty-four gear combinations were possible; however, only 15 combinations were in use on those vessels sampled. Additionally, not all 15 gear combinations were in use during each month of the sampling period; therefore, only those gear types that captured sharks during the months of highest abundance and had a minimum sample size of four tows were included in the analyses. This approach was precautionary to ensure any differences identified would be attributed appropriately to the gear and not confounded with monthly differences in abundance. A one-way analysis of variance was used to compare shark catch rates (species-specific and all species combined) of the five gear combinations that met the criteria list above. If significant differences existed among gear combinations, a SNK multiple comparison procedure was used to determine which combinations differed from one another.

The associations between tow time and the catch rates of sharks, and between tow speed and catch rates were analyzed by Spearman rank correlations (Zar 1999) for those months when sharks were captured. Catch rates were defined as the estimated number of sharks per net and were calculated using equation (1). All analyses were performed using SAS 9.1 software (SAS Institute 2002) and an $\alpha$ level of 0.05 was used to evaluate the significance of all analyses.

RESULTS

Shark bycatch evaluated in this study came from vessels operated in state waters east of the barrier islands and in adjacent federal waters at depths ranging from 2.0 to 15.2 m. Tow times ranged from 0.6 to 6.6 hours; most (85.2%) of the observed trawls occurred during the day. The target species were penaeid shrimp species; predominantly white shrimp (*Litopenaeus setiferus*) during the spring and fall, and brown shrimp (*Farfantepenaeus aztecus*) during the summer months.

Sharks occurred in 33.9% of the 127 observed tows and were captured during all months sampled except November, December, and January (Table 5-1). A total of 217 sharks from 6 species were identified during the study (Table 5-2); individual sizes ranged from 29.4 to 92.3 cm TL. All shark species were discarded bycatch with unknown release conditions. Atlantic sharpnose sharks (*Rhizoprionodon terraenovae*) were the most abundant species and accounted for 82.0% of the total number of sharks sampled (Table 5-2). Atlantic sharpnose sharks were present in 25.2% of the tows observed and were captured during May, June and July (Table 5-2; Figure 5-2).

Average catch rates for all shark species combined differed significantly among months (F value = 16.60, d. f. = 6, 88, $p < 0.0001$). Catch rates for June and July were not significantly different from each other, but were significantly higher than the other months (Figure 5-2). During June, 84.2% of the observed trawls captured sharks; in July that percentage increased to 92.9% (Table 5-1).

Catch rates of Atlantic sharpnose also differed significantly among months (F value = 14.66, d. f. = 2, 42, $p <0.0001$). All three months differed from each other significantly, with the highest catch rate occurring in June (13/net/hr), followed by July

(3/net/hr) and May (<1/net/hr) (Figure 5-2). Atlantic sharpnose sharks were captured in 84.2% of June trawls and 85.7% of July trawls observed (Table 5-1).

The aggregate catch rates for sub-adult sharks differed among the gear combinations (F value = 3.19, d. f. = 4, 25, $p$ = 0.0301); the highest catch rates were associated with triple wing nets configured with a Super Shooter TED and without a BRD (Figure 5-3). The lowest catch rates were associated with two configurations: mongoose nets configured with Georgia Jumpers and without BRDs, and flat nets configured with Super Shooters and without BRDs; catch rates for these two gear configurations did not differ significantly from each other (Figure 5-3). A similar analysis planned for the CPUEs for Atlantic sharpnose sharks was not conducted because gear combinations were not observed during each month that Atlantic shaprnose sharks were captured. As catch rates varied among months for Atlantic sharpnose sharks, a possible confounding issue between gear configuration and monthly effects could have led to misinterpretation of results.

Results from the Spearman correlation analysis indicated neither tow time nor tow speed was correlated with the aggregate catch of sub-adult sharks or the catch rate of Atlantic sharpnose sharks (Table 5-3).

## DISCUSSION

Although six species of sharks were captured in commercial shrimp trawls fishing off the Georgia coast, Atlantic sharpnose shark was the most abundant (i.e., in frequency of occurrence and total numbers) species caught. Atlantic sharpnose sharks are very common small coastal sharks found in estuarine and near shore waters off

South Carolina, Georgia, Florida, and in the Gulf of Mexico (Castro 1983; McCandless 2007). Their presence in shrimp trawls is a function of their abundance and their small size. Most of the Atlantic sharpnose sharks captured were neonates and small juveniles less than 55 cm TL. Similar catch characteristics for Atlantic sharpnose sharks were observed during a fishery-independent trawl survey conducted in Georgia waters (Chapter 3). With the exception of bonnethead sharks (*Sphyrna tiburo*), the other four species captured in commercial trawls generally are born at sizes greater than 55 cm TL, which may be the size at which they are able to swim faster than the gear or are of sufficient size to be successfully "excluded" by TEDs. In a fishery-independent trawl survey conducted in the Gulf of Mexico, Atlantic sharpnose sharks and bonnetheads were the most frequently captured species (Shepherd and Myers 2005). The seasonality of shark bycatch in the shrimp trawl fishery coincided with the observed pupping season for shark species in Georgia waters (Gurshin 2007; Belcher, unpublished data).

Fishery closures have been suggested as a means to protect vulnerable life stages or critical habitat (i.e., mating aggregation areas and nurseries) for shark species (Barker and Schluessel 2005). Georgia's commercial shrimp trawl fishery operates under a year-round area closure that excludes these vessels from the inshore waters. Georgia's marine waters include approximately 448,400 acres of sounds, creeks, and rivers east of the freshwater demarcation line, and territorial waters extending from the sound/beach boundaries out to the 3-mile radar line (Figure 5-1). Currently, Georgia's shrimp trawl fleet can fish in state waters east of the sound/beach boundaries out to three miles offshore, an area equivalent to 207,985 acres or 47% of all marine waters.

Georgia closed the sounds to trawling in the mid 1970’s to protect overwintering white shrimp and to maximize shrimp spawning potential in the spring. In essence, this closure created a limited-access Marine Protected Area for many species of marine organisms, including sharks.

Many coastal shark species use bays, estuaries and shallow near-shore waters as pupping and nursery areas (Castro 1993; McCandless et al. 2007). In Georgia, sub-adult sharks representing 11 species have been captured in both the estuaries and near shore waters (C. Belcher, unpublished data). Although the sound closure was not implemented to specifically address the issue of shark bycatch, it does provide protection to nursery areas for at least five species. Sub-adults from five species commonly occurred during fishery-independent surveys conducted in estuarine waters; these species included Atlantic sharpnose shark, bonnethead shark, sandbar shark (*Carcharhinus plumbeus*), blacktip shark (*C. limbatus*), and finetooth shark (*C. isodon*) (See Chapters 2, 3, and 4; Gurshin 2007).

In addition to a partial area closure, Georgia’s commercial shrimp trawl fishery is managed as part of the commercial food shrimp fishery, which is controlled by a fishing season. Currently, the fishery can be opened as early as May 15 and generally closes at the end of December, with the potential to extend the season through the end of February. The pupping season for many shark species in Georgia occurs from mid-April through the end of September. Because of the high degree of overlap in the two seasons, a full pupping season closure of Georgia’s near shore waters would conflict with the shrimp fishery, as approximately 55% of the observed commercial fishing effort occurs during those same months (J. Califf GADNR, unpublished data). At a minimum, the first six weeks of the pupping season are closed to shrimp trawling; however, the trend during the last 15 years has been to delay opening of the shrimp season until after June 1. Five (1994, 1996, 2001, 2004, 2005) of the last 14 years had season openings as late as June 15, which provided an additional four weeks of protection. Because the peak of the pupping season occurs during the months of June and July, those additional weeks may provide additional protection to neonates that are born in nearshore waters and migrate into the sounds and estuaries. GA DNR and some commercial fishers have had discussions during which support was offered for opening the season as late as July 1; however, not all commercial fishers accept this strategy. Nonetheless, delaying the opening of the shrimp season to July 1 could provide additional protection to small sharks during a critical month.

TEDs and BRDs have been effective in reducing bycatch in shrimp fisheries elsewhere. For example, results from a study of the prawn fishery off of northern Australia indicated that TEDs and BRDs reduced the catch of sharks by 17.7% as compared to a control net without either device (Brewer et al. 2006). The authors concluded that the TEDs were more effective than the BRDs in reducing shark bycatch (Brewer et al. 2006). Unfortunately, comparisons were not made between the varying gear types to determine which combinations performed better. Net type was not considered a factor as all vessels were outfitted with the same net type (Brewer et al. 2006).

Although NMFS' shrimp trawl bycatch characterization protocol was not designed to address issues of gear comparisons, the data collected during the current study did allow for limited inferences about the effects of the net, TED, and BRD types. The results of the multiple comparison procedure allowed for general contrasts to be made among net types by comparing the catch rates for the three net types configured with just the super shooter TED. Because triple wing nets have significantly higher catch rates than the flat nets, one can reasonably conclude that this type of net has an affect on shark catch rates (Figure 5-3). I could not determine the effectiveness of the mongoose net because the catch rates for this net did not significantly differ from the catch rates of either the flat net or triple wing.

The triple wing net is the most efficient net type for shrimp fishing with regard to net spread and how closely it tends the bottom. However, triple wing nets require more horsepower to pull than the other two net types (Harrington et al. 1988) and have limited use in the fishery. The triple wing is also the only net of the three that fishes directly on the bottom, whereas both the mongoose and flat nets fish a minimum of 3 to 4 inches off the bottom (Harrington et al. 1988). Fishes that encounter the triple wing would have a harder time escaping this net compared to other types because the bibs increase the difficulty of swimming over or under the net. The mongoose net would allow for animals to swim under the net, whereas the flat net would allow for animals to pass over or under the net. The majority of the Georgia shrimp fleet use mongoose nets as a means of increasing their shrimp catch (J. Page - GADNR, pers. comm.); therefore, restricting trawlers to the use of mongoose or flat nets should not affect a large number of vessels.

Of the three TED types observed during this study, only the two hard TEDs could be evaluated for potential effects on shark catch rates. Since the current study was conducted, the Morrison soft TED has been decertified for use in the shrimp fishery and was replaced by the Parker soft TED in the late 1990’s (L. Parker - University of

Georgia, pers. comm.). However, the Parker TED has not been widely adopted in the fishery, and the effectiveness of soft TEDs at reducing shark catch rates is unknown. Results of the multiple comparison procedure suggest that neither hard TED performed better at reducing the number of sub-adult sharks captured. Although hard TEDs are capable of excluding large fish, the bar spacing (generally 10.2 cm) of hard TEDs allows small sharks to pass through. Atlantic sharpnose and bonnethead sharks are born at small sizes (<35 cmTL), which may allow them to more easily pass between the bars than other species. A decrease in bar spacing may help reduce the numbers of sharks caught in trawls.

Unfortunately, only the 12" x 5" fish eye was observed in trawls frequently enough during periods of high shark abundance. The results of the gear comparison indicated that the 12" fish eye was ineffective in reducing the number of sharks captured. With the exception of the large mesh funnel, the other two BRDs were similar in design to the 12" fish eye, but with smaller dimensions. As such, I expect these other designs to have little or if any affect in reducing shark catch rates. Brewer et al. (2006) reached similar conclusions about the limited effects of BRDs on the bycatch of elasmobranchs in an Australian prawn fishery.

As scientists work to produce estimates of shark bycatch in shrimp trawls, additional data collection issues need to be addressed. All sharks should be selectively sampled from the total catch of the sampled net. Because of the large sizes and relatively low abundance of sharks compared to other finfish species captured in trawls, ensuring homogeneity of the sample catch for shark species will be difficult. Continuing to use the methodology described in this study to expand the catch and estimate the number of sharks captured will result in under or over estimates of the shark bycatch. Further, knowing an estimated rate of discard mortality for shark species is important for estimating the effects of shrimp trawling on shark mortality. Current estimates of shark trawl bycatch in the southeast U.S. and the Gulf of Mexico assume 100% (Siegfried 2007); however, an estimated bycatch mortality rate of 66% has been reported for elasmobranchs in the northern Australian prawn fishery (Stobutzki et al. 2002).

## CONCLUSIONS

Although various sharks are encountered seasonally in Georgia's commercial shrimp trawls; the Atlantic sharpnose shark is the most common. The current management regime for the trawl fishery in Georgia may sufficiently reduce shark interactions without requiring further restrictions for the fishery. The closure of the sounds, although not enacted for protection of sub-adult sharks, has acted as a Marine Protected Area for the majority (53%) of shark nursery habitat in state waters. Delaying the start of the shrimping season would provide protection to small sharks migrating from nearshore to inshore waters. The use of TEDs in nets has helped reduce the number and sizes of sharks captured in shrimp trawls elsewhere (Brewer et al. 2006); however, decreasing bar spacing on TEDS may be a gear modification that could help reduce the number of small sharks caught. Presently, Georgia's commercial fleet is encountering increased attrition because of the high cost of fuel and the reduced market value for domestic product compared to inexpensive foreign imports. This reduction in the number of boats, as well as the reduction in the number of trips, will lead to decreased shark bycatch as well.

To ensure reduced bias associated with the estimates of shark bycatch associated with this fishery, stock assessment scientists need sampling strategies that adequately reflect the true numbers of sharks captured, and the seasonality of the fishing effort and presence of sharks in the catch, rather than expanding the estimates equally across all months and all trips. Additional factors to consider when calculating estimates of shark bycatch include the associated mortality rate for sharks captured in the trawl, as well as the current stock status, ecology, and biology of commonly captured species.

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Table 5-1. Encounter rates for shark species captured as bycatch in Georgia's commercial shrimp trawl fishery from April 1995 through March 1998, by month.

| Species | January (*n* = 8) | February (*n* = 0) | March (*n* = 0) | April (*n* = 6) | May (*n* = 12) | June (*n* = 19) | July (*n* = 14) | August (*n* = 18) | September (*n* = 13) | October (*n* = 13) | November (*n* = 12) | December (*n* = 12) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Atlantic sharpnose | 0.0% | --- | --- | 0.0% | 33.3% | 84.2% | 85.7% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| Bonnethead | 0.0% | --- | --- | 16.7% | 8.3% | 15.8% | 28.6% | 16.7% | 16.7% | 0.0% | 0.0% | 0.0% |
| Scalloped hammerhead | 0.0% | --- | --- | 0.0% | 8.3% | 21.1% | 28.6% | 5.6% | 7.7% | 7.7% | 0.0% | 0.0% |
| Blacktip | 0.0% | --- | --- | 0.0% | 8.3% | 21.1% | 14.3% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| Spinner | 0.0% | --- | --- | 0.0% | 0.0% | 0.0% | 0.0% | 11.1% | 0.0% | 0.0% | 0.0% | 0.0% |
| Finetooth | 0.0% | --- | --- | 0.0% | 0.0% | 5.3% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| All species combined | 0.0% | --- | --- | 16.7% | 41.7% | 84.2% | 92.9% | 22.2% | 25.0% | 7.7% | 0.0% | 0.0% |

Table 5-2. Frequencies, size ranges, and encounter rates of sub-adult sharks, by species, captured during observed commercial shrimp trawls in Georgia waters between April 1995 and March 1998. Encounter rate is calculated as the number of sets that encountered at least one individual of a given species divided by the total number of sets (n=127).

| Species | Number Of Individuals | Percent of Total | Encounter Rate (%) | Size Range (TL cm) |
|---|---|---|---|---|
| Atlantic sharpnose | 178 | 82.0% | 25.2% | 29.4 - 92.3 |
| Bonnethead | 14 | 6.5% | 11.0% | 51.2 - 81.0 |
| Scalloped hammerhead | 14 | 6.5% | 9.5% | 39.7 - 70.4 |
| Blacktip | 7 | 3.2% | 5.5% | 61.2 - 70.7 |
| Spinner | 2 | <1% | 1.6% | --- |
| Finetooth | 2 | <1% | <1% | 53.9 and 60.5 |
| All Species Combined | | | 33.9% | 29.4 – 92.3 |

Table 5-3. Correlation matrix of Spearman correlation coefficients and associated p-values for relationships between shark catch rates and tow time and tow speed for observed commercial shrimp trawls in Georgia waters (April 1995 – March 1998). Catch rates were defined as the estimated total number per net. * – statistically significant.

| | | Tow Time (Hours) | Tow Speed (Knots) |
|---|---|---|---|
| Atlantic sharpnose shark | Spearman Correlation Coefficient | 0.10 | 0.03 |
| | *p*-value | 0.3676 | 0.8248 |
| | n | 82 | 74 |
| All shark species combined | Spearman Correlation Coefficient | 0.11 | -0.01 |
| | *p*-value | 0.3240 | 0.9231 |
| | n | 82 | 74 |

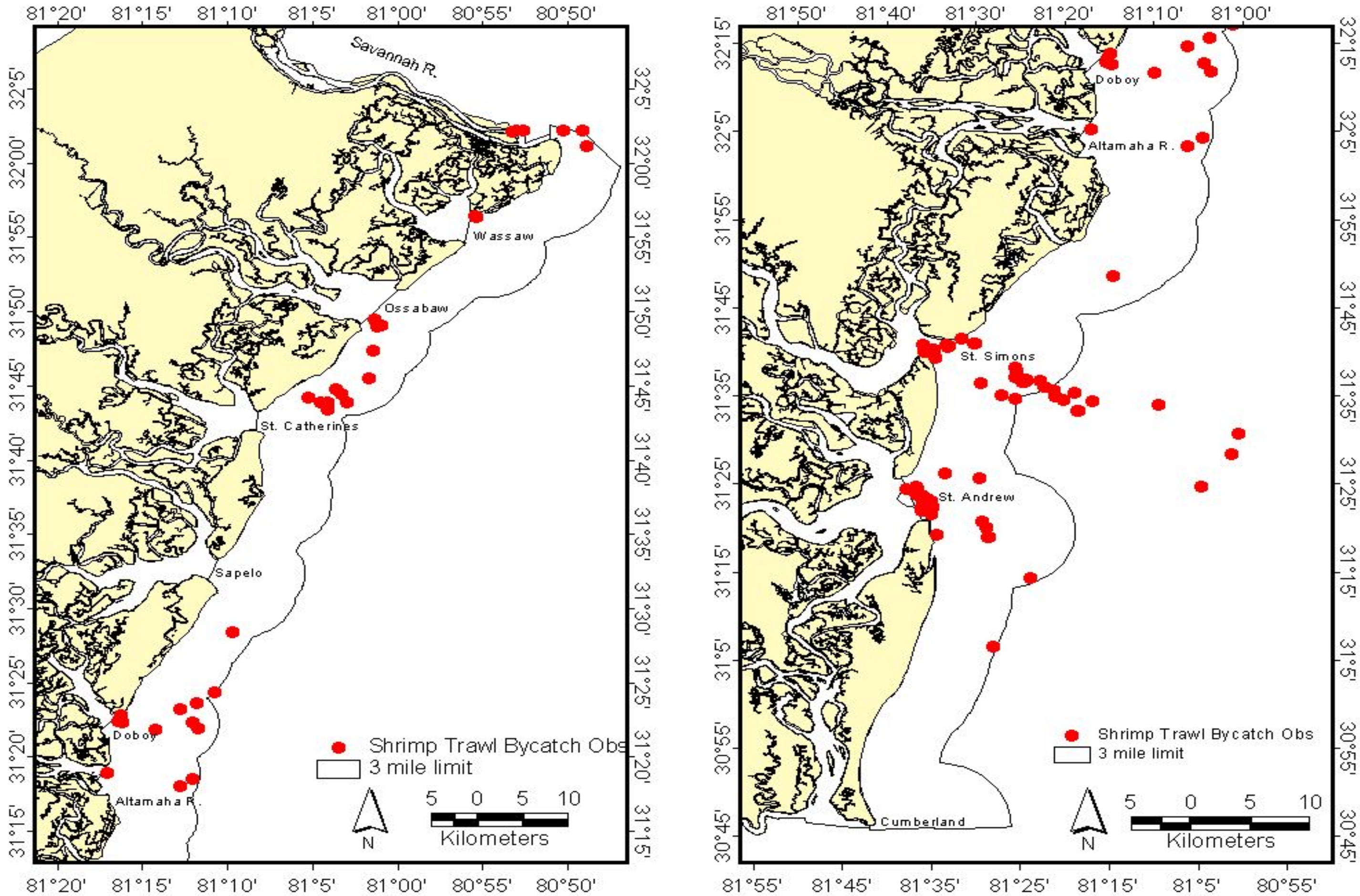


Figure 5-1. Map of commercial shrimp trawl locations off the coast of Georgia sampled by bycatch observers between April 1995 and March 1998.

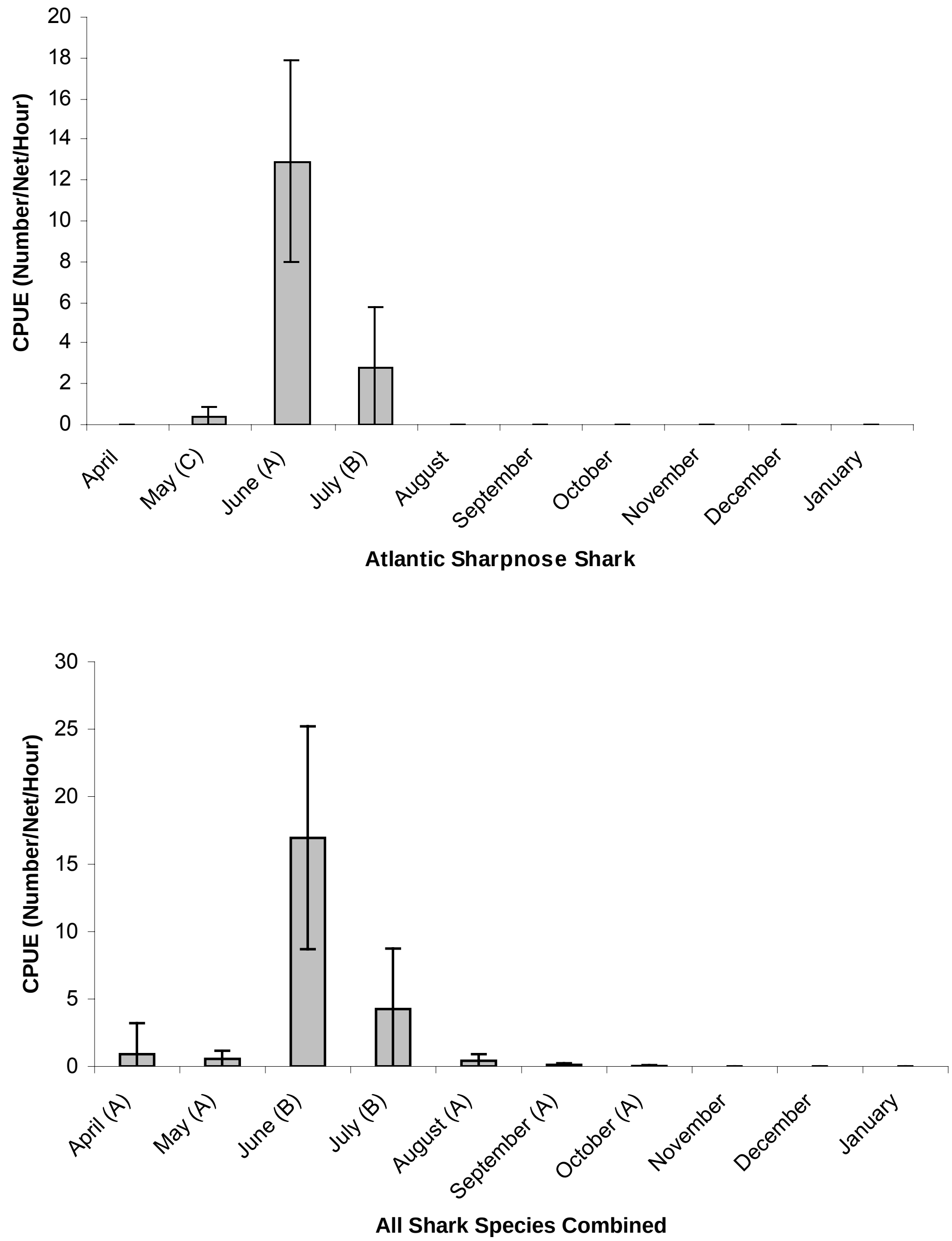


Figure 5-2. Comparison of average monthly catch rates for sharks captured as bycatch in Georgia's commercial shrimp trawl fishery between April 1995 – March 1998. Months with similar letters indicate statistical equivalency. Months without letters had observed trawls, but sharks were not captured. Error bars represent 95% confidence intervals.

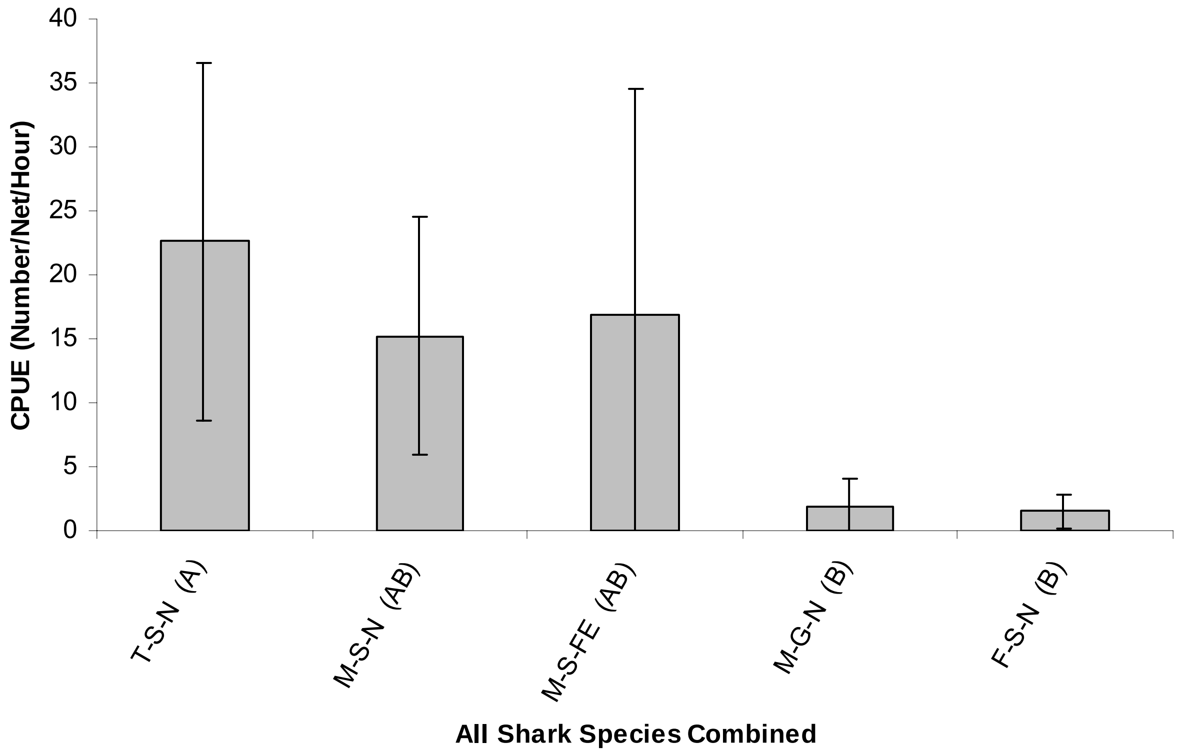


Figure 5-3. Comparison of average catch rates by gear combination for sharks captured as bycatch in Georgia's commercial shrimp trawl fishery during the months of June and July. Gear combinations with similar letters indicate statistical equivalency. Error bars represent 95% confidence intervals. Abbreviations for gear type identify net type-TED type-BRD type. F=flat net; M=mongoose net; T=triple wing net; G=Georgia jumper TED; S=super shooter TED; FE=12" x 5" fish eye; N=no BRD.

# CHAPTER 6

# CONCLUSIONS

Georgia's estuaries and nearshore waters are productive nursery areas for Atlantic sharpnose shark, bonnethead, blacktip shark, and sandbar shark. Both neonates and juveniles of each species are captured in Georgia's marine waters, indicating that these areas act as both primary (i.e., presence of neonates) and secondary (i.e., presence of juveniles) nurseries. Georgia's estuarine waters may serve as nurseries for scalloped hammerhead, finetooth shark, spinner shark, bull shark, lemon shark and blacknose shark, but catches of these species were insufficient to make that determination.

In Chapter 2, I examined some of the assumptions behind the current sampling protocol for sub-adult sharks in GA. My results indicate that bait type can bias catch rates and species selection. Although results indicated neither tidal stage nor lunar phase affected overall catch rates for three of the four species, the lack of power associated with high catch variability and low sample sizes may have contributed to this result. This problem is illustrated by catch rates of blacktip shark that differed among combinations of lunar and tide phases, yet the multiple comparison test was unable to detect a significant differences among treatment combinations. Repeating the experiment with a larger sample size may overcome this problem. In areas where tidal amplitude is less than in coastal Georgia, environmental conditions may not be as variable, and the power necessary to detect differences among treatment means may be achieved with fewer samples. Georgia's inshore waters are a complex of nine estuarine systems, each with differing types of freshwater inputs, channelization and coastal development. How these factors affect the distribution and abundance of sub-adult sharks and the results of my study is unknown.

In Chapter 3, I examined the utility of an additional gear type (i.e., trawls) for surveying sub-adult sharks. The GADNR trawl survey has been conducted since the mid 1970s and has an integral part in the management of the penaeid shrimp fishery; this survey has long-term significance for fisheries management in GA. My results indicate that longline and trawl surveys provide similar information, especially for Atlantic sharpnose and bonnethead sharks; however, the trawl provides the distinct advantage of being able to sample offshore waters and currently is the only gear that captures neonate bonnetheads. Independence from shark feeding behavior is another advantage of the trawl gear over the longline. Though not evaluated in this study, gillnets are another gear type that does not rely on shark feeding behavior and may be useful for sampling sharks in Georgia's estuaries. Future research should include an examination of limitations, selectivity, and efficiency for gillnets for sampling sub-adult sharks in Georgia waters.

In Chapter 4, I examined the effects of mesohabitat features on the presence of sub-adult sharks. My results indicate that Atlantic sharpnose and blacktip sharks are generalist species that are found across a wide range of mesohabitats, whereas bonnethead and sandbar sharks are specialist species. Although bonnethead and sandbar sharks do have unique water chemistry preferences, mesohabitat characteristics better explained the absence of these species from sampling areas. My results support findings from other studies that suggested non-environmental factors could affect the presence of sub-adult sharks. For example, the presence of predators and the availability of food may have a stronger influence on sub-adult habitat use than environmental factors such as water depth or salinity. Surveys examining the abundance of large sharks in estuaries during the pupping season and the abundance and availability of prey items could be used to evaluate how these factors influence the use of nursery areas.

In Chapter 5, I investigated shark bycatch encountered during commercial shrimp trawl operations off the coast of Georgia. The perception among environmentalists and some fishery managers is that many sharks are incidentally captured during this fishery, adding a non-directed fishing mortality that directly affects the survival of sub-adult sharks. Current estimates of the shark bycatch assume all tows capture sharks, that captures are equivalent among months, and that the mortality rate for sharks captured is 100%. My results indicate that not all tows capture sharks, that sharks are not captured during all months, and that catch rates are not uniform across months. Species composition in my study indicates disproportionate effects among species; small coastal sharks, specifically, the Atlantic sharpnose shark were the most affected by the trawls. Management actions that could help shark bycatch have included the use of marine protected areas, gear and season restrictions. Georgia's current trawl regulations include a *de facto* marine protected area as the estuaries are closed to commercial trawling and the ability to delay the food shrimp season opening until the end of June. The delay in season opening would provide additional protection to sub-adult sharks in offshore state waters. Additional gear restrictions that could help reduce the numbers of sharks captured in trawls include reduced bar spacings on turtle excluder devices and the prohibition of triple wing trawls in the trawl fishery.

The results presented in this dissertation support the importance of Georgia's estuaries as multi-species nurseries for sharks. Although Georgia does not have directed commercial fisheries for sharks, the effects of bycatch from other commercial fisheries, recreational fishing, and increasing coastal development on sub-adult sharks should be considered when developing management actions related to those activities. Although many of the ecological interactions of sub-adult sharks in Georgia's estuaries are unknown, their role as apex predators indicates they play a critical part in maintaining the health of the ecosystem. Therefore, the protection of shark nursery areas is not only a mechanism to rebuild the stocks of sharks that are already severely depleted, but also a means to ensure the continued health of Georgia's coastal ecosystems.

# APPENDICES

Appendix 4-1. Species managed in the Northwestern Atlantic by the National Marine Fisheries Service's Highly Migratory Division. * - Indicates species that are prohibited from being landed.

**Tuna**

| Common Name | Scientific Name |
|---|---|
| Bluefin Tuna | *Thunnus thynnus* |
| Yellowfin Tuna | *Thunnus albacares* |
| Bigeye Tuna | *Thunnus obesus* |
| Albacore | *Thunnus alalunga* |
| Skipjack Tuna | *Katsuwonus pelamis* |
| | |
| Swordfish | *Xiphias gladius* |

**Billfishes**

| Common Name | Scientific Name |
|---|---|
| Blue Marlin | *Makaira nigricans* |
| White Marlin | *Tetrapturus albidus* |
| Longbill Spearfish | *Tetrapturus pfluegeri* |
| Sailfish | *Istiophorus platypterus* |

**Sharks**

| Common Name | Scientific Name | Common Name | Scientific Name |
|---|---|---|---|
| Atlantic Angel * | *Squatina dumerili* | Narrowtooth Shark * | *C. brachyuru* |
| Atlantic Sharpnose Shark | *Rhizoprionodon terraenovae* | Night Shark * | *Carcharhinus signatus* |
| Basking Shark * | *Cetorhinus maximus* | Nurse Shark | *Ginglymostoma cirratum* |
| Bigeye Sand Tiger * | *Odontaspis noronhai* | Oceanic Whitetip shark | *Carcharhinus longimanus* |
| Bigeye Sixgill * | *Hexanchus vitulus* | Porbeagle | *Lamna nasus* |
| Bigeye Thresher * | *Alopias superciliosus* | Sand Tiger * | *Carcharias taurus* |
| Bignose Shark * | *Carcharhinus altimus* | Sandbar Shark | *Carcharhinus plumbeus* |
| Blacknose Shark | *Carcharhinus acronotus* | Scalloped Hammerhead | *Sphyrna lewini* |

Appendix 4-1. Continued.

**Sharks**

| Common Name | Scientific Name | Common Name | Scientific Name |
|---|---|---|---|
| Blacktip Shark | *Carcharhinus limbatus* | Sevengill Shark * | *Heptranchias perlo* |
| Blue Shark | *Prionace glauca* | Shortfin Mako | *Isurus oxyrinchus* |
| Bonnethead | *S. tiburo* | Silky shark | *Carcharhinus falciformis* |
| Bull Shark | *Carcharhinus leucas* | Sixgill Shark * | *Hexanchus griseus* |
| Caribbean Reef Shark * | *C. perezi* | Smalltail Shark * | *C. porosus* |
| Caribbean Sharpnose Shark * | *Rhizoprionodon porosus* | Smooth Hammerhead | *S. zygaena* |
| Dusky Shark * | *Carcharhinus obscurus* | Spinner Shark | *Carcharhinus brevipinna* |
| Finetooth Shark | *C. isodon* | Thresher Shark | *Alopias vulpinus* |
| Galapagos Shark * | *C. galapagensis* | Tiger Shark | *Galeocerdo cuvier* |
| Great Hammerhead | *S. mokarran* | Whale Shark * | *Rhincodon typus* |
| Lemon Shark | *Negaprion brevirostris* | White Shark * | *Carcharodon carcharias* |
| Longfin Mako * | *Isurus paucus* | | |