Identification and evaluation of shark bycatch in Georgia's commercial shrimp trawl fishery with implications for management

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Abstract Many US states have recreational and commercial fisheries that occur in nursery areas occupied by subadult sharks and can potentially affect their survival. Georgia is one of few US states without a directed commercial shark fishery, but the state has a large, nearshore penaeid shrimp trawl fishery in which small sharks occur as bycatch. During our 1995-1998 investigation of bycatch in fishery-dependent sampling events, 34% of 127 trawls contained sharks. This bycatch totaled 217 individuals from six species, with Atlantic sharpnose shark, *Rhizoprionodon terraenovae* (Richardson), the most common and finetooth shark, *Carcharhinus isodon* (Müller and Henle), and spinner shark, *Carcharhinus brevipinna* (Müller and Henle), the least common. The highest catch rates for sharks occurred during June and July and coincided with the peak months of the pupping season for many species. Trawl tow speed and tow time did not significantly influence catch rates for shark species. Gear configurations (net type, turtle excluder device, bycatch reduction device) affected catch rates for shark species. Management strategies that may reduce shark bycatch in this fishery include gear restrictions, a delayed season opening, or reduced bar spacing on turtle excluder devices.

Introduction

Bycatch associated with commercial fisheries throughout the world has become a growing concern for fisheries management since the 1980s (Alverson *et al*. 1994). The 2007 Magnuson-Stevens Fishery Conservation Act defines bycatch as "fish which are harvested in a fishery, but are not sold or kept for personal use, and includes economic discards and regulatory discards" (National Marine Fisheries Service 2007a). The general public and many conservation groups consider bycatch a source of unnecessary mortality of vulnerable resources or endangered species such as dolphins caught in tuna seine fisheries and sea turtles caught in shrimp trawl and pelagic longline fisheries (Alverson *et al.* 1994).

In the northwestern Atlantic Ocean, the penaeid 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 of Mexico and 8.00 kg of bycatch to 1 kg of shrimp in waters off the southeastern coast of the United States (Alverson *et al.* 1994). Since the late 1980s, 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 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, especially overfished species such as red snapper, *Lutjanus campechanus* (Poey), in the Gulf of Mexico (Gulf of Mexico Fishery Management Council 1997), and weakfish, *Cynoscion regalis* (Bloch & Schneider), and Spanish mackerel, *Scomberomorus maculatus* (Mitchill), in the southeastern USA (South Atlantic Fishery Management Council 1996).

Sharks are particularly vulnerable to overfishing because most have slow growth and late sexual maturity, produce few offspring, and have long life spans (Camhi 1998; Stevens *et al.* 2000). Some of the U.S. populations of sharks have declined by as much as 85% since the late 1970s (Camhi 1998). Generally, these declines are attributed to directed fishing pressure from commercial and recreational fisheries, but effects from other fisheries that encounter sharks as bycatch also play a role (Barker and Schluessel 2005).

Incidental catch (i.e. bycatch) in the commercial shrimp trawl fishery has been identified as a large source of subadult shark mortality (Camhi 1998; Stobutski *et al.* 2002; Shepherd & Myers 2005). The most recent stock assessment for small coastal sharks indicated that as much as 45% of the fishing mortality associated with blacknose sharks, *Carcharhinus acronotus* (Poey), was attributed to the Gulf of Mexico shrimp trawl fishery (National Marine Fisheries Service 2007b). Annual bycatch estimates for small coastal sharks in the Gulf of Mexico trawl fishery ranged from 443,215 to 1,172,572 fish, whereas similar estimates for the South Atlantic range from 55,718 to 147,409 fish (National Marine Fisheries Service 2007b). Because the results of the most recent peer-reviewed stock assessment (National Marine Fisheries Service 2007b) indicated that blacknose sharks are both overfished and undergoing overfishing, the Highly Migratory Species Division (HMS) of the National Marine Fisheries Service is required to implement management actions that will end overfishing for this species. Under the Magnuson Stevens Fishery Conservation and Management Act (National Marine Fisheries Service 2007a), eight regional management councils are given the authority to manage federal fisheries in the Exclusive Economic Zone (EEZ), which extends from the edge of a state's territorial waters out to 370 km (200 nautical miles). State management agencies manage fisheries that occur within their territorial waters out to the EEZ. As the Gulf of Mexico and the

South Atlantic shrimp fisheries are managed by their respective regional fishery management councils and the corresponding states, HMS will have to work with the councils and states to ensure the necessary reductions in blacknose shark bycatch are met.

Georgia's shrimp trawl fishery is the most economically important commercial fishery in the state (Page 2007). The fishery operates in state territorial waters outside of the sound/beach boundary (i.e. 0 to 4.8 km off the coast) and the EEZ throughout much of the year. The purpose of this study was to examine the composition and temporal distribution of shark species taken as bycatch in the Georgia shrimp trawl fishery. Additionally, the effects of gear configuration (e.g. net type, TEDs and BRDs), tow time and tow speed on the capture rates of sharks were examined. Based on the results of this study and an assessment of regulations presently applied to the shrimp trawl fishery, potential management approaches were identified that may help reduce the amount of shark bycatch with minimal effects to the shrimp trawl fishery.

Methods

Shrimp trawl bycatch data were collected monthly during the shrimp trawling season in Georgia's state waters and adjacent federal waters from April 1995 to January 1998. All months except February and March were sampled during the study period. The Georgia Department of Natural Resources (GADNR) has the authority to open state waters for the commercial shrimp trawl season as early as mid-May, with a season closure at the end of December (Title 27, *Official Code of Georgia Annotated*, chapter 4). However, the season can be extended through the end of February if shrimp size and quantity remain sufficient (Title 27, *Official Code of Georgia Annotated*, chapter 4). Federal waters are open year-round to commercial shrimp trawling, which allows for continued fishing after state waters are closed (Title 27, *Official Codeof Georgia Annotated*, chapter 4).

Observers onboard commercial shrimp trawlers fishing in both state and federal waters recorded bycatch information. Sampling was conducted under the Shrimp Trawl Bycatch Characterization Sampling Protocol (National Marine Fisheries Service 1992), which was designed to characterize the complete species composition of bycatch associated with the shrimp trawl fishery; therefore, shark data used for this study were a subset of the available data. Additional data collected during each trip and examined for this study included vessel information (e.g. length, horsepower) and gear specifications (e.g. TED type, BRD type). Data included at the individual-tow level included location, tow time, tow speed and catch characteristics.

Shark bycatch evaluated in this study came from shrimp trawl 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 (Fig. 1). The target species were penaeid shrimp species, predominantly white shrimp, *Litopenaeus setiferus* (Linnaeus), during the spring and fall, and brown shrimp, *Farfantepenaeus aztecus* (Ives), during the summer months. Participation in the study was voluntary on the part of boat captains, and therefore not random. Initially, sampling was intended to be coastwide, but reduced cooperation from some trawler captains during the latter portion of the study limited sampling to waters off the central part of the Georgia coast.

Flat, mongoose and triple wing trawls are commonly used in the commercial shrimp fishery. Flat nets do not have a bib (an extension in the middle of the top of the net; Harrington *et al.* 1988). The mongoose net has a single bib on the upper edge of the net and is the most commonly used net in the southeastern US (Harrington *et al.* 1988). The triple wing net is similar to the mongoose net, but has bibs on both the upper and bottom edges of the net (Harrington *et al.* 1988).

Turtle excluder devices used by the commercial vessels observed during this study were either mesh ramps or metal grids installed in front of the bag, or codend, of a trawl. TEDs are angled towards openings at either the top or bottom of the net allowing large organisms to escape, with the primary purpose of excluding sea turtles. Two types of hard TEDs were used on trawls in the study, and both types 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.

BRDs are openings in the trawl net that allow for the escapement of finfish and other organisms that are too small to be excluded by the TED. Whereas TEDs mechanically deflect organisms out of the net, BRDs rely on behavioral differences of fish and shrimp (Crespi and Prado 2008). Fish are capable of swimming while in the net and can orient themselves to the direction of the trawl, whereas shrimp species exhibit less directional swimming and are more easily swept into the codend of the net (Crespi and Prado 2008). BRDs were categorised by both design and dimension. A large-mesh funnel BRD is a section of the trawl behind the TED made of larger mesh. A fish eye design is an oval metal frame sewn into the net behind the TED that provides an opening to the outside of the net; the most common sizes were the 30.5 cm x 12.7 cm fish eye and the 22.9 cm x 11.4 cm North Carolina diamond fish eye.

Participating vessels fished multiple nets, and the net sampled during a given tow was randomly selected. Larger vessels usually fished a “try net”, a smaller trawl located in front of the main nets, 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. Only main nets were used for bycatch characterization. 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.

After 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 subsample for each hour towed was sampled from the mixed bycatch for characterisation. The number of individuals and collective weight were recorded for each species. If more than 30 individuals of a species were in the subsample, they were mixed and 30 individuals were randomly selected for length measurements. Lengths of finfish, including sharks, were reported in cm TL. Catch rate was calculated as the estimated number of sharks captured per net per hour towed. The total number of sharks captured per net was calculated, as recommended by National Marine Fisheries Service (1992), with the following equation:

$$\text{Sharks per Net} = \text{Number of Sharks in Sample} \bullet \frac{\text{Total Net Weight}}{\text{Total Sample Weight}}$$

where total net weight is the weight of the total catch in the sampled net and sample weight is the weight of the complete sample. Number of sharks per net divided by the number of hours towed provided an estimate of the number of sharks caught per net hour. Catch rates were calculated for the aggregate shark catch and for frequently encountered species (i.e. those that occurred in 10% or more of the tows sampled).

Catch rates for frequently encountered species and the aggregate catch were evaluated for normality prior to analysis. Species-specific and aggregate catch rates were non-normally distributed, and a $\log_{10}$ transform was applied to the catch data to correct for positive skews (Mertler and Vannata 2005). Although the $\log_{10}$ transformations normalized the data, the variances remained heterogeneous, suggesting a non-parametric approach would be more appropriate for analysis. Parametric tests on rank-transformed data can be useful as analogs for non-parametric tests (Conover and Iman 1981). Accordingly, catch rate data were rank transformed prior to analysis.

Aggregate and species-specific shark catch rates were compared among months with one-way ANOVAs of rank-transformed data and post-hoc analysis by Student-Newman-Keuls (SNK) multiple comparison test. 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).

The effects of trawl type, TED type and BRD type were tested using only samples from gear types that captured sharks during the months of highest abundance and had a minimum sample size of four tows. This approach was precautionary to better ensure any differences identified would be attributed appropriately to the gear and not confounded with monthly differences in abundance, as not all gear combinations were observed during each month of the sampling period. A one-way ANOVA and SNK test were used to compare the rank-transformed catch rates for frequently encountered species and all species combined for the gear combinations that met the criteria above.

Because of the non-normality of the catch data, Spearman rank correlations (Zar 1999) were used to determine if the number of sharks caught per net were associated with tow time and tow speed. Correlations were examined for the aggregate catch and frequently encountered species. Because of the seasonality associated with shark catches, only those tows made during months when sharks were captured were included in the analysis. All analyses were performed using SAS[1] 9.1 software (SAS Institute 2002), and resulting P values were compared to an α of 0.05 to determine the significance of all analyses.

[1] Reference to trade names does not constitute US Government endorsement of commercial products.

Results

The commercial shrimp trawlers that participated during this project ranged from 9.8 to 26.7 m in length with engine sizes ranging from 240 to 1,000 horsepower. Net size ranged from 10.6 to 22.4 m headrope length. Mesh size of the codend of the trawl was 41-mm stretched mesh. Tow speeds ranged from 2.8 to 8.3 km h^{-1}, and either 2 or 4 (mode = 4) nets were towed. Tow times ranged from 0.6 to 6.6 hours; most (85.2%) of the 127 observed trawls occurred during the day. All commercial trawlers used TEDs in their nets as mandated by the National Marine Fisheries Service; however, BRDs were not mandated until late 1996. As a result, some of the trawls sampled during this study were not configured with BRDs.

The most common net type observed during this study was the mongoose net (77% of the tows sampled), followed by the flat net (17%) and the triple wing (7%). Hard TEDs were used in 93% of the observed tows, with the Super Shooter used more frequently (73% of observed tows) than the GA Jumper. Nets without BRDs represented 56% of the trawls sampled. The most commonly used BRD was the fish eye design that was observed in 36% of the tows, with the large-mesh funnel used in the remaining 8% of the tows. The 30.5 cm x 12.7 cm fish eye was observed in 17% of the tows, and the North Carolina diamond fish eye was observed in 13% of tows.

Sharks occurred in 33.9% of the tows and were captured during all months sampled except November, December and January (Table 1). A total of 217 sharks from six species were captured during the study (Table 2); lengths ranged from 29.4 to 92.3 cm TL. All sharks were discarded bycatch with unknown mortality. Atlantic sharpnose shark, *Rhizoprionodon terraenovae* (Richardson), was the most abundant species and accounted for 82.0% of the total number of sharks sampled (Table 2). Atlantic sharpnose sharks occurred in 25.2% of the tows sampled and were captured during May, June and July (Table 2; Fig. 2).

Catch rates for all shark species combined differed among months ($F_{6, 88}$ = 16.60, P < 0.001). Catch rates in June and July were not significantly different but were greater than the other months (Fig. 2). During June, sharks occurred in 84.2% of the observed; in July that percentage increased to 92.9% (Table 1). Neither tow time nor tow speed correlated with the total number of sharks caught per net (Table 3).

Atlantic sharpnose shark catch rates also differed significantly among months ($F_{2,42}$ = 14.66, P <0.001),with the greatest catch rate in June (Fig.2). Atlantic sharpnose sharks occurred in 84.2% of June trawls and 85.7% of July trawls (Table 1). Neither tow time nor tow speed correlated with the number of Atlantic sharpnose sharks caught per net (Table 3).

The aggregate catch rates for sharks differed among the gear combinations ($F_{4,25}$ = 3.19, P = 0.030). Because catch rates of mongoose nets configured with Super Shooters were highly variable (Fig. 3), it was not possible to conclude how the mean catch rate for this gear configuration related to the means of the other gear combinations. It was possible to conclude from the analysis that highest catch rates were associated with triple wing nets configured with a Super Shooter TED and without a BRD, and lower catch rates were associated with mongoose nets configured with a Georgia Jumper and without a BRD and flat nets configured with a Super Shooter and without a BRD.

The results of the multiple comparison procedure allowed for general contrasts to be made among net, TED, and BRD types. By comparing the catch rates for the three net types configured with just the super shooter TED, a reasonable conclusion would be that triple wing nets caught greater numbers of sharks as bycatch, with flat nets catching the least (Fig. 3).

Because of the high variability of catch rates associated with the mongoose net, it was not possible to conclude if the associated average catch rate of sharks was significantly lower than the average catch rate of the triple wing. Of the three TED types observed during this study, only the two hard TEDs could be evaluated for potential effects on shark catch rates. By looking at the resulting groupings for mongoose nets configured with either the Georgia Jumper or Super Shooter TED and without a BRD, it is possible to conclude that TED type does not have an effect on shark catch rates (Fig. 3). Similarly, by looking at the difference in mean catch rates associated with mongoose nets configured with Super Shooters and either a fish eye BRD or without a BRD, it is possible to conclude that the fish eye BRD does not have an effect on shark catch rates.

Discussion

Six species of sharks were captured in commercial shrimp trawls fishing off the Georgia coast, and Atlantic sharpnose shark was the most abundant (i.e. in frequency of occurrence and total numbers) species caught. Atlantic sharpnose sharks are common small coastal sharks in estuarine and near shore waters in the southeastern Atlantic and in the Gulf of Mexico (Castro 1983; McCandless *et al.* 2007). Their presence in shrimp trawls is a function of their abundance and, possibly, their small size. Most of the Atlantic sharpnose sharks captured were neonates and small juveniles less than 55 cm TL. Similar size and life stage characteristics for Atlantic sharpnose sharks were observed during a fishery-independent trawl survey conducted in Georgia waters (Belcher 2008). With the exception of bonnetheads, *Sphyrna tiburo* (Linnaeus), the other four species [spinner shark, *Carcharhinus brevipinna* (Müller and Henle), blacktip shark, *C.*

limbatus (Müller and Henle), finetooth shark, *C. isodon* (Müller and Henle), and scalloped hammerhead *S. lewini* (Griffith and Smith)] 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 bonnethead sharks 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 2008).

Fishery closures (e.g. area and/or seasonal) have been suggested as a means to protect critical habitat (viz. mating aggregation areas and nurseries) or vulnerable life stages 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 (viz. sounds and marine waters behind the barrier islands) and effectively creates a 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, subadult sharks representing 11 species have been captured in both the estuaries and near shore waters (Belcher 2008). Although not implemented to specifically address the issue of shark bycatch, the sound closure provides protection to nursery areas for at least five shark species. Subadults from five species commonly occurred during fishery-independent surveys conducted in estuarine waters; these species included Atlantic sharpnose shark, bonnethead, sandbar shark, *Carcharhinus plumbeus* (Nardo), blacktip shark and finetooth shark (Gurshin 2007; Belcher 2008).

In addition to a fishing area restriction, Georgia's commercial shrimp trawl fishery is controlled by a fishing season. Currently, the fishery can be opened as early as May 15 and 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. As 55% of the observed commercial shrimp fishing effort occurs during the pupping season (J. Califf, unpublished data), a corresponding seasonal closure within the fishery is not feasible. At a minimum, the first 6 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 opened 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 where trawling is prohibited. Historically, GADNR has met with representatives of the trawl industry prior to the opening of the shrimp season; and some, but not all, trawl fishers have expressed interest in delaying the opening of the season to as late as July 1. By delaying the opening of the shrimp season to July 1 additional protection would be provided to small sharks during a critical month.

Turtle excluder devices and bycatch reduction devices have been effective in reducing bycatch in shrimp fisheries elsewhere. For example, a study of the northern Australia prawn fishery found that TEDs and BRDs reduced the catch of sharks by 17.7% compared to a control net without either device (Brewer *et al.* 2006). Brewer *et al.* (2006) concluded that the TEDs were more effective than the BRDs in reducing shark bycatch. Since both of TEDs and BRDs are currently required in Georgia's shrimp trawl fishery, we can assume reductions in shark bycatch are occurring in that fishery as well. A controlled study that uses a net without TEDs and BRDs is needed to determine the actual reduction amount.

Unfortunately, Brewer et al. (2006) did not compare the catch rates among the varying gear types to determine which combinations performed better; nor was net type considered a factor because all vessels were outfitted with the same net type. The present study was able to provide insight into the effect of net type on shark bycatch. As the triple wing had the highest catch rate, a potential gear restriction could be to prohibit its use in the fishery.

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 cm TL), which may allow them to more readily pass between the bars than other species. Smaller bar spacing may help reduce the numbers of small sharks caught in trawls because the minimum size of excluded fish would be reduced. Research currently conducted by the University of Georgia's Marine Extension Service is examining the effects of closer bar spacings on TEDs as a substitute for requiring a BRD (L. Parker University of Georgia – pers. comm.)

The 12" x 5" fish eye was the only BRD observed in trawls frequently enough during periods of high shark abundance to be evaluated for effects on shark bycatch. This study found the fish eye was ineffective in reducing the number of sharks captured. 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, addressing data collection issues will be beneficial to shark management. For example, sampling all sharks (instead of a subset) from the total catch of the sampled net will increase accuracy of the data on which management decisions are made. Because of the large sizes and relatively low abundance of sharks compared to other finfish species captured in trawls, ensuring that shark species are adequately accounted for in a subsample will be difficult. Continuing to use the methodology described in this study to estimate the number of sharks captured will result in less precise estimates of the shark bycatch.

Conclusions

The current management regime for the shrimp trawl fishery in Georgia already provides additional protections to subadult sharks and as such, future restrictions may not be necessary. The closure of the sounds, although not enacted for protection of subadult sharks, has acted as a Marine Protected Area for the majority (53%) of shark nursery habitat in state waters. Delaying the start of the shrimp 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, smaller 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.

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REFERENCES

Alverson D. L., Freeberg M. H., Murawski S. A., & Pope J. G. (1994) *A Global Assessment of Fisheries Bycatch and Discards.* FAO Fisheries Technical Paper No. 339. 233 pp.

Barker M. J. & Schluessel V. (2005) Managing global shark fisheries: suggestions for prioritizing management strategies. *Aquatic Conservation: Marine and Freshwater Ecosystems* **15**, 325-347.

Belcher, C. N. (2008) *Investigating Georgia's Shark Nurseries: Evaluation of Sampling Gear, Habitat Use, and a Source of Subadult Mortality*. Ph.D. Dissertation, Athens, GA: University of Georgia, 137 pp.

Brewer, D., Heales D., Milton D., Dell Q., Fry G., Venables B., & Jones P. (2006) The impact of turtle excluder devices and bycatch reduction devices on diverse tropical marine communities in Australia's northern prawn fishery. *Fisheries Research* ***81***, 176-188.

Camhi, M. (1998) *Sharks on the Line: A State-by-State Analysis of Sharks and Their Fisheries*. Islip, NY: National Audubon Society, 156 pp.

Castro, J. I. (1983) *The Sharks of North American Waters*. College Station, TX: Texas A&M University Press, 179 pp.

Castro, J. I. (1993) The shark nursery of Bulls Bay, South Carolina, with a review of the shark nurseries of the southeastern coast of the United States. *Environmental Biology of Fishes* ***38***, 37-48.

Conover, W. J. & Iman R. L. (1981) Rank transformations as a bridge between parametric and nonparametric statistics. *American Statistician* ***35*** (Suppl. 3), 124-129.

Crespi V. & J. Prado. (2008) *Fishing Equipment. Bycatch Reduction Devices (BRD).* January 18 2010. http://www.fao.org/fishery/equipment/brd/en

Diamond, S. L. (2003) Estimation of bycatch in shrimp trawl fisheries: a comparison of estimation methods using field data and simulated data. *Fishery Bulletin* ***101*** (Suppl. 3), 484-500.

Dowdy, S. M. & Wearden S. (1983) *Statistics for Research*. New York: John Wiley and Sons, Inc., 537 pp.

Gulf of Mexico Fishery Management Council (1997) *Amendment 9 to the Fishery Management Plan for the Shrimp Fishery of the Gulf of Mexico, U. S. Waters*. Tampa, FL: Gulf of Mexico Fishery Management Council, 516 pp.

Gurshin, C. W. D. (2007) Shark nursery grounds in Sapelo Island National Estuarine Research Reserve, Georgia. In: C. T. McCandless, N. E. Kohler, & H. L. Pratt, Jr. (eds.) *Shark Nursery Grounds of the Gulf of Mexico and the East Coast Waters of the United States*. Bethesda, MD: American Fisheries Society, pp. 141 - 151.

Harrington, D.L., Watson J. W., Parker L. G., Rivers J. B. & Taylor C. W. (1988) *Shrimp Trawl Design and Performance*. Marine Extension Bulletin Number 12. Athens, GA: University of Georgia, Georgia Seagrant College Program, 41 pp.

McCandless, C. T., Kohler N. E., & Pratt, H. L. (eds.) (2007) *Shark Nursery Grounds of the Gulf of Mexico and the East Waters of the United States*. Bethesda, MD: American Fisheries Society, 390 pp.

Mertler, C. A. & Vannatta R. A. (2005) *Advanced and Multivariate Statistical Methods: Practical Application and Interpretation,* Third Ed. Glendale, CA: Pyrczak Publishing, 348 pp.

National Marine Fisheries Service (1992) *Shrimp Trawl Bycatch Characterization Sampling Protocol Manual for Data Collection*. Galveston, TX: National Marine Fisheries Service. 62 pp.

National Marine Fisheries Service (2007a) *Magnuson-Stevens Fishery Conservation and Management Act*. Silver Spring, MD : National Marine Fisheries Service. 178 pp.

National Marine Fisheries Service (2007b) *SEDAR 13 Stock Assessment Report: Small Coastal Sharks, Atlantic Sharpnose, Blacknose, Bonnethead, and Finetooth Shark*. Silver Spring, MD: National Marine Fisheries Service. 375 pp.

Page, J. M. (2008) *Assessment of Georgia's Marine Fishery Resources.* Final Report, Award No. NA05NMF4071001. Brunswick, GA: Georgia Department of Natural Resources, Coastal Resources Division. 21pp.

Shepherd, T. D. & Myers R. A. (2005) Direct and indirect fishery effects on small coastal elasmobranches in the northern Gulf of Mexico. *Ecology Letters* ***8***, 1095-1104.

South Atlantic Fishery Management Council (1996) *Amendment 2 to the Fishery Management Plan for the Shrimp Fishery of the South Atlantic Region*. Charleston, SC: South Atlantic Fisheries Management Council. 227 pp.

Stevens, J. D., Bonfil R., Dulvy N. K., & Walker P. A. (2000) The effects of fishing on sharks, rays, and chimaeras (chondrichthyans), and the implications for marine ecosystems. *ICES Journal of Marine Science* ***55*** (Suppl. 4), 476-494.

Stobutzki, I. C., Miller M. J., Heales D. S. & Brewer D. T. (2002) Sustainability of elasmobranchs caught as bycatch in a tropical prawn (shrimp) fishery. *Fishery Bulletin*. ***100***, 800-821.

C. N. Belcher and C. A. Jennings. In Press. Identification and evaluation of shark bycatch in Georgia's commercial shrimp trawl fishery with implications for management. Fisheries Management and Ecology. (SEDAR21-DW-23)

Zar, J. H. (1999) *Biostatistical Analysis,* Fourth Ed. Upper Saddle River, NJ: Prentice-Hall, 663 pp.

Table 1. Frequency of occurrence for shark species captured in Georgia's commercial shrimp trawl fishery from April 1995 through March 1998, by month. Frequency of occurrence is calculated as the percentage of tows that captured at least one individual ; *n* is the number of tows observed.

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 shark	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 shark	0.0	---	---	0.0	8.3	21.1	14.3	0.0	0.0	0.0	0.0	0.0
Spinner shark	0.0	---	---	0.0	0.0	0.0	0.0	11.1	0.0	0.0	0.0	0.0
Finetooth shark	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 2. Frequencies, size ranges, and frequency of occurrence for subadult sharks, by species, captured during observed commercial shrimp trawls in Georgia waters between April 1995 and March 1998. Frequency of occurrence 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	Frequency of Occurrence (%)	Size range (TL cm)
Atlantic sharpnose shark	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 shark	7	3.2	5.5	61.2 - 70.7
Spinner shark	2	<1	1.6	-----
Finetooth shark	2	<1	<1	53.9 and 60.5
All Species Combined	217	100	33.9	29.4 - 92.3

Table 3. Correlations between shark catch rates and tow time and tow speed for observed commercial shrimp trawls in Georgia waters (April 1995 – March 1998).

	Tow time, h			Tow speed, km h^{-1}		
Species	Correlation coefficient	*P*	n	Correlation coefficient	*P*	n
Atlantic sharpnose shark	0.1	0.368	82	0.03	0.825	74
All shark species combined	0.11	0.324	82	-0.01	0.923	74

Figure Legend

Figure 1. Map of commercial shrimp trawl locations off the coast of Georgia sampled by bycatch observers between April 1995 and January 1998. < filename: figure 1.tif >

Figure 2. Mean catch rates of sharks by commercial shrimp trawls, April 1995 – March 1998. Months with different letters indicate significant differences (P<0.05); months without letters had observed trawls, but sharks were not captured. Error bars represent 95% confidence intervals.
< filename: figure 2.tif >

Figure 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 different letters indicate significant differences (P<0.05). Error bars represent 95% confidence intervals. < filename: figure 3.tif >

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Fig. 1

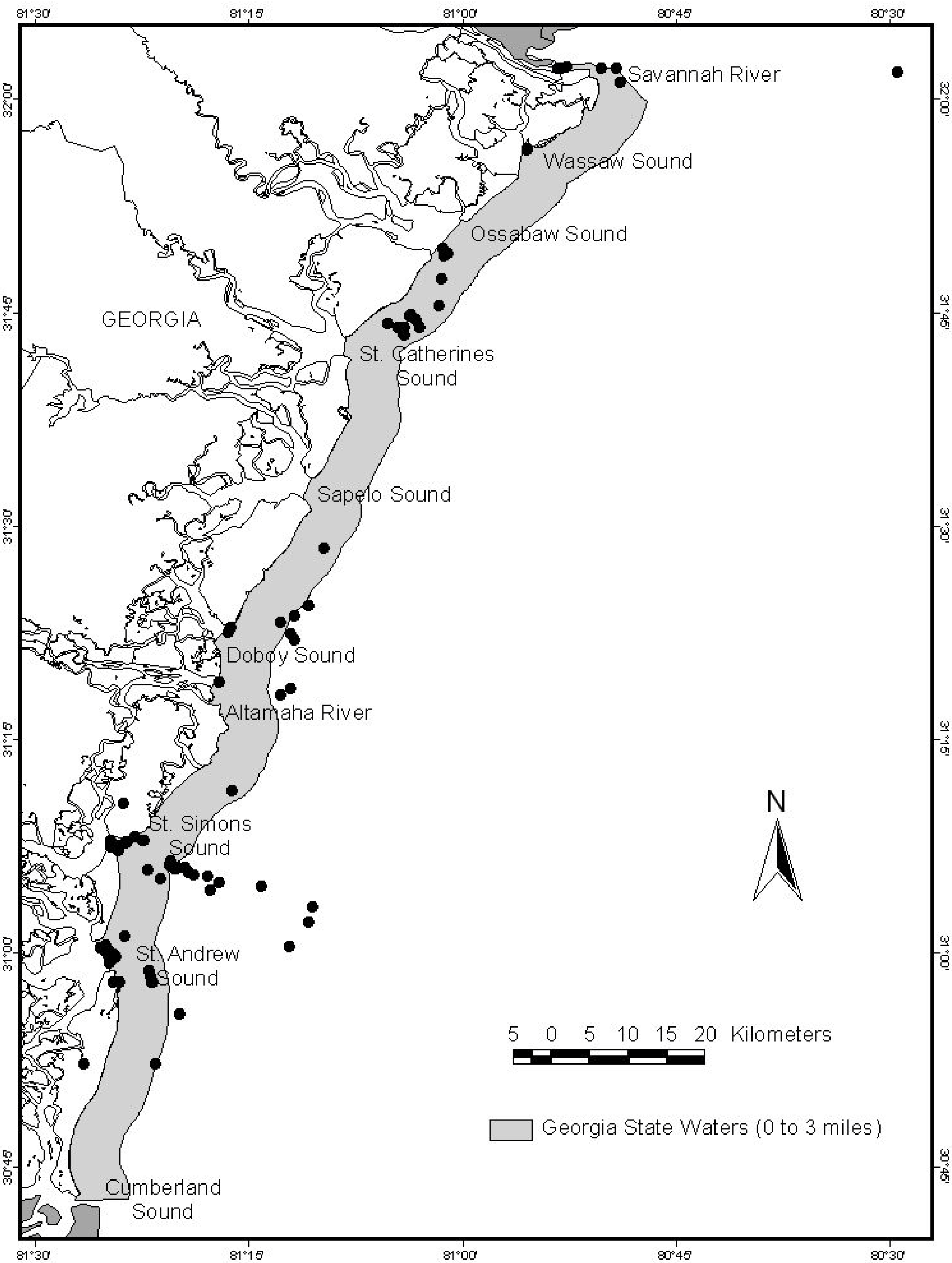

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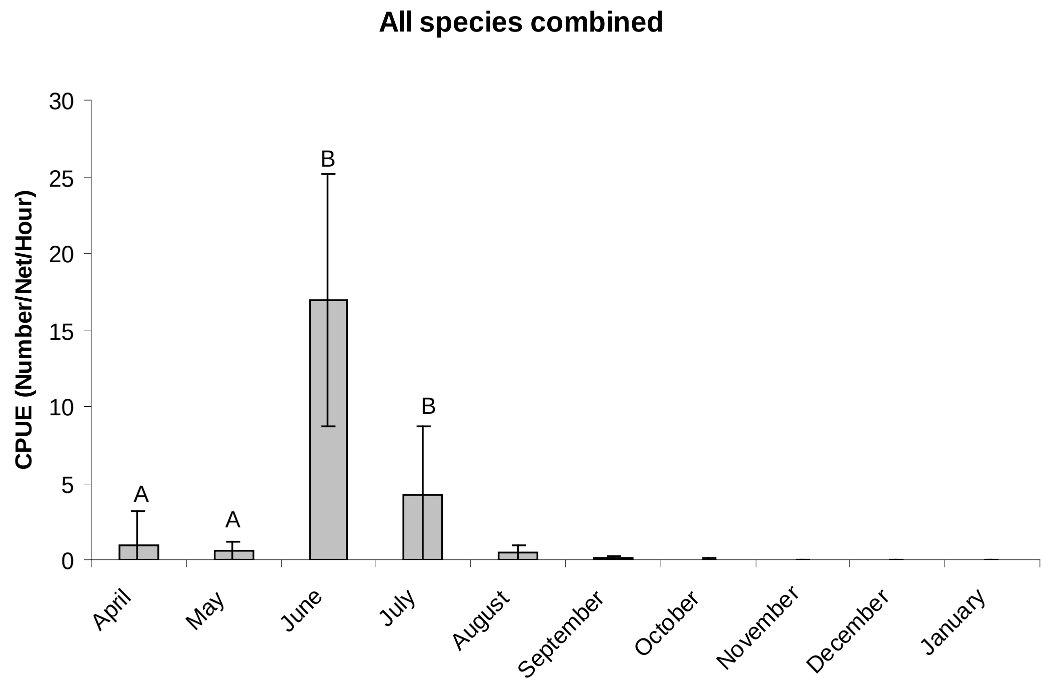
Fig 2.



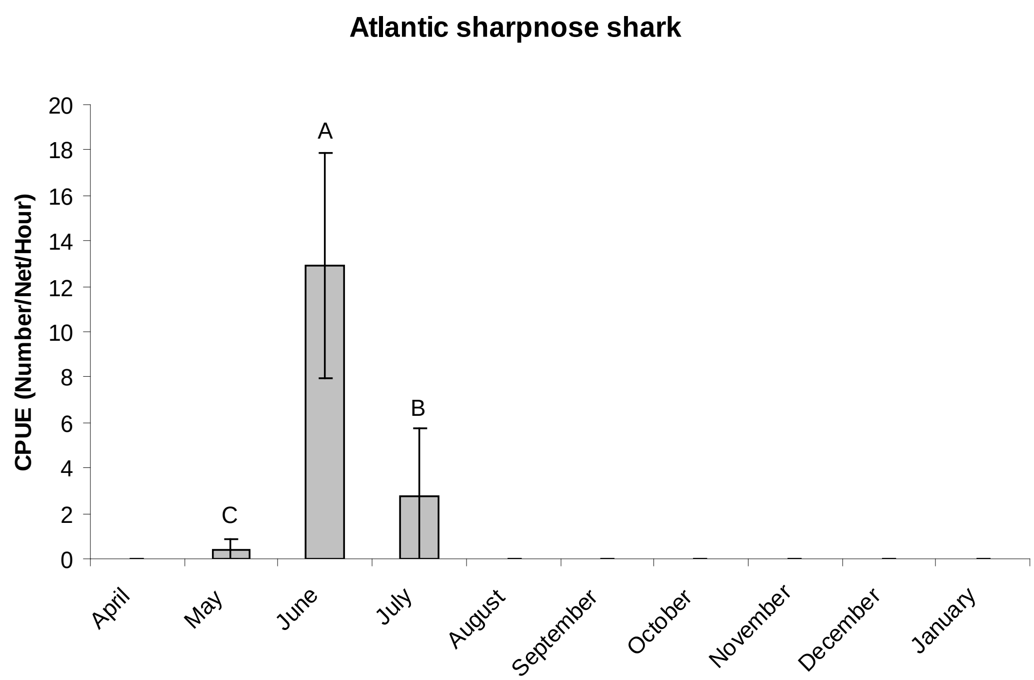


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Fig. 3