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Use of a Fishery-Independent Trawl Survey to Evaluate Distribution Patterns of Subadult Sharks in Georgia

CAROLYN N. BELCHER*

*Marine Fisheries Section, Coastal Resources Division, Georgia Department of Natural Resources,
One Conservation Way, Suite 300, Brunswick, Georgia 31520, USA*

CECIL A. JENNINGS

*U.S. Geological Survey, Georgia Cooperative Fish and Wildlife Research Unit, D.B. Warnell School of
Forestry and Natural Resources, University of Georgia, Athens, Georgia 30602, USA*

Abstract.—We investigated the utility of a fishery-independent trawl survey for assessing a potential multispecies shark nursery in Georgia's nearshore and inshore waters. A total of 234 subadult sharks from six species were captured on 85 of 216 trawls. Catch rates and size distributions for subadult sharks and the ratio of neonates to juveniles were consistent among areas. The highest concentrations of subadult sharks occurred in creeks and sounds. Species composition varied among areas. The Atlantic sharpnose shark *Rhizoprionodon terraenovae* was the most abundant species in sound and nearshore stations, whereas the bonnethead *Sphyrna tiburo* was the most abundant species in creeks. The aggregate of other species occurred with higher frequency in the sounds and nearshore. Sampling characteristics of the trawl survey were compared with those from a fishery-independent longline survey of subadult sharks to assess the similarity of the two gears. A total of 193 subadult sharks from seven species were captured during 57 of 96 longline sets, whereas 52 subadults from four species were captured during 20 of 48 trawls. Selectivity and efficiency differed between the two gears. The trawl had lower catch rates, caught smaller sharks, and encountered a different suite of species than the longline. General seasonal trends in relative abundance also differed between the two gears; the longline showed an increasing trend in abundance, whereas the trawl showed a stable trend. Although trawls were not found to be efficient for sampling subadult sharks from most species, they can be a useful source of supplemental data.

Sharks are 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 1970s to the mid-1980s (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 to be included in future assessments (NMFS 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 they 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 m deep (Carlson and Brusher 1999).

For many species, neonate and younger juvenile sharks occupy habitats that are distinct from those used by older juveniles and adults, especially during the summer months (Branstetter 1990). Fishery-dependent data are lacking for the subadult 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 in sharks is direct (Holden 1974; Carlson and

Brusher 1999; Helfman 2007). The importance of studying these life stages is twofold: (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 subadult 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 providing relative indices of abundance for subadult sharks. Carlson and Brusher (1999) present potential indices of abundance for multiple species generated from fishery-independent gill-net 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 *Carcharhinus plumbeus*. The Cooperative Atlantic States Shark Pupping and Nursery Grounds (COASTSPAN) survey was established in 1998 as a co-operative program between the National Marine Fisheries Service and state agencies along the East Coast of the United States to assess usage of coastal areas as shark nursery grounds and to develop sampling methodologies to be used for producing fishery-independent indices of subadult shark abundance. Under the COASTSPAN protocol, two gears (i.e., hand-retrieved longlines and gill nets) are being used to sample subadult sharks. In Georgia, the COASTSPAN project uses a hand-retrieved longline, with effort focused in the state's estuaries and inshore waters.

Longlines can be used to measure relative abundance for fish species if they are fished with a standardized protocol; 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 nets and trammel nets), they can be more selective than other gear types (Murphy and Willis 1996). Trawl gear has been used to measure relative abundance of fish and has the key advantage of being able to provide an estimate of the numbers of individuals per area sampled. 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 (Murphy and Willis 1996; Rago 2005).

Although trawls are not traditionally used to target large sharks (Rago 2005), they frequently encounter small sharks as bycatch (Castro 1983; Camhi 1998). The Georgia Department of Natural Resources' Coastal Resources Division 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 subadult sharks because the bycatch could provide insight about offshore abundances, which are not currently sampled with longlines.

The purposes of the present study were to (1) determine the utility of the bottom-trawl survey for evaluating the spatial distribution of subadult sharks in Georgia's nearshore and estuarine waters; (2) determine whether 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 subadult sharks.

Methods

Trawl survey.—The Georgia Department of Natural Resources' Coastal Resources Division has used a stratified, fixed-station sampling design since the late 1970s to conduct monthly trawl sampling on board the R/V *Anna*, an 18.3-m trawler. Sampling generally occurred during the first 2 weeks of each month and 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): Wassaw, Ossabaw, Sapelo, St. Simons, St. Andrew, and Cumberland. Three area classifications—creek or river, sound, and offshore—were delineated within each sound system. Two fixed stations within each type of area were sampled. A total of 36 stations were sampled each month coastwide (Figure 1). Shark bycatch was quantified in 2003 from trawls that occurred during the pupping season, which in Georgia waters generally extends from mid-April to 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 2 weeks of the month and on neap tides when possible. Tow speeds (i.e., the speed over the bottom) were standardized depending on the direction of the tow. Tows made against the tide were maintained at a speed of 3.7 km/h (2.0 knots), whereas those made with the tide were maintained at 4.63 km/h (2.5 knots). Tow time was constant at 15 min for each station.

Longline survey.—Longline sampling, conducted under the COASTSPAN protocol established by the National Marine Fisheries Service's Apex Predator Investigation (NMFS 1997), occurred from mid-April to the end of September in 2003. The longline, which was bottom-set and retrieved by hand, was secured to the bottom via standard 4.1-kg Danforth multipurpose anchors, the ends of which were marked with orange A-2 Polyform fluorescent buoys. The longline consisted of a 305-m mainline of 6.4-mm braided nylon and
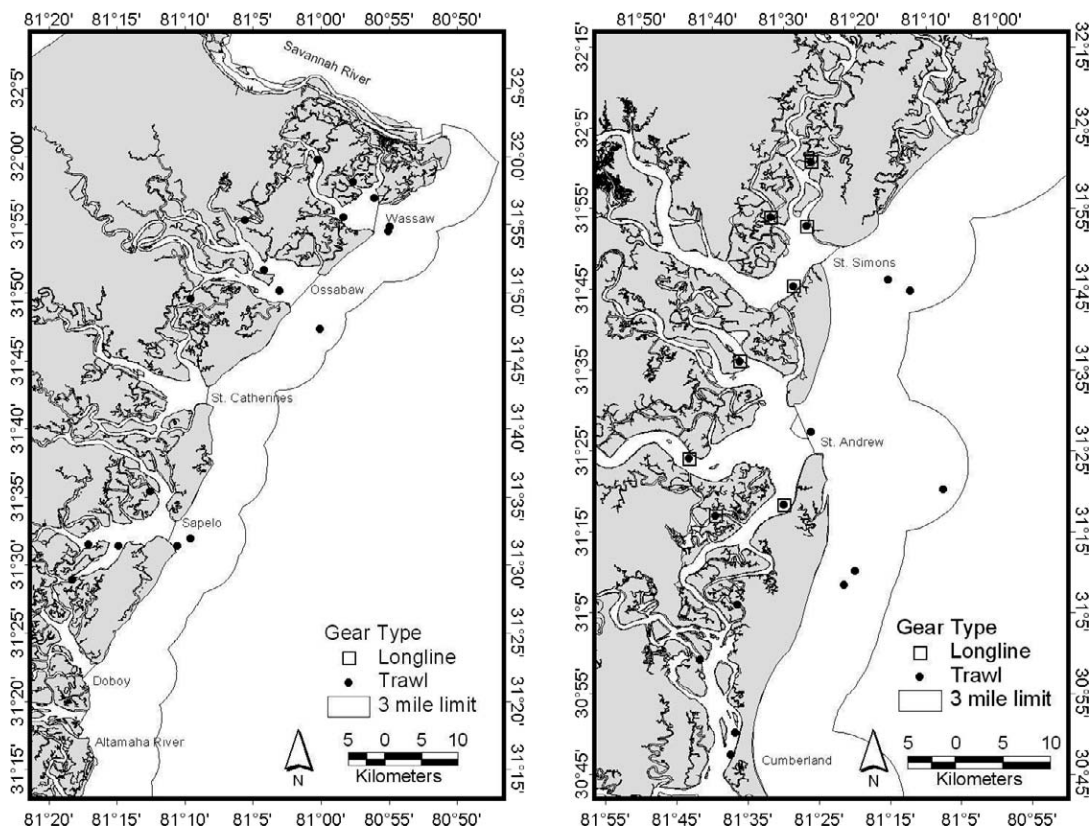
FIGURE 1.—Map of trawl stations (filled hexagons) and hand-retrieved longline stations (open hexagons) fished in Georgia estuaries during 2003.

50 removable gangions or droplines. From the terminal end, each gangion was comprised of a 12/0 Mustad nonoffset circle hook with depressed barb, 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. Half of the 50 hooks were baited with squid *Loligo* spp., and the remaining hooks were 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 or river and sound) of St. Simons and St. Andrew sounds (Figure 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 2 weeks of each month because concurrent sampling with both gears was not possible.

Shark sampling from shrimp trawl bycatch.—All sharks encountered as bycatch in the trawls were identified to species, sexed, measured for both fork

length (FL, cm) and total length (TL, cm), and weighed (kg); characteristics of the umbilical scar were also recorded. Sharks were classified as neonates or juveniles based on the presence of an umbilical scar and the degree of healing (NMFS 1997). Species- and sex-specific lengths at maturity presented by Castro (1983) were used to distinguish juveniles from adults.

All sharks caught in trawl tows 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 prevented the use of a live well; however, all sharks shorter than 50 cm TL were placed in an aerated 18.93-L (5-gal) bucket until they could be processed. Sharks longer than 50 cm TL were processed immediately, tagged on the first dorsal fin with a numerically referenced plastic roto-type tag (i.e., the 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 ensure maximum survival once they were 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 alongside 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 fish. When necessary, for hooks that could not be easily removed (e.g., embedded in the jaw), one of two procedures was used: (1) the hook was cut with wire cutters and removed from the fish's mouth or (2) the leader was cut as close as possible to the hook (for large sharks [>1.2 m TL] that were too big to bring onto the boat). 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 effort.—Although catch per unit 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 1 h 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 valid for the trawl because it continues to fish as time increases; however, the assumption may not be valid 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 (>90%) was gone after 30 min. Because a linear relationship between trawl catches and tow time has not been confirmed, trawl CPUEs could not be expressed in terms of 30 min.

Because both surveys have standardized sampling protocols, CPUE was defined as the number of individuals captured per sampling event for both longline sets and tows. The CPUEs were calculated for the aggregate shark catch and for individual species represented by a grand total of 15 or more individuals.

Statistical Analyses

Trawl catch characteristics.—Catch rates and average FLs 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). The species-specific and aggregate CPUEs and FLs were nonnormally distributed. Because the catch data exhibited a negative binomial distribution, an inverse hyperbolic sine transform was applied to those data (Zar 1999). Because the FLs exhibited a substantial positive skew, $\log_{10}$ transformation was applied (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 by using Excel 2000 software (Microsoft Corporation, Redmond, Washington).

Multinomial χ^2 analyses (Zar 1999) were used to determine whether overall species composition and life stage composition for the aggregate catch and most abundant species differed among areas. Chi-square analyses were conducted by using the Statistical Analysis System (SAS) version 9.1 (SAS Institute 2002).

Because of small sample sizes produced by the two standardized survey protocols, the high variation in the data, and the exploratory nature of the study, a statistical significance level α of 0.10 was used for all 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 FLs 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 nonnormal, and transformations were not successful in normalizing the data. As a result, these data were analyzed with appropriate nonparametric tests or parametric methods applied to rank transformations of the data.

Because the catch data were not normally distributed, parametric analyses of covariance (ANCOVAs) could not be used on the raw data to determine whether the longline and trawl detected similar seasonal trends of abundance for the commonly occurring species and the aggregate catch. Although a nonparametric rank ANCOVA 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 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 that occur in July). The presence or absence of neonate and juvenile sharks

TABLE 1.—Frequencies and encounter rates, by species, for subadult sharks captured during standardized trawls in Georgia estuaries during 2003. Encounter rate is calculated as the number of sets that encountered at least one individual of the given species divided by the total number of sets ($n = 216$).

Species	Total number captured	Number of positive stations	Encounter rate (%)
Atlantic sharpnose shark *Rhizoprionodon terraenovae*	151	61	28
Bonnethead *Sphyrna tiburo*	75	42	19
Blacktip shark *Carcharhinus limbatus*	3	3	1
Scalloped hammerhead *S. lewini*	2	2	1
Sandbar shark *C. plumbeus*	2	1	<1
Blacknose shark *C. acronotus*	1	1	<1
All species	234	85	39

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 since 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 general linear models procedure and the rank-transformed catch rates and water temperatures to evaluate whether seasonal abundance patterns differed between gears. An α of 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 FLs 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 FLs of the aggregate catch and the most abundant species caught by both gears. Overall species composition and life stage characteristics for the aggregate catch and the most abundant species were analyzed with multinomial χ^2 analyses (Zar 1999). Wilcoxon rank-sum tests and χ^2 analyses were conducted in SAS and were evaluated at an α of 0.10.

Results

Trawl Catch Characteristics

A total of 234 subadult sharks from six species were captured during 85 of 216 trawls (Table 1). The two most abundant shark species, which accounted for 96.6% of the total shark bycatch, were the Atlantic sharpnose shark and bonnethead. The total number of

sharks captured per sampling event ranged from 0 to 12 (mean = 1.1, SD = 2.2). Other species captured in trawls were the blacktip shark, scalloped hammerhead, sandbar shark, and blacknose shark (Table 1). Because of low capture numbers, these latter species were combined into a single group (i.e., "other species") for inclusion in the overall species analyses.

Trawl catch rates for subadult sharks among areas were not different for the aggregate catch or for the Atlantic sharpnose shark (Table 2). The bonnethead catch rates differed among areas; catches in the offshore sector (mean = 0.14 fish/sampling event, SD = 0.48) were significantly lower than those in the inshore sectors (sound: mean = 0.43 fish/sampling event, SD = 1.06; creek or river: mean = 0.47 fish/sampling event, SD = 1.26).

The average FLs of sharks did not differ among areas for the aggregate catch or for the Atlantic sharpnose shark (Table 2). The average FLs differed among areas for bonnetheads; the larger bonnetheads occurred in offshore waters. Average sizes (FL) of bonnetheads were 46.4 cm (SD = 14.9) in the offshore sector, 41.3 cm (SD = 11.9) in the sound sector, and 37.1 cm (SD = 6.0) in creek–river sector.

TABLE 2.—Results of Kruskal–Wallis test of differences in catch per unit effort (CPUE; fish/sampling event) and fork length (FL, cm) among sampling areas for aggregate and species-specific catches of subadult sharks collected during 2003 (df = 3; asterisks denote significant differences among areas at $P < 0.10$).

Species	Calculated χ^2
Atlantic sharpnose shark	
CPUE	1.36
FL	0.67
Bonnethead	
CPUE	6.43*
FL	7.04*
All species combined	
CPUE	1.04
FL	3.88

Table 3.—Contingency table examining the relationship between species composition of subadult sharks and trawl sampling area type in Georgia estuaries during 2003.

	Species			
Area	Atlantic sharpnose shark	Bonnethead	Other sharks	Total
Creek or river				
Frequency	29	34	1	64
Row %	45.31	53.13	1.56	
Sound				
Frequency	75	31	4	110
Row %	68.18	28.18	3.64	
Offshore				
Frequency	47	10	3	60
Row %	78.33	16.67	5.00	
Total	151	75	8	234

Life stage was independent of the sampling area for Atlantic sharpnose sharks ($\chi^2_{0.10,2} = -1.05$, $P = 0.59$) and bonnetheads ($\chi^2_{0.10,2} = 0.20$, $P = 0.99$). The ratio of juveniles to neonates for Atlantic sharpnose sharks (1:3) was consistent among areas. Bonnetheads also had a consistent ratio of juveniles to neonates (10:1) among areas. 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 sector (1:1 ratio), whereas juveniles dominated the creek–river sector (2:1) and neonates dominated the offshore sector (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 and higher frequencies in the sound sector (Table 3). Atlantic sharpnose sharks were the dominant species in the sound and offshore sectors, whereas bonnetheads were the dominant species in the creek–river sector (Table 3). When other species were captured in any numbers, they were more likely to be in the sounds and offshore waters (Table 3).

Between-Gear Comparisons

A total of 193 subadult sharks from seven species were captured during 57 of 96 longline sets, whereas 52 subadults from four species were captured at trawl stations (Table 4). All species captured at trawl stations also were encountered at longline stations.

Four species—the Atlantic sharpnose shark, sandbar shark, bonnethead, and blacktip shark—accounted for 97.4% of the total shark catch on the longline. Two species, the Atlantic sharpnose shark and bonnethead, accounted for 96.2% of the total shark catch in the trawls. The catch rate of bonnetheads was higher in trawls than on longlines; however, catch rates for other

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

	Number of positive sets		Encounter rate (%)	
Species	Longline	Trawl	Longline	Trawl
Atlantic sharpnose shark	42 (122)	12 (27)	44	25
Sandbar shark	15 (30)	0 (0)	16	0
Bonnethead	19 (28)	13 (23)	20	27
Blacktip shark	8 (8)	1 (1)	8	2
Bull shark *Carcharhinus leucas*	2 (3)	0 (0)	2	0
Scalloped hammerhead	1 (1)	1 (1)	1	2
Finetooth shark *C. isodon*	1 (1)	0 (0)	1	0
All species	57 (193)	20 (52)	59	42

species in the study were higher on longlines than in trawls. Blacktip sharks and scalloped hammerheads 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 and the bull shark (Table 4).

The significant interaction terms in the ANCOVA results indicated that the trawl and longline gears sampled the aggregate of subadult sharks and Atlantic sharpnose sharks differently (Table 5; Figure 2). For bonnetheads, the interaction between water temperature and gear type was not statistically significant and indicated that the two gears exhibited similar trends (Table 5; Figure 2). However, further examination of the results indicated that water temperature may be a poor indicator of abundance for subadult bonnetheads and that the abundance did not differ between the two gears as neither main effect was significant (Table 5). The total catch for all species ($Z = -2.73$, $P = 0.0071$) and for Atlantic sharpnose sharks ($Z = -2.38$, $P = 0.02$) differed significantly between gears; the longline caught more sharks per sampling event than the trawls (Figure 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 sharks ($Z = -4.35$, $P < 0.0001$), bonnetheads ($Z = -4.01$, $P = 0.0002$), and the aggregate catch ($Z = -5.06$, $P < 0.0001$). The average sizes of Atlantic sharpnose sharks (mean = 38.4 cm FL, SD = 13.3) and bonnetheads (mean = 51.9 cm FL, SD = 13.5) captured on the longline were larger than those of the fish caught during trawls (Atlantic sharpnose sharks: mean = 30.3 cm FL, SD = 4.8; bonnetheads: mean = 36.3 cm FL,

TABLE 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 subadult sharks in St. Simons and St. Andrew estuaries, Georgia, during 2003, as explained by water temperature. Asterisks indicate that the assumption of homogeneous slopes was not valid.

Source	Type III sum of squares	df	Mean square	F	P
Atlantic sharpnose shark					
Model	50,810.15	3	16,936.72	17.37	<0.0001
Water temperature	32,885.64	1	32,885.64	33.72	<0.0001
Gear type	436.61	1	436.61	0.45	0.5046
Water temperature × gear type	7,515.49	1	7,515.49	7.71	0.0063*
Error	136,543.85	140	975.31		
Corrected total	187,354.00	143			
Bonnethead					
Model	3,548.43	3	1,182.81	1.30	0.2770
Water temperature	2,408.29	1	2,408.29	2.65	0.1060
Gear type	533.05	1	533.05	0.59	0.4454
Water temperature × gear type	167.26	1	167.26	0.18	0.6688
Error	127,403.57	140	910.03		
Corrected total	130,952.00	143			
All species combined					
Model	68,131.47	3	22,710.49	20.62	<0.0001
Water temperature	41,269.75	1	41,269.75	37.48	<0.0001
Gear type	634.98	1	634.98	0.58	0.4489
Water temperature × gear type	11,195.26	1	11,195.26	10.17	0.0018*
Error	154,165.53	140	1,101.18		
Corrected total	222,297.00	143			

SD = 7.6). In general, the size distributions associated with each gear type exhibited either symmetrical dome-shaped size selectivity (trawl-caught sharks) or asymmetric dome-shaped size selectivity that was strongly skewed towards large sizes (longline-caught sharks; Figure 4).

The proportions of neonate and juvenile bonnetheads 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 3.6:1.0 for the trawl.

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

Discussion

Utility of Bottom-Trawl Gear for Sampling Subadult Sharks

The results of the present study indicate that bottom trawls provide useful information for assessing the subadult portion of both the Atlantic sharpnose shark and bonnethead populations in Georgia and perhaps in similar southeastern U.S. waters. Although six species were captured during trawls, Atlantic sharpnose sharks and bonnetheads 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 the average size of the subadult shark aggregate catch among areas probably reflects gear selectivity and not the actual size distribution of the subadult population 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 the 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. In addition, many small species (e.g., Atlantic sharpnose shark and bonnethead) may be incapable of swimming faster that the net is pulled. The majority of subadults encountered during trawls were less than 45 cm FL (Figure 4). Other shark species that are common to Georgia waters (e.g., blacktip shark and sandbar shark) are born at sizes larger than 45 cm (Castro 1983; Compagno 1984) and may be capable of swimming faster than the net is pulled.

Subadult 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, Georgia (Gurshin 2007), and in South Carolina estuaries (Ulrich et al. 2007) also have shown similar patterns in abundance for this
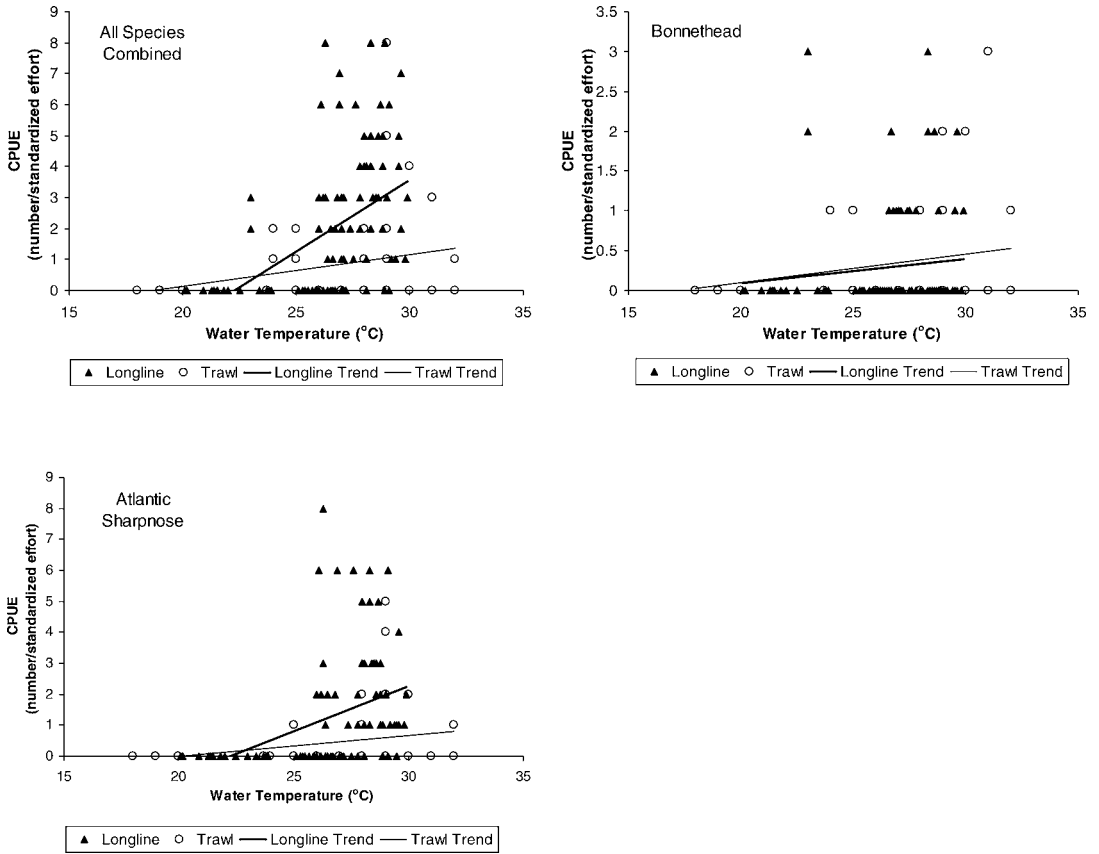
FIGURE 2.—Seasonal trends (as a function of water temperature) in subadult shark catch per unit effort (CPUE; standardized) by gear type for all shark species, Atlantic sharpnose sharks, and bonnetheads in Georgia estuaries, 2003.
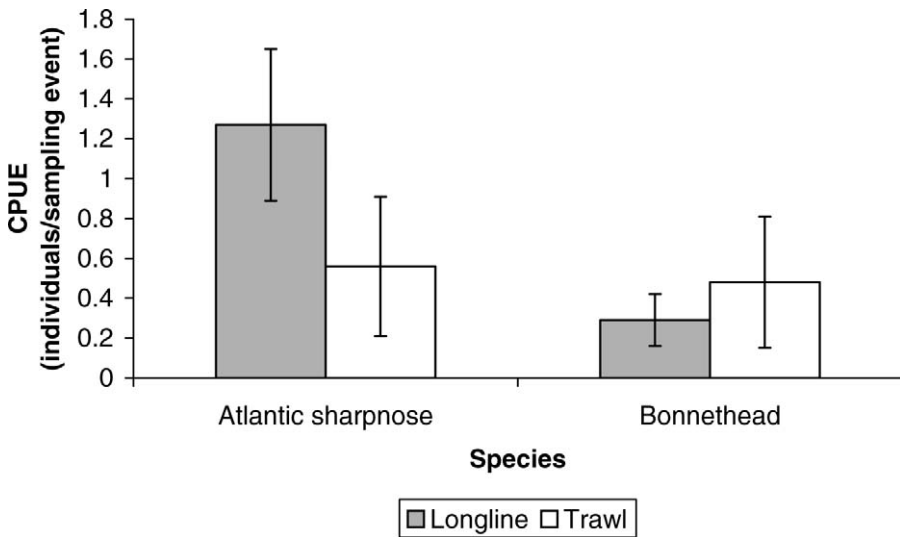

FIGURE 3.—Mean (±95% confidence interval) subadult shark catch per unit effort (CPUE; standardized) by gear type for Atlantic sharpnose sharks and bonnetheads in Georgia estuaries, 2003.
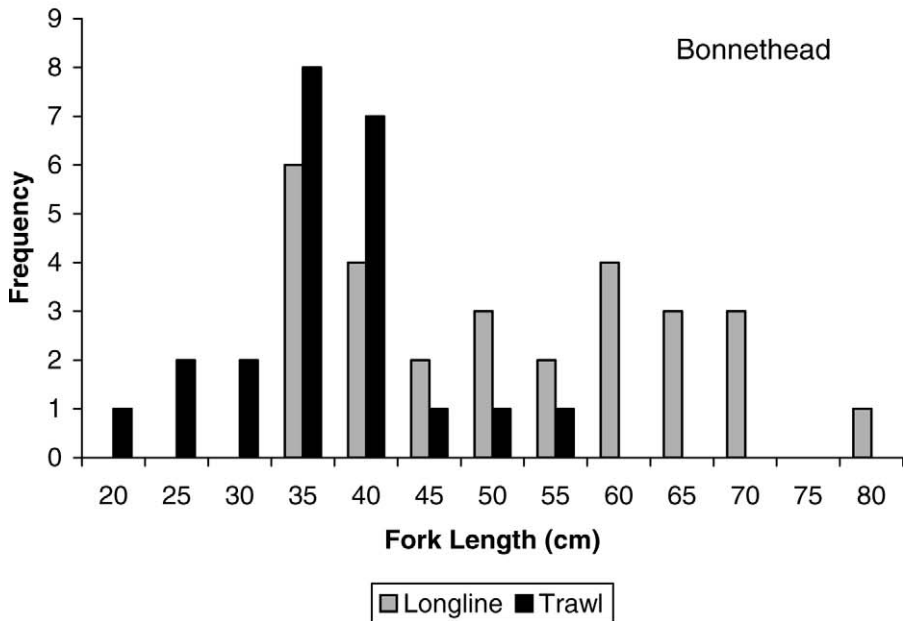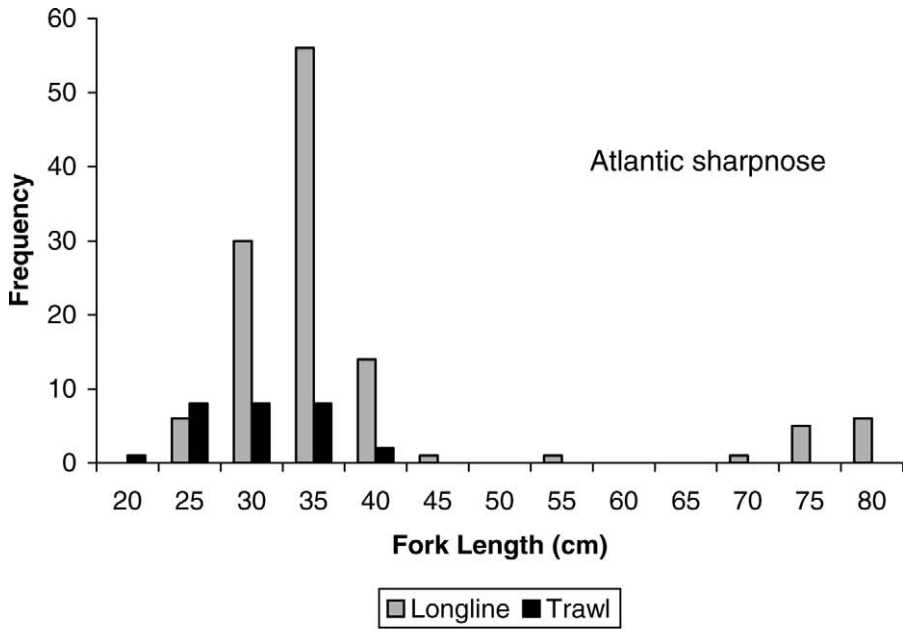
FIGURE 4.—Length frequency distributions of subadult Atlantic sharpnose sharks and bonnetheads captured by longlines and trawling in Georgia estuaries during 2003.

TABLE 6.—Contingency table examining the relationship between gear type and species composition of subadult sharks captured in Georgia estuaries during 2003.

Gear	Species			Total
	Atlantic sharpnose shark	Bonnethead	Other sharks	
Longline				
Frequency	122	28	43	193
Row %	63.21	14.51	22.28	
Trawl				
Frequency	27	23	2	52
Row %	51.92	44.23	3.84	
Total	149	51	45	245

species. The results of our study suggest that Atlantic sharpnose sharks 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 (Snelson and Williams 1981; Castro 1993; Simpfendorfer and Milward 1993; McCandless et al. 2007). The suggested advantages of these areas are protection from predators and abundant food sources (Branstetter 1990; Castro 1993; Simpfendorfer and Milward 1993). Other studies suggest 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 provide protection from predators, one would expect to find the average size of sharks caught inshore to be smaller than the size of sharks caught offshore and to observe 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 shark) that exhibit a productive life history (i.e., rapid growth, early maturity, and annual reproduction) and high rates of population growth.

Results from the trawl data collected during the present study support distributional patterns of bonnetheads observed by Heupel et al. (2006) and Ulrich et al. (2007). Heupel et al. (2006) found that juvenile bonnetheads larger than 60 cm TL and adult bonnetheads in Pine Island Sound, Florida, were resident to the estuary and did not seem to undergo long-distance coastal migrations. 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 were captured in April and early May. In Georgia, the offshore areas were used by larger bonnetheads but with lower frequency than the inshore areas. Such habitat use patterns suggest that pupping might occur in inshore waters. Given (1) the spatial overlap in

sampling between the two sampling gears used during the present study and (2) the capture of neonate bonnetheads during trawl tows but not during longline sets, the conspicuous absence of neonates from other studies is possibly a function of gear type. Ulrich et al. (2007) analyzed data that were collected with gill nets and longlines, whereas Heupel et al. (2006) analyzed data for bonnetheads that were collected with gill nets.

The proportion of neonates to juveniles for the aggregate catch varied among areas. Contrary to hypotheses about shark nurseries, the current study demonstrated that a higher ratio of neonates occurred offshore than in the creeks and sounds. If one assumes that inshore areas provide 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, which was represented predominantly by juveniles. The most abundant species in the offshore sector was the Atlantic sharpnose shark, which was represented mostly by neonates. In evaluating multispecies nursery areas, the neonate to juvenile ratio needs to be assessed at the species level because distributional patterns also affect these ratios.

Gear Comparisons

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

Comparisons between the trawl and longline gears indicate that each gear sampled the population of subadult sharks differently. The species diversity of the longline catch was higher than the diversity of the trawl catch. The species (e.g., sandbar shark, blacktip shark, and bull shark) that occurred with lower frequency or were absent from trawl catches are born at larger sizes

than either the Atlantic sharpnose shark or the bonnet-head, which were commonly caught in the trawls. Sandbar sharks, blacktip sharks, 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 conjecture that larger-sized species are able to avoid the net (Rago 2005).

Although the aggregate catch rate and the Atlantic sharpnose shark catch rate were higher on the longline than in the trawl, determining the true magnitude of difference between the two gears is difficult because their fishing capabilities differ. Although both gears are fished essentially along the estuarine or the 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 depth strata sampled by the trawl.

Catch rates for bonnetheads did not differ between the two gears. A lack of efficiency associated with the longline for capturing bonnetheads was documented by Ulrich et al. (2007); the majority of bonnetheads captured during their study were caught with gill nets and not on hooks baited with teleosts. Part of this inefficiency could be attributed to bait type. Belcher (2008) found that bait type influenced longline catch rates as bonnetheads were captured only on hooks baited with squid. Bonnethead diets are largely composed of crustaceans and mollusks (Castro 1983; Compagno 1984). Because half of the hooks on each set during the present study were baited with fish, bonnetheads may have been underrepresented in longline catches. Although evidence exists for differ-ences 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 the present study was evident as the average size of subadult sharks at both the species and aggregate levels 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 either that neonates are encountered more frequently during trawls or that they are not attracted to the baits used during longline sets. The results of the present study indicate that this assumption is only supported for bonnetheads. The results of the aggregate catch and Atlantic sharpnose shark life stage analyses indicate that equal ratios of neonates to juveniles are present in the catch of the two gears. All sharks that lack the umbilical evidence to classify them as neonates 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 attracts a broader range of ages. Only the trawl gear captured bonnethead neonates, which is probably a function of feeding ecology for this particular species and 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 subadult portion. Generally, trawls are not used to assess shark populations because of sharks' large sizes, 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 use of active gears to target sharks may be cost prohibitive, bycatch information from surveys employing active gear could be a valid source for ancillary data and trends in abundance for smaller shark species, such as the Atlantic sharpnose shark and bonnethead.

Subadult sharks are 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 (e.g., Atlantic sharpnose shark and bonnethead) occur often enough that data collected from trawls could be useful in developing indices of abundance for neonates and small juveniles.

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