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Abstract.—Before the gears were used for catch comparisons, a two-seam net and a tongue trawl were evaluated for changes in net dimensions with fishing depth and tow direction. When towed as it would be during catch comparisons, the two-seam net had a width of 16.1 m and was estimated to extend 2.1 m vertically at the center of the headrope. The horizontal spread of the tongue trawl was 13.5 m and its vertical spread was 4.2 m at center. Small, statistically consistent differences in openings (<0.5 m) occurred with depth and direction. The major factor influencing changes in catch (kg/ha) with depth (10-fold increase in shallow water) appeared to be the faunal distribution with depth, independent of towing characteristics. Differences in biomass (kg/tow, kg/ha), and in the biomass (kg/ha) ratios of taxa to shrimp between the two-seam and tongue trawls were documented for eight major biological groups. Major differences in total catch by net occurred between years primarily because of changes in the catch of miscellaneous invertebrates and shrimp. Significant differences in the lengths of nine priority species occurred between the two gears. Mean lengths in the two nets differed by more than 1 cm for spot *Leiostomus xanthurus* (which was larger in the tongue net), Atlantic croaker *Micropogonias undulatus* (larger in the two-seam net), and Spanish mackerel *Scomberomorus maculatus* (larger in the tongue net). Mean ratio of fish to shrimp biomass was 31:1 overall (21:1 for the two-seam net and 41:1 for the tongue trawl). Ratios of total biomass and the biomass of any taxonomic grouping to shrimp biomass did not differ statistically between the two gears. Biomass ratios were recalculated from published data by a standard methodology. Subsequent comparisons indicated increases in the ratios over time and highlighted a need to validate the technique of subsampling heterogenous trawl samples. Finfish by-catch in both gears was dominated by sciaenids (44% by weight of all fish). Red drum *Sciaenops ocellatus*, spotted seatrout *Cynoscion nebulosus*, snappers (Lutjanidae), and groupers (Epinephelinae) were not caught by either net. Catches of Spanish mackerel and king mackerel *Scomberomorus cavalla* were documented and warrant further investigation to evaluate the effects of by-catch on local populations.

Since the early 1900s, the shrimp fishery off the southeastern United States has harvested shrimp primarily by trawling in nearshore coastal waters. During trawling, many fish and invertebrate species are caught in addition to the targeted shrimp. This nontargeted or incidental catch, generally referred to as by-catch, has been the subject of numerous studies (Lunz et al. 1951; Anderson 1968; Keiser 1977; Brown et al. 1979; Low et al. 1982). Estimates of the by-catch magnitude per boat have ranged from 54.4 kg/h (Knowlton 1972) to 548.4 kg/h (Rothmayr 1965). The biomass ratio of fish to shrimp has ranged from 0.30:1 (Keiser 1976) to 49,500:1 (Keiser 1977).

Murray et al. (1992) considered by-catch in the shrimp fishery as "the most important issue southeastern U.S. fishery managers must address." On both the Atlantic and Gulf of Mexico coasts, there has been increased public and scientific concern over the status of fish stocks of commercial and recreational value and whether the stocks are significantly impacted by shrimp trawling. The major basis for this concern is that the shallow nearshore waters represent both the areas of greatest shrimp trawling activity and important nursery grounds for many species, including spot, Atlantic croaker, weakfish, and red drum (scientific names of these and most other species cited are given in Table 2). Powers et al. (1987) estimated that a 90% increase in the yield of red snapper *Lutjanus campechanus* in the Gulf of Mexico could result from reduction in shrimp by-catch. However, Gutherz and Pellegrin (1988) estimated that approximately 4.8×10^6 juvenile red snapper were caught annually by shrimp trawling over a 10-year period and concluded that the impact of juvenile mortalities on the total population was probably minimal. Understanding the magnitude of the by-catch and how it relates to the total population of each species collected is critical to proper management of our fishery resources.

During the last 10 years, trawling for shrimp in Atlantic waters off the southeastern United States has been done with two types of nets. For brown shrimp, which live predominately near the bottom, most shrimpers have used a traditional two-seam net with a relatively small vertical opening (≈2 m). For white shrimp, which shrimpers believed live higher in the water column, various nets (falcon, tongue, mongoose, or fly), designed for increased vertical opening and overhanging headrope, have been developed and fished. Previous estimates of by-catch in the Atlantic shrimp fishery have been based primarily on catches by low-opening two-seam nets. Questions have arisen over differences in by-catch that might be associated with the differently configured tongue nets.

The purposes of this paper are (1) to briefly describe the performance characteristics of the two-seam and tongue nets, (2) to summarize the magnitude and species composition of the by-catch from the two types of trawls, (3) to specify statistical differences in by-catch between gears during brown and white shrimp fishing seasons, and (4) to compare our findings with other observations and studies from other areas.

Methods

Area sampled.—Most of the comparative trawling was conducted in three local shrimping grounds: two areas north of Charleston Harbor and an area off Stono Inlet (Figure 1). A few tows were made off the North Edisto River and south of the Charleston South Jetty. All tows were made amongst the operating shrimp fleet or where the fleet had recently fished. Shrimpers often were towing both inshore and offshore of our research vessel, the RV *Lady Lisa*, a 23-m St. Augustine double-rigged trawler. Rotary currents in these coastal areas vary with tidal stage and local wind conditions, and alternating trawling directions are used to minimize the effect of these factors on catch.

Gear description.—The two nets compared were a tongue (Falcon) net and a two-seam net, both built as 26.5-m nets. Both nets were constructed by Beaufort Marine Supply of Bluffton, South Carolina. The top, bottom, wings, and first and second tail bags had 4.8-cm-stretch mesh constructed of number 15 nylon thread. The cod ends had 4.2-cm-stretch mesh made of number 30 nylon thread. The nets were towed simultaneously with the two-seam net on the port side and the tongue trawl on the starboard side. It was originally planned to alternate the nets between vessel sides, but the complications of changing nets and towing bridles (two bridles for the two-seam net, three for the tongue trawl) would have prevented a sufficient number of trawls from being completed in the budgeted time. Towing two nets required that a certain amount of rudder angle be applied to maintain course with unbalanced net drag on each side. To minimize the effect of this on the catches, tow direction was alternated (referred to as side toward shore during trawl), which required varying amounts of rudder angle during tows in alternating direction. The overall effect of these procedures on catches was evaluated during mensuration.

The 27.2-m footrope of the tongue net (Figure 2) had chain loops of progressively decreasing size (3 loops of 1.0-cm chain, 10 loops of 0.8-cm chain, 10 loops of 0.6-cm chain, 5 loops of 0.5-cm chain, and 2 additional loops of 0.6-cm chain) on each side of the middle. A 0.9-m chain extension ran between the center of the footrope and the tickler chain. The length of the tickler chain, attached between the doors (102 cm by 305 cm), was kept approximately 1.2 m shorter than the footrope to drag 0.9 m ahead of the footrope. The 26.6-m headrope of the tongue net had one large (60-cm) Norwegian float attached to the top center of the net and two 22.3-cm styrofoam floats, each located one-fourth of the distance from each end of the 23.3 m of net webbing. When stretched lengthwise, the tongue trawl measured 17.2 m from the center of footrope to the end of the cod end. The cod end of the tongue trawl was protected by chafing gear of 10.2-cm stretch mesh with 20-cm plastic streamers.

The 29.2-m footrope of the two-seam net (Figure 3) had chain loops of progressively decreasing size (12 loops of 0.8-cm chain, 10 loops of 0.6-cm chain, then 3 additional loops of 0.6-cm chain) on each side of the middle, with one loop of 0.6-cm chain in the middle of the footrope. A 1.0-m chain extension connected the center of the footrope with the tickler chain. The 26.7-m headrope of the two-seam net had three 22.3-cm styrofoam floats positioned at about quarter distances (≈6 m) along the 22.5 m of net webbing. When stretched on the ground, the two-seam net measured approximately 13.5 m in length between the center of the footrope and end of the cod end. The cod end on the two-seam trawl was protected by chafing gear of heavy 7.6-cm stretch "scallop" mesh.

Net mensuration.—Measurements of the width and height of each net in actual towing configuration were transmitted from SCANMAR[1] hydroacoustic transponders attached to the net wings

[1] Use of trade name does not imply endorsement.

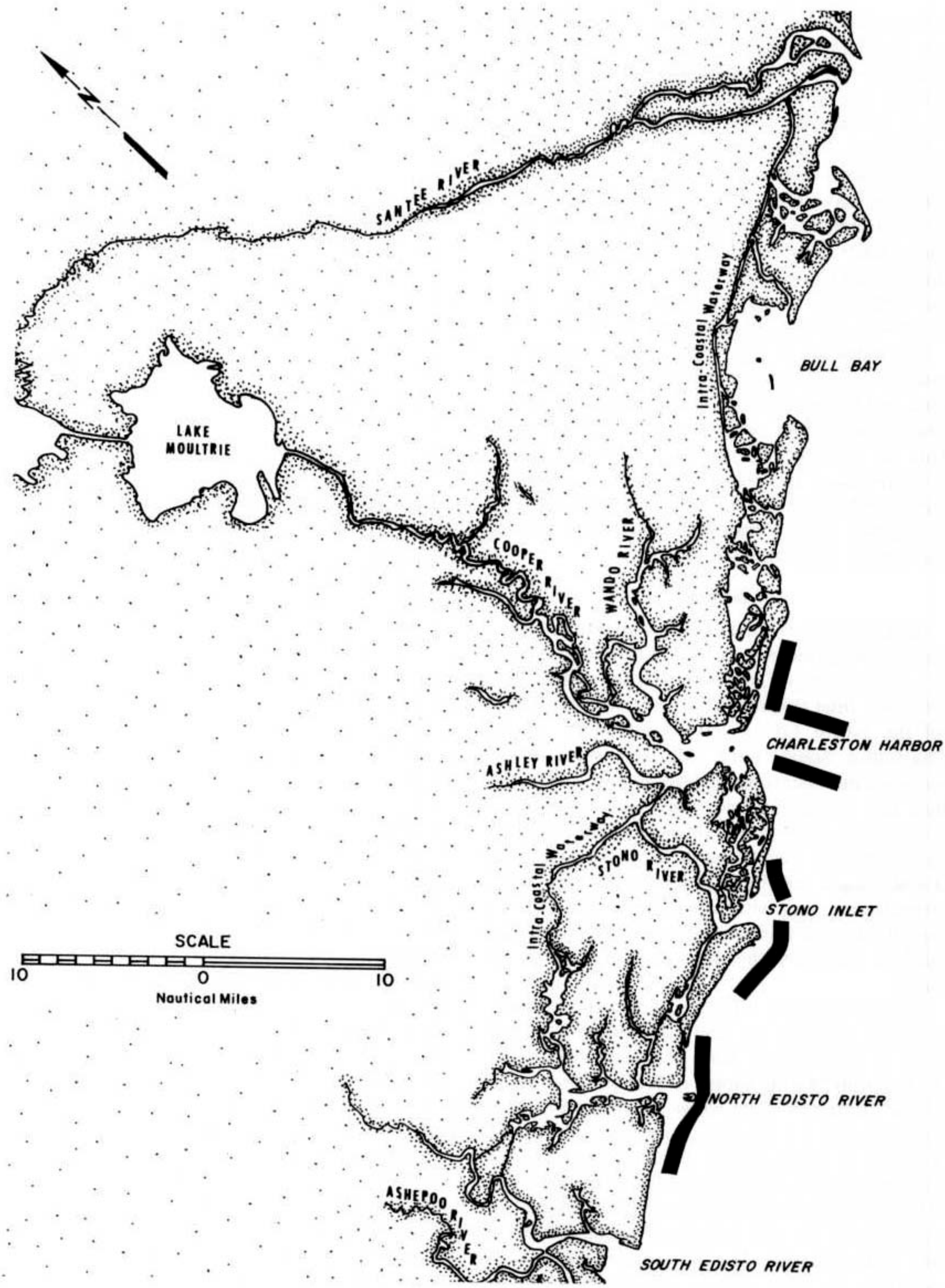

FIGURE 1.—Locations of trawl paths during trawl mensuration and catch comparisons.

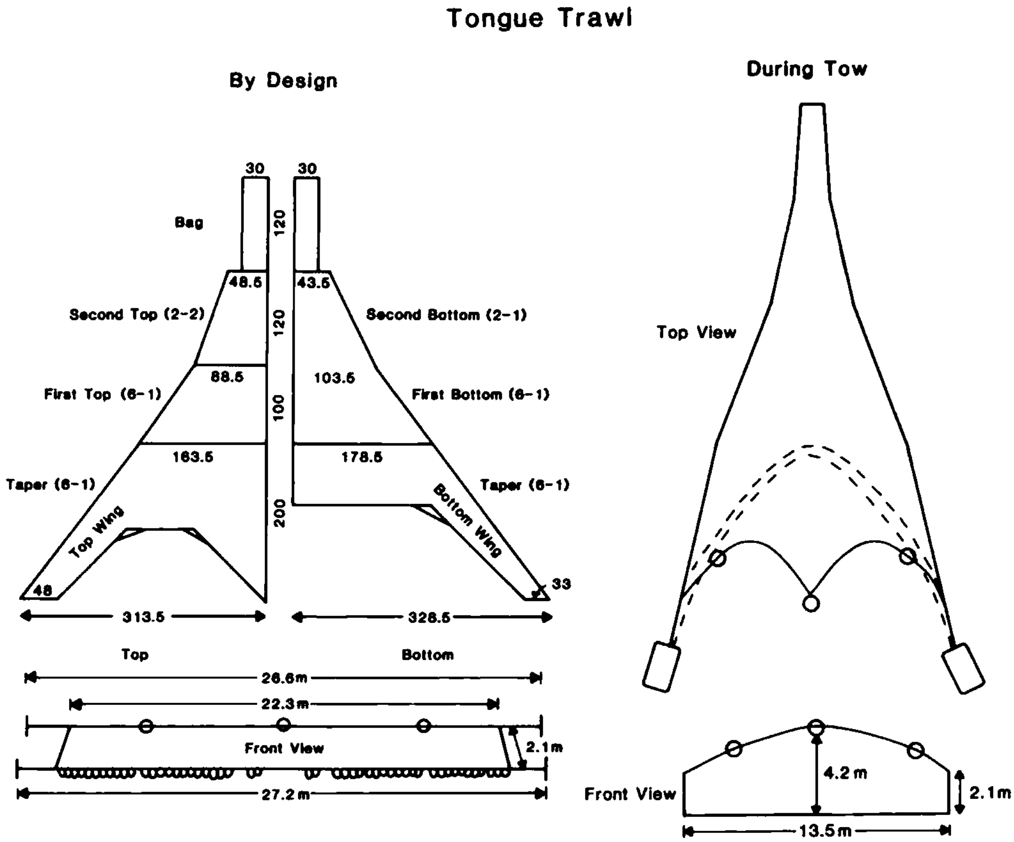

FIGURE 2.—Schematic representation of the tongue trawl. Numbers with "m" represent distances in meters, plain numbers indicate number of meshes along a seam, and numbers in parentheses represent slope in meshes.

and headrope to an underwater hydrophone near the ship and digitally displayed to the nearest 0.1 m. During special net mensuration cruises, nets were fished from the RV *Lady Lisa* as they would be during comparative trawling operations. Multiple measurements (usually more than 10) were obtained during several tows (usually three or more) with each net on the inshore and then the offshore side of the vessel (altered by changing vessel's heading to reciprocal courses) and in each of two depth zones (4.0–5.5 m, 10.7–12.2 m). The width of the net opening was determined as the distance between two transponders at each end of the wing webbing on the headrope. Vertical height was determined by a transponder in the center of the headrope that measured distance above bottom. With few exceptions, the total catch by each net during mensuration was either weighed or the weight was estimated from the volume. Comparisons of net dimensions between depth zones and vessel directions were evaluated with Kruskal–Wallis nonparametric tests. Mean net dimensions were used to standardize catch by area swept and by volume of water strained.

Trawling methodology.—Catch comparisons between the two nets were completed during two brown shrimp seasons (26 June–13 July 1989 and 25 June–16 August 1990) and one white shrimp season (27 August–14 September 1990) (Table 1). Nets were towed simultaneously in water depths between 12 and 37 m at approximately 1.3 m/s (at an engine setting of 1,200 revolutions/min) for 20 min. Because towing times were short, neither net had a turtle excluder device. The two-seam net was consistently fished from the port outrigger, the tongue net from the starboard outrigger. Towing bridles, measuring 91 m, typically were fully deployed at the trawling block. When possible, trawl tows were made in alternate (opposite) directions. All tows were made during daylight between 1 h after sunrise and 1 h before sunset (legal trawling hours in South Carolina). Many commercial

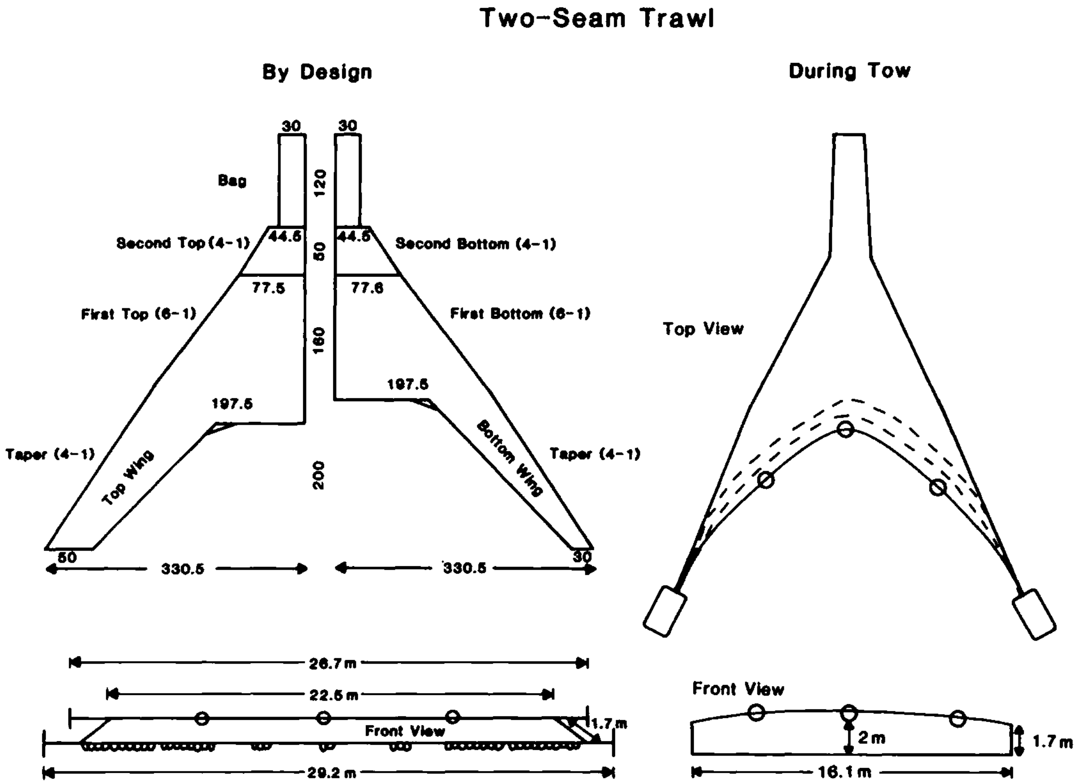

FIGURE 3.—Schematic representation of the two-seam trawl. Numbers with "m" represent distances in meters, plain numbers indicate number of meshes along a seam, and numbers in parentheses represent slope in meshes.

shrimping operations stopped late in the day. Occasionally, several tows were conducted after most of the fleet had departed, but where vessels had operated earlier in the day and in the company of a few remaining boats.

Priority finfish and shrimp (Table 2) were identified, counted, and weighed by species. All or a valid subsample (following Grosslein 1969) were measured to the nearest centimeter total length or fork length. All other finfish and invertebrates were identified to the lowest possible taxonomic group for a complete species inventory but were weighed by aggregate groupings (i.e., other finfish, miscellaneous invertebrates, etc.).

Catch data were standardized as catch per tow, catch per area swept, and fish : shrimp ratio. Results of trawl mensuration were used to determine the mean dimensions of the opening of each trawl.

TABLE 1.—Distribution of sampling effort (282 total tows) for catch comparisons.

Cruise number	Date	Shrimp season	Week	Number of tows
8901	26–30 Jun 1989	Brown	1	58
8902	10–13 Jul 1989	Brown	2	50
9001	25–29 Jun 1990	Brown	3	62
9002	14–16 Aug 1990	Brown	4	16
9003	27–30 Aug 1990	White	5	44
9004	10–14 Sep 1990	White	6	52

TABLE 2.—Priority species for the net comparison study.

Penaeus setiferus	White shrimp
Penaeus aztecus	Brown shrimp
Penaeus duorarum	Pink shrimp
Callinectes sapidus	Blue crab
Scomberomorus cavalla	King mackerel
Scomberomorus maculatus	Spanish mackerel
Cynoscion nebulosus	Spotted seatrout
Cynoscion regalis	Weakfish
Leiostomus xanthurus	Spot
Menticirrhus americanus	Southern kingfish
Micropogonias undulatus	Atlantic croaker
Sciaenops ocellatus	Red drum
Pomatomus saltatrix	Bluefish
Paralichthys dentatus	Summer flounder
Paralichthys lethostigma	Southern flounder
Epinephelinae	Groupers
Lutjanidae	Snappers

TABLE 3.—Mean dimensions and catches (±SD) of two-seam and tongue shrimp trawls towed under fishing conditions during mensuration trials. Numbers of measurements are in parentheses.

Depth and vessel side	Two-seam net Height (m)	Two-seam net Width (m)	Two-seam net Catch (kg/tow)	Tongue net Height (m)	Tongue net Width (m)	Tongue net Catch (kg/tow)
Shallow						
Inshore	2.7 ± 0.2 (6)[a]	16.4 ± 0.7 (47)	88.7 (1)	4.2 ± 0.9 (44)	13.2 ± 0.7 (40)	105.0 ± 71.9 (4)
Offshore	2.8 ± 0.1 (2)[a]	15.9 ± 0.8 (37)	70.0 ± 34.6 (4)	[b]	[b]	136.6 (1)
Deep						
Inshore	[a]	16.2 ± 0.3 (32)	11.0 ± 6.5 (5)	4.3 ± 0.2 (32)	13.7 ± 0.5 (31)	7.5 ± 4.8 (6)
Offshore	2.5 ± 2.5 (3)[a]	15.9 ± 0.3 (40)	9.9 ± 7.2 (6)	4.3 ± 0.1 (28)	13.8 ± 0.3 (28)	8.6 ± 4.5 (5)
All	[a]	16.1 ± 0.6 (156)	30.2 ± 34.7 (16)	4.2 ± 0.5 (104)	13.5 ± 0.6 (99)	40.3 ± 59.5 (16)

[a] Measurements are questionable because of gear limitations.
[b] Prevailing conditions prevented measurement of net dimensions.

The vessel speed, estimated by chip log as 1.29 m/s, was used to estimate the distance towed over the bottom. In addition to the calculation of total weight (kg) caught per tow, catch weight per hectare of bottom area swept and weight per 10,000 m^3 of water filtered were estimated for each priority species or group from these measurements. Ratios of catch weight to shrimp weight (both in kg/ha) were calculated for each tow to estimate relative by-catch magnitudes for eight taxonomic groups (total catch, all invertebrates, priority shrimp, all fish, priority fish, other fish, Spanish mackerel, and king mackerel). Throughout the text, the value of this ratio will be understood as a ratio to 1 kg shrimp/ha per tow. Mean values for this ratio were calculated as the arithmetic means of the ratios for individual tows.

Kruskal–Wallis (or Wilcoxon for paired data) nonparametric tests were primarily used because the assumptions of homogeneity of variance (F-max test) and normality (Shapiro–Wilk statistic) were not met for most comparisons, some even after a $\log(x + 1)$ transformation. To evaluate effort, mean and standard deviation of catch (kg/ha) by gear and major taxonomic group were used, following Parkinson et al. (1988), to determine the sample size needed (N) for a 90% likelihood of detecting a 90% change at the $\alpha = 0.05$ level [$N = 100^2 \cdot k \cdot (\mathrm{SD}/\bar{x})^2/p^2$; k = constant dependant on α and β; $\bar{x}$ = mean catch; p = % minimal detectable change]. Data were tested statistically for differences in catch by gear (P2 = port two-seam trawl or ST = starboard tongue trawl), year (1989 or 1990), week (1–6), and season (brown = brown shrimp or white = white shrimp). To evaluate differences in specimen size between the two trawls for each of the 13 priority species, ANOVA (analysis of variance) was used to test for differences in mean length and the Kolmogorov–Smirnov test was used to assess differences in the frequency distribution among lengths. Paired t-tests were used for the gear and catch comparisons during mensuration.

Results

Trawl Mensuration

The mensuration study was completed during 27 tows: 12 tows for measuring the tongue net (106 measurements) and 15 tows for measuring the two-seam net (156 measurements). Several data sets were incomplete because of vessel limitations and equipment malfunction. Inadvertently, catches of nine paired tows were not measured or estimated, although the mensuration data for these tows were valid. No measurements were obtained on the tongue trawl from the offshore side of the vessel when the vessel was in shallow water because of inclement weather and prevailing conditions.

Dimensions of the mouth opening stabilized in less than 2.0 min after the trawls were fully deployed in towing position. For each net, average net dimensions varied 0.5 m or less between depth zones and between inshore and offshore sides of the vessel (Table 3). During trawling, dimensions of the tongue trawl averaged 13.5 m in width and 4.2 m in height (Figure 2). The average width of the two-seam net was 16.1 m, but height determination on this net was somewhat problematic (Figure 3). The height sensor of the SCANMAR system was not designed to resolve distances very close to the height transponder. During calibration of the instrument, this distance was determined to be approximately 2.3 m. Anomalous readings occurred on all but 11 of the 176 attempted height measurements of the two-seam net, and the anom-

TABLE 4.—Statistical comparisons of net performance during mensuration trials, in relation to net type, fishing depth, and vessel side relative to shore. Asterisks denote $P \leq 0.05$*, $P \leq 0.01$**, or $P \leq 0.001$***; NS denotes not significant ($P > 0.05$); empty cell denotes absence of valid test; KW denotes Kruskal–Wallis test.

Comparison	Height (KW)	Width (KW)	Catch KW	Catch t-test
Two-seam versus tongue net[a]	***	***	NS	NS[b]
Shallow versus deep zone[a]			***	***
Inshore versus offshore side[a]			NS	NS
Two-seam net				
Shallow versus deep zone		NS	**	*
Inshore versus offshore side		***	NS	NS
Tongue net				
Shallow versus deep zone[c]	**	***	**	*
Inshore versus offshore side[d]	NS	NS	NS	NS

[a] Pooled data.
[b] Paired t-test result.
[c] Comparisons are restricted to fishing from the inshore side of the vessel.
[d] Comparisons are restricted to fishing in the deep zone.

alies were eliminated from the analyses. Height of the headrope center on the two-seam net was estimated to be 2.1 m based on the average of the 11 accepted readings and the 1.7-m distance between the headrope and footrope at the ends of the wings. According to the above dimensions and the speed of the vessel, the tongue trawl sampled 2.1 ha/tow, filtering 65,700 m^3 of water, and the two-seam net sampled 2.5 ha/tow, filtering 46,000 m^3 of water.

Analysis of variance and Kruskal–Wallis tests indicated that the height and width of the tongue net were significantly different from those of the two-seam net (Table 4). Regardless of water depth, cross-sectional area of the two-seam trawl was always less than 50.0 m^2 and that of the tongue trawl was always greater than 50.0 m^2. During trawl mensuration, there was a significant difference in catch between depth zones regardless of the trawl type. Shallow tows averaged 92.5 kg/tow, always being more than 40.0 kg/tow, and deep tows averaged 9.2 kg/tow, always being 24.0 kg/tow or less. One exception to this trend occurred when a roughtail stingray *Dasyatis centroura* (204.1 kg), the only one encountered, was caught in deep water in a two-seam trawl whose remaining total catch was 9.8 kg. The tongue trawl had slightly (<0.5 m) but consistently larger height and width in the deep zone than in the shallow zone, but dimensions did not differ between inshore and offshore sides of the vessel. No inshore–offshore differences in catch were found for either trawl. For the two-seam trawl, valid tests were completed only for width, which showed no differences between depth zones and slightly (<0.5 m) greater values when the net was towed on the inshore side.

General Catch

Altogether, 182 species, including 96 species of fish, were collected during this survey; 162 species occurred in the two-seam net and 154 in the tongue trawl. Among the 25 species identified only from the two-seam net were several bottom-dwelling

TABLE 5.—Catch summary for the port two-seam net (P2) and the starboard tongue trawl (ST).

Group	Total catch (kg)	Net	Mean ± SD catch per: Tow (kg/tow)	Area (kg/ha)	Volume (kg/10,000 m^3)
Total	15,830.25	P2	49.19 ± 60.36	20.86 ± 25.18	11.27 ± 13.61
		ST	63.08 ± 69.70	31.04 ± 34.13	9.85 ± 10.84
Invertebrates	13,431.84	P2	40.21 ± 53.49	17.21 ± 22.25	9.30 ± 12.03
		ST	55.05 ± 64.97	27.13 ± 31.80	8.61 ± 10.10
Priority shrimp	503.65	P2	1.72 ± 1.55	0.76 ± 0.61	0.41 ± 0.33
		ST	1.85 ± 1.53	0.94 ± 0.71	0.30 ± 0.23
All fish	2,242.71	P2	8.88 ± 19.19	3.61 ± 8.05	1.95 ± 4.35
		ST	7.03 ± 8.99	3.40 ± 4.42	1.08 ± 1.40
Priority fish	1,180.52	P2	5.36 ± 18.62	2.24 ± 7.85	1.21 ± 4.24
		ST	3.02 ± 4.90	1.47 ± 2.39	0.47 ± 0.76
Other fish	1,062.19	P2	3.52 ± 3.74	1.36 ± 1.41	0.73 ± 0.76
		ST	4.01 ± 6.38	1.93 ± 3.13	0.61 ± 0.99
Spanish mackerel	94.98	P2	0.30 ± 0.46	0.12 ± 0.18	0.07 ± 0.10
		ST	0.37 ± 0.50	0.18 ± 0.25	0.06 ± 0.48
King mackerel	29.39	P2	0.12 ± 0.60	0.02 ± 0.08	0.01 ± 0.04
		ST	0.09 ± 0.39	0.03 ± 0.14	0.01 ± 0.05

TABLE 6.—Catches (biomass and number) of priority species in the port two-seam trawl (P2) and the starboard tongue trawl (ST).

Species	Net	Weight (kg) Total	Weight (kg) Mean (SE) per tow	Number Total	Number Mean per hour	Number Mean (SE) per tow
White shrimp	P2	80.54	0.57 (0.07)	3,650	77.6	25.88 (4.46)
	ST	130.93	0.93 (0.11)	6,012	127.9	42.64 (6.61)
Brown shrimp	P2	143.71	1.02 (0.12)	14,554	309.7	103.22 (12.20)
	ST	120.40	0.85 (0.10)	11,535	245.4	81.81 (9.00)
Pink shrimp	P2	18.98	0.13 (0.05)	1,912	40.7	13.56 (12.28)
	ST	9.09	0.06 (0.01)	1,005	21.4	7.13 (2.91)
Blue crab	P2	52.00	0.37 (0.10)	919	19.6	6.52 (2.17)
	ST	43.56	0.31 (0.06)	520	11.1	3.69 (1.20)
King mackerel	P2	16.74	0.12 (0.05)	161	3.4	1.14 (0.56)
	ST	12.65	0.09 (0.03)	128	2.7	0.91 (0.37)
Spanish mackerel	P2	43.03	0.31 (0.04)	1,871	39.8	13.27 (1.88)
	ST	51.95	0.37 (0.04)	2,125	45.2	15.07 (1.67)
Spotted seatrout	P2	0		0		
	ST	0		0		
Weakfish	P2	37.99	0.27 (0.07)	1,449	30.8	10.28 (2.02)
	ST	22.63	0.16 (0.03)	1,052	22.4	7.46 (1.07)
Spot	P2	194.38	1.38 (0.37)	24,044	511.6	170.52 (24.43)
	ST	91.26	0.65 (0.13)	16,455	350.1	116.70 (13.77)
Southern kingfish	P2	20.86	0.15 (0.04)	4,513	96.0	32.01 (3.48)
	ST	23.63	0.17 (0.03)	2,501	53.0	17.74 (1.67)
Atlantic croaker	P2	403.05	2.86 (1.38)	37,872	805.8	268.60 (218.2)
	ST	182.73	1.30 (0.39)	7,621	162.2	54.05 (17.18)
Red drum	P2	0		0		
	ST	0		0		
Bluefish	P2	22.00	0.16 (0.02)	367	7.8	2.60 (0.64)
	ST	28.31	0.20 (0.03)	366	7.8	2.60 (0.42)
Summer flounder	P2	8.58	0.06 (0.01)	145	3.1	1.03 (0.22)
	ST	7.07	0.05 (0.01)	98	2.1	0.70 (0.17)
Southern flounder	P2	8.54	0.06 (0.01)	40	0.8	0.28 (0.12)
	ST	4.83	0.03 (0.01)	29	0.6	0.21 (0.15)
Groupers	P2	0		0		
	ST	0		0		
Snappers	P2	0		0		
	ST	0		0		

species of pipefishes, rays, eels, crabs, and algae that occurred infrequently. The tongue trawl exclusively collected 17 species, some being pelagic such as striped mullet *Mugil cephalus*, ctenophores, smooth puffers *Lagocephalus laevigatus*, and several typically large species such as cobia *Rachycentron canadum*, sharks, and sharksuckers *Echeneis naucrates*. However, species composition was quite similar for catches from the two types of nets. The total cumulative catch from the 282 trawls weighed 15,830 kg (Table 5). Trawl tows were made in depths from 12 to 27 m. The majority of the catch was composed of nonpriority invertebrates. Priority shrimp (504 kg) made up 3.2% of total catch and priority fish (1,181 kg) made up 7.5%. Mean catches, per tow and per hectare of bottom trawled were 1.1–1.6 times greater in the tongue than in the two-seam trawl for all major groups except all fish and priority fish. The catches per water volume strained were 1.1–2.6 times greater in the two-seam than in the tongue trawl for all groups. Collections of priority species were dominated in both biomass and number per tow by Atlantic croaker, spot, brown shrimp, southern kingfish, white shrimp, and blue crab (Table 6). Bluefish were also common in catches. Very few summer flounder and southern flounder were caught. Four priority species groups

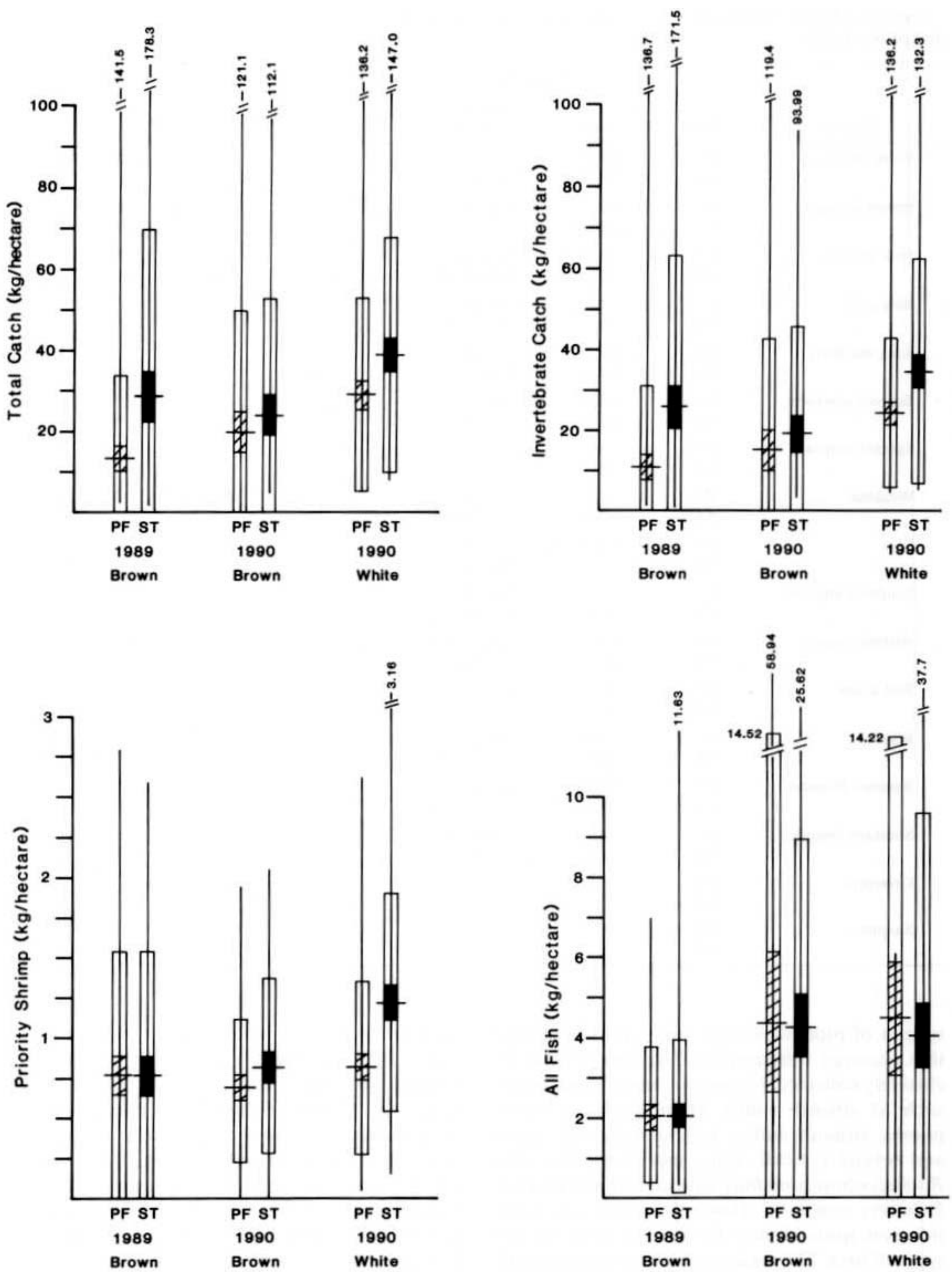

FIGURE 4.—Total, invertebrate, priority shrimp, and all fish catches (biomass per hectare) by the port two-seam trawl (PF) and the starboard tongue trawl (ST) during the 1989 and 1990 brown shrimp seasons and the 1990 white shrimp season. Horizontal lines are means, crosshatched and black rectangles denote standard errors, open rectangles denote standard deviations, and vertical lines are ranges.

TABLE 7.—Results of Kruskal–Wallis tests for significant differences among effort classes for each of eight major groups. Asterisks denote $P \leq 0.05$*, $P \leq 0.01$**, or $P \leq 0.001$***; NS denotes not significant ($P > 0.05$).

Variable	Class	Total catch	Invertebrates	Priority shrimp	All fish	Priority fish	Other fish	Spanish mackerel	King mackerel
kg/tow	Gear	*	*	NS	NS	NS	NS	NS	NS
	Year	***	**	***	***	***	**	***	**
	Week	***	***	***	***	***	***	***	***
	Season	***	***	***	**	NS	***	NS	***
kg/ha	Gear	***	***	*	NS	NS	NS	NS	NS
	Year	***	***	***	***	***	**	***	***
	Week	***	***	***	***	***	***	***	***
	Season	***	***	***	**	NS	**	NS	***
Ratio: kg/ha to kg shrimp/ha	Gear	NS	NS		NS	NS	NS	NS	NS
	Year	NS	NS		NS	NS	NS	***	*
	Week	***	***		***	***	***	***	***
	Season	NS	*		NS	*	NS	***	***

not taken during this survey were spotted seatrout, red drum, groupers, and snappers. Total brown shrimp catch during the brown shrimp seasons of 1989 and 1990 was 26,089 shrimp weighing 264 kg; white shrimp caught during the 1990 white shrimp season totaled 9,662 shrimp weighing 211 kg. Pink shrimp occurred relatively infrequently (2,917 shrimp weighing 28 kg). Overall, 22 of the 282 tows (7.8%) did not collect any of the priority shrimp species. An aggregate 3,996 Spanish mackerel weighing 95 kg and 289 king mackerel weighing 29 kg were taken in 282 tows. Three loggerhead turtles *Caretta caretta* were taken weighing 169 kg.

Seasonal differences in catch (kg/ha) occurred. Higher mean catches of all groups, all invertebrates, and priority shrimp were taken during the white shrimp season than during either brown shrimp season (Figure 4). The mean catch of total finfish (Figure 4) was higher in 1990 than in 1989. Both mackerel species were caught in all three sampling periods, but the highest mean catches occurred during the 1989 brown shrimp season.

Catch Comparisons

Catch data were not normally distributed and variances were not homogeneous, even after logarithmic transformation of the data. Fishing effort expended exceeded the criterion number of tows (Parkinson et al. 1988) for both gears in all major groups except priority fish in two-seam net catches. For priority fish, the 141 tows with the two-seam net were sufficient to be 90% sure of detecting a 135% change in catch at the $\alpha = 0.05$ level.

Catches (kg/tow and kg/ha) of all major groups by week and year were significantly different (Ta-

TABLE 8.—Comparison of lengths of priority species between net types. Asterisks denote $P \leq 0.001$; NS denotes not significant ($P > 0.05$).

Species	Length (cm)[a] Port two-seam Mean	Port two-seam Range	Port two-seam SD	Starboard tongue Mean	Starboard tongue Range	Starboard tongue SD	Analysis of variance	Kolmogorov–Smirnov
White shrimp	14.09	7–20	1.26	14.09	10–21	1.16	NS	***
Brown shrimp	11.91	6–19	1.87	11.37	6–20	1.47	***	***
Pink shrimp	10.05	6–13	1.37	10.01	7–19	1.11	NS	***
Blue crab	12.78	6–18	1.98	13.35	7–19	2.06	***	***
King mackerel	17.58	6–39	10.24	17.55	7–39	10.20	NS	NS
Spanish mackerel	14.41	3–38	3.44	15.61	3–50	4.96	***[b]	***
Weakfish	14.40	3–36	3.41	14.76	6–27	2.88	***	***
Spot	10.93	6–22	2.84	11.98	7–20	2.84	***	***
Southern kingfish	15.51	3–37	4.41	15.18	3–31	3.88	***	***
Atlantic croaker	15.76	3–37	2.20	14.16	7–25	2.41	***	***
Bluefish	18.39	9–28	3.44	18.85	10–27	3.25	NS	NS
Summer flounder	17.67	9–34	3.79	18.13	9–32	4.35	NS	NS
Southern flounder	25.68	12–39	5.27	24.00	13-33	4.81	NS	NS

[a] Total or fork length, depending on species.
[b] Wilcoxon test.

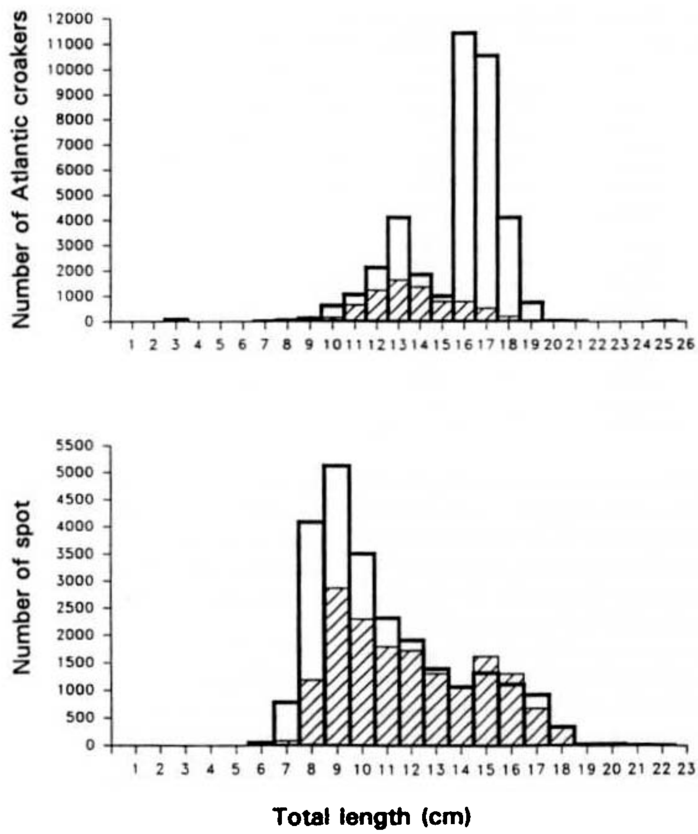

FIGURE 5.—Length-frequency histograms for Atlantic croaker, spot, king mackerel, and Spanish mackerel. Bold-lined, open-boxed data are from the two-seam trawl; hatched area represents catches in the tongue trawl.

ble 7). Trawls during week 4 (Table 1) had significantly higher catches (kg/ha) of all groups except the two mackerels. Highest catches of Spanish mackerel occurred during week 2; king mackerel catches were highest during week 6. Catches in 1990 were significantly greater for all groups, except Spanish mackerel catches were significantly higher in 1989. Except priority fishes and Spanish mackerel, catches for all major groups were significantly greater during the white shrimp than during the brown shrimp season.

With the data from all seasons combined, there were no significant differences between the tongue and two-seam net in catch per hectare of the priority fish, other fish, Spanish mackerel, or king mackerel, but total catch, invertebrate catch, and shrimp catch were statistically greater (1.1–1.4 times) in the tongue trawl (Tables 5, 7). Catch comparisons based only on tows made before 1300 hours produced the same results.

Of the 13 priority species collected, statistically significant differences in mean length (ranging from 0.33 to 1.60 cm) of individuals caught by the two nets were found for 7 species (Table 8). For Atlantic croaker, spot, and Spanish mackerel, differences in mean length were more than 1 cm (Figure 5). Lengths of Atlantic croaker, brown shrimp, and southern kingfish were statistically larger in the two-seam trawl. Statistically greater lengths were noted in the tongue trawl for Spanish mackerel, spot, blue crab, and weakfish. No statistical differences were found between gears in the mean lengths for king mackerel (Figure 5), pink and white shrimp, bluefish, and summer and southern flounder. Statistical differences between nets in the frequency distributions of lengths occurred for all priority species examined except king mackerel, bluefish, and summer and southern flounder.

The ratio of catch of each major group to catch of priority shrimp varied with gear, year, and sea-

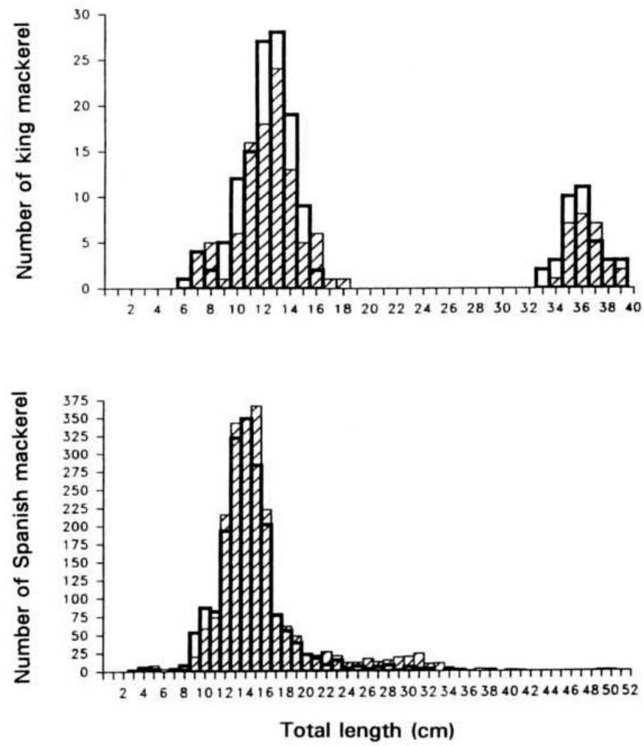

FIGURE 5.—Extended.

son (Table 9). This ratio was most variable during the 1989 brown shrimp season for all seven groups. The mean ratio for each of the seven groups was higher in the tongue trawls than in the two-seam trawls during this 1989 season. For all fish and priority fish during the 1990 white shrimp season, greater variability and larger mean ratios occurred in the catches from the two-seam net. Generally, mean ratios of most groups were highest in the 1989 brown shrimp season, intermediate in the 1990 brown shrimp season, and least in the 1990 white shrimp season.

The majority of the catches in each gear had ratios of fish to shrimp biomass less than 10 (Figure 6). Ratios for 13 tows with the two-seam trawl and 9 with the tongue trawl could not be calculated because no shrimp were caught; these tows were excluded from these analyses. The mean ratio for the two-seam trawl was 21.01 (range, 0.26–332.72); the mean ratio for the tongue trawl was 41.20 (range, 0.49–2,021.08). Shrimp biomass exceeded fish biomass (ratios less than 1) in 16.4% of the two-seam and 16.7% of the tongue trawls. Catches with both maximal (> 100) and minimal (< 1) ratios were taken at varying time periods throughout the day, but tows during the first 3 h of the day (0600–0900 hours) had higher frequencies of both extremes than would be expected by chance (χ^2, $P < 0.05$).

No statistical differences in ratio between the two gears existed for any of the taxonomic groups (Table 7). Statistically highest ratios for Spanish mackerel occurred in 1989; highest ratios for king mackerel occurred in 1990. No statistical differences in ratios between the two years were found for any other group. Significantly highest ratios for all groups but the mackerels occurred in week 1 (week 2 for Spanish mackerel; week 6 for king mackerel). Catches with highest ratios for invertebrates, priority fish, and Spanish mackerel occurred during the brown shrimp season, whereas ratios for king mackerel were highest during the

TABLE 9.—Mean biomass ratios (biomass of group to biomass of shrimp, both in kg/ha) in relation to shrimp season and net type (P2 = port two-seam trawl; ST = starboard tongue trawl). Numbers of tows are in parentheses.

		1989 brown shrimp season		1990 brown shrimp season		1990 white shrimp season	
Group	Statistic	P2 (45)	ST (47)	P2 (34)	ST (36)	P2 (48)	ST (50)
Total	Mean	291.65	1,899.04	38.28	55.61	47.87	49.38
	SE	83.46	941.34	10.85	18.31	6.22	10.72
	Median	15.27	37.34	13.17	20.88	31.67	25.40
	25th percentile	6.36	7.31	7.61	10.94	19.67	15.22
	75th percentile	361.15	774.67	54.75	48.68	56.92	55.97
Invertebrates	Mean	238.36	1,688.86	26.34	40.70	41.28	44.80
	SE	76.23	909.59	6.91	14.81	5.64	10.25
	Median	9.15	36.58	9.27	15.45	26.56	19.15
	25th percentile	5.12	5.92	4.50	7.03	15.19	12.67
	75th percentile	201.98	672.67	34.68	27.92	51.85	50.82
All fish	Mean	43.47	100.54	11.94	14.55	6.67	4.62
	SE	11.76	46.14	5.19	6.62	1.72	0.87
	Median	2.75	5.80	3.12	4.58	3.09	2.23
	25th percentile	1.00	0.95	1.69	2.93	2.01	1.35
	75th percentile	46.87	55.14	6.85	7.83	5.92	4.00
Priority fish	Mean	8.94	21.28	8.54	8.29	3.96	1.52
	SE	2.38	7.64	4.13	4.19	1.64	0.27
	Median	1.45	1.24	1.73	2.42	1.43	0.78
	25th percentile	0.27	0.39	0.72	0.62	0.48	0.37
	75th percentile	10.73	13.00	3.43	4.96	2.81	1.63
Other fish	Mean	34.53	79.26	3.40	6.26	2.71	3.11
	SE	9.88	40.02	1.39	2.57	0.58	0.76
	Median	1.46	1.75	1.29	1.90	1.85	1.13
	25th percentile	0.43	0.44	0.70	1.14	1.10	0.73
	75th percentile	35.29	28.86	2.51	3.24	2.76	2.76
Spanish mackerel	Mean	1.67	6.75	0.26	0.30	0.15	0.16
	SE	0.84	3.64	0.10	0.09	0.03	0.04
	Median	0.12	0.24	0.03	0.08	0.08	0.06
	25th percentile	0.01	0.03	0.0	0.0	0.0	0.0
	75th percentile	0.49	0.98	0.18	0.36	0.21	0.20
King mackerel	Mean	1.88	5.14	0.003	0.003	0.03	0.02
	SE	1.05	2.99	0.001	0.001	0.005	0.005
	Median	0.0	0.0	0.0	0.0	0.01	0.008
	25th percentile	0.0	0.0	0.0	0.0	0.0	0.0
	75th percentile	0.0	0.0	0.0	0.0	0.03	0.03

white shrimp season. The ratios of total catch, all fish, and other nonpriority fish to shrimp biomass were not significantly different between seasons.

Discussion

Trawl Mensuration

An approximation for the horizontal opening of a shrimp net—0.6 times the length of the headrope (Roe 1969)—has been used by several authors to expand catch data to catch per area swept (Wenner et al. 1979, 1980; Wenner and Wenner 1989). Our trawl mensuration indicated good agreement for the two-seam net, which opened 0.61 times the headrope length. The tongue trawl yielded a factor of 0.51, indicating that a more appropriate factor for tongue trawls may be 0.5. Both nets reached full fishing configuration very shortly (<2 min) after full deployment.

The small (<0.5 m) but statistically consistent differences that occurred in net width of the two-seam net between inshore and offshore vessel sides were not reflected in differences in catch (Table 4). This observation supports the conclusion that the side of the vessel toward shore during the tow (towing direction) did not influence the catch. Also, the effect of the rudder angle on catch within the limits of our specified towing technique was considered negligible based on the lack of difference in catch. For the tongue trawl, no significant difference was found in net dimensions or in catch based on vessel side toward shore during a tow.

Significant differences in catch with depth occurred for both nets during mensuration. There

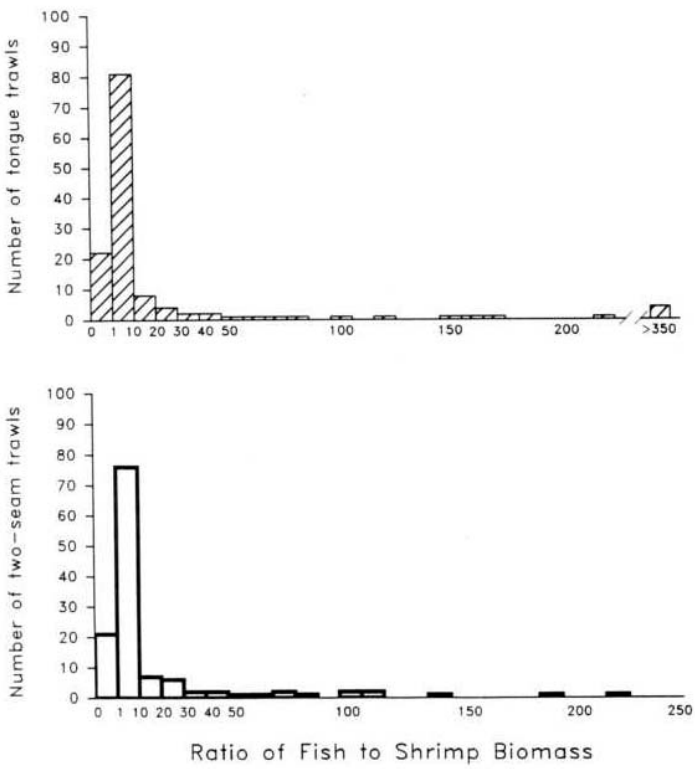

FIGURE 6.—Frequency histograms of ratios of fish to shrimp biomass (kg/ha) for tongue and two-seam trawls.

were no (for two-seam) or only slight (<0.5 m for tongue) differences in net dimensions between depth zones. Differences in biomass and species diversity with depth are documented for this region (Struhsaker 1969; Webster et al. 1989; Boylan et al. 1990). Thus, it is our conclusion that the order-of-magnitude differences in total catch between depths reflects a real distributional difference in the biota and not the minor differences in net dimensions.

General Catch

The dominant taxa (spot, Atlantic croaker) reported in past studies (Anderson 1968; Wenner and Sedberry 1989) from catches by similar gear were among the dominant priority species in the current study. The 96 taxa of fish and 86 other taxa collected in this study from depths of 12–27 m off South Carolina represents a diversity similar to that previously reported from the southeastern U.S. coast: 74–94 species of fish (Anderson 1968; Webster et al. 1989; Wenner and Wenner 1989) and 63 species of decapods and stomatopods (Wenner and Wenner 1989).

In the current study, four priority taxa were not caught: red drum, spotted seatrout, snappers, and groupers. These taxa, have been taken in past studies with shrimp trawls, but very infrequently and in low numbers (27 red drums were collected by Wenner 1987; 278 spotted sea trout by Anderson 1968 and a few by Wenner and Sedberry 1989; and a few red snappers by Webster et al. 1989, Wenner and Sedberry 1989, and Boylan et al. 1990). Off Texas, red snapper is among the 25 most abundant species in the by-catch of shrimp trawls, and such catches may be affecting the population (Bryan et al. 1982). Powers et al. (1987) estimated the yield of red snapper could increase by 90% in the Gulf of Mexico if the by-catch were eliminated. There is no evidence to support a similar concern for these four taxa off South Carolina at the present time.

Our catch rates and observed densities of total catch, fishes, and shrimp were similar to those reported for like times and areas, but they were generally lower than earlier catches in this area and lower than catches in estuarine waters and the Gulf of Mexico. Webster et al. (1989) and Boylan et al. (1990), both using tongue trawls in the same depths (9–27 m), estimated total catch at 29.7 kg/ha and 22.7 kg/ha, respectively, similar to our tongue net results (31.1 kg/ha). In Texas, however, Bryan et al. (1982) reported total catches of 51.0–103.6 kg/ha. Our estimates of fish biomass (3.4 kg/ha for the tongue net and 3.6 kg/ha for the two-seam net) were lower than estimates for Charleston Harbor (12.2 kg/ha for an 18.3-m semiballoon net) by Wenner (1987). For June through September, our average catch rates for fishes (21.1 kg/h for the tongue net and 26.6 kg/h for the two-seam net) were also lower than the average reported by Keiser (1976: 101.9 kg/h). Our average estimates of shrimp density on the shrimping grounds—0.76 kg/ha during the brown shrimp season and 0.94 kg/ha during the white shrimp season—are understandably higher than the yearly, regional estimate of 0.32 kg/ha by Wenner and Wenner (1989). In the Gulf of Mexico off Texas, shrimp densities have averaged as high as 19.2 kg/ha (Bryan et al. 1982).

Catch Comparison

Although the two-seam net covered 16% more area of the bottom per tow than the tongue net (2.5 and 2.1 ha, respectively), the two nets caught similar quantities of benthic fish species, which made up most of the priority fish and other fish categories. The tongue net caught more shrimp than the two-seam net during white shrimp season, confirming the shrimpers' choice of tongue style nets for white shrimp, which tend to move high in the water column. The significantly larger total catches and catches of invertebrates and priority shrimp in the tongue net reflects the large volume strained and high incidence of jellyfish within the water column during several seasons.

Differences in length frequencies of several taxa between the two nets suggest variation in catchability related to differential use of the habitat by various life history stages. The occurrence of larger Spanish mackerel and spot in the tongue trawl could have resulted from larger, older individuals hovering higher in midwater than smaller specimens, where they would be more vulnerable to a higher-opening net. Larger Atlantic croaker may be more abundant near the bottom, where they would be collected in greater numbers by a net opening over a greater horizontal distance along the bottom. However, size differences could reflect the relative abilities of the animals to avoid nets with different openings (16.1 m versus 13.5 m in width; 2.1 m versus 4.2 m in height) or differences in retention of smaller species in cod ends with different chafing gears.

Calculation of fish-to-shrimp biomass ratios provided useful indices for summarizing by-catch and comparing the relative changes in catch of fish and shrimp. Over all tows, fish-to-shrimp ratios averaged twice as high for the tongue net than for the two-seam net. These differences were not statistically valid, and during the white shrimp season, the mean fish-to-shrimp ratio was lower for the tongue trawl. Considerable caution must be used in comparing such ratios with similar ratios in the literature, because the ratio has been calculated in different ways. Keiser (1976) used logarithmic transformations to calculate a mean ratio (1.98) and 95% confidence limits (0.22–17.84). Wolff (1972) presented fish and shrimp weights by individual trawl, but he used the ratio of a single yearly sum of fish weight to a single yearly sum of shrimp weight to express his "average" fish-to-shrimp ratio (5.38). Summed weights were also used to determine the ratio by Low et al. (1990: maximum ratio, 2.23 off South Carolina) and Whitaker et al. (1989: overall ratio, 0.5 for fall inside Calibogue, Port Royal, and St. Helena sounds South Carolina). Keiser (1977) used the median ratio of 2.58 for May–August and 1.20 for September–December. Pellegrin (1982) calculated true means of individual trawl ratios and reported ratios ranging from 4.2 to 15.9 for the Gulf of Mexico. Bryan et al. (1982) calculated the mean but used a ratio to the biomass of only commercial-sized shrimp (≥ 11.2 cm total length).

Although calculated quite differently, all of these ratios are referred to as the "fish : shrimp ratio." Perhaps these variations in calculations contributed to the rejection of such ratios by National Marine Fisheries Service (1991). Standardizing the ratio by calculating the mean of ratios for each trawl (as in current study) will yield values that can be compared by area and time to monitor relative changes in fish and shrimp. Such comparisons should also evaluate the percentages of tows with no shrimp, with more shrimp than fish (ratios less than 1), and with substantially more fish than shrimp (ratios greater than 20).

In comparison with the published ratios summarized above, our 21.01 ratio for the two-seam net and 41.20 ratio for tongue trawl seem anomalously high; however, recalculations of reported ratios based on the original data for each tow yield different conclusions (Table 10). In general, there is considerable variability in this ratio, particularly when our ratios are compared with the much ear-

TABLE 10.—Summary of reported fish-to-shrimp biomass ratios from studies in North Carolina (NC), South Carolina (SC), and Georgia (GA). When necessary, data have been recalculated to yield means of ratios from individual tows.

Source	Area	% of tows without shrimp	% of ratios less than 1	Mean ratio	% of ratios greater than 20	Minimum ratio	Maximum ratio	SD
Roelofs (1951)	NC	0	35.3	1.99	0	0.38	6.67	1.87
Latham (1951)	NC	0	0	6.11	0	2.00	15.00	4.36
Wolff (1972)	NC	11.1	12.5	22.43	25.0	0.60	185.90	45.26
Holland (1989)	NC	0	0	15.25	27.4	1.78	49.00	12.31
Pearce et al. (1989)	NC	0	0	17.46	5.6	11.91	31.44	4.52
Keiser (1976)	SC	1.4	25.5		3.8	0.30	136.10	
Low et al. (1990)								
Two-seam trawl	SC	0	29.2	2.06	4.2	0.54	4.33	1.13
Tongue trawl	SC	0	50.0	5.03	10.0	0.57	40.41	12.44
Current study								
Two-seam trawl	SC	9.2	14.9	21.01	17.0	0.26	332.72	52.23
Tongue trawl	SC	6.4	15.6	41.20	15.6	0.49	2,021.08	192.99
Keiser (1977)	GA		20.0		5.6	0.11	49,500.00	

lier North Carolina data of Latham (1951) and Roelofs (1951). Eldridge et al. (1974) reported high landings of shrimp during the years of these two earlier studies, and our much higher ratios may reflect a relatively lower abundance of shrimp.

Comparisons of our fish-to-shrimp ratios with those from two previous South Carolina studies (Keiser 1976; Low et al. 1990) indicate that our study produced much higher ratios, more tows without shrimp, fewer tows with more shrimp than fish, a greater percentage of tows with ratios more than 20, and a larger maximum ratio. A major difference may rest in the methods of processing the catch. In both previous studies, the catch was subsampled with a washtub or bushel basket, whereas the entire catch was worked up in the current study. Such a subsampling technique underestimates some species such as crabs (Keiser 1976). Wolff (1972) reported ratios from small inshore vessels when the entire catch was worked up and ratios from larger vessels when subsampling was used. Regrouping data from Wolff (1972) indicated that the fish-to-shrimp ratio was only 9.7 for subsampled catches but 22.4 for completely analyzed catches. Our observations raise doubts concerning the validity of the subsampling technique. In future by-catch studies, subsampling techniques, if used, should be validated to resolve the potential for error.

Differences in the rigging of gear or towing methodology between research trawling and shrimp trawling could contribute to differences in ratios not explained by methods of calculation or sampling. However, through assistance from and consultations with shrimpers and net makers, we think these differences are small. Shrimpers often tow for 2–4 h, whereas our trawls fished only 20 min. Observations with underwater video cameras indicate that many fish are herded by the mouth of a trawl and caught at the time the gear is retrieved. Frequent hauling of the nets may increase the apparent percentage of these fishes relative to that of shrimp on the bottom. Therefore, we think that differences between our fish-to-shrimp ratios and previous ratios can be accounted for by a combination of actual differences in abundance and distribution of fish and shrimp and possible differences in methodology. Future changes in methodology to minimize fish catches may include the use of fish excluder devices or the use of new net designs such as "four-bangers" (four small nets towed simultaneously). The efficiency of these changes should be critically evaluated.

Spanish mackerel and king mackerel have been caught as shrimp by-catch in the past (Anderson 1968). Knowlton (1972) reported that Spanish mackerel made up less than 0.5% of the total catch by commercial shrimpers, and Keiser (1976) found Spanish and king mackerels made up less than 1.5% of the total biomass. Low et al. (1990) found that Spanish and king mackerels together contributed 0.58% of the total catch biomass and 2.22% of the fish biomass collected. The mackerels were more prevalent by weight in our study: 0.79% of the total catch and 5.55% of the fishes. It is not known how fluctuations in numbers and biomass relate to changes of the population in the region. However, the magnitude and apparent increase of mackerels in the by-catch warrant further study.

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References

Anderson, W. W. 1968. Fishes taken during shrimp trawling along the South Atlantic coast of the United States, 1931–35. U.S. Fish and Wildlife Service Special Scientific Report Fisheries 570.

Boylan, J. M., R. P. Webster, H. R. Beatty, and E. L. Wenner. 1990. Results of trawling efforts in the coastal habitat of the South Atlantic Bight. Final SEAMAP-SA report to U.S. National Marine Fisheries Service, Southeastern Regional Office, St. Petersburg, Florida.

Brown, B. E., J. A. Brennan, and J. E. Palmer. 1979. Linear programming simulations of the effects of bycatch on the management of mixed species fisheries off the northeastern coast of the United States. U.S. National Marine Fisheries Service Fishery Bulletin 76:851–860.

Bryan, C. E., T. J. Cody, and G. C. Matlock. 1982. Organisms captured by the commercial shrimp fleet on the Texas brown shrimp (*Penaeus aztecus* Ives) grounds. Texas Parks and Wildlife Department, Technical Series 31, Austin.

Eldridge, P. J., R. J. Rhodes, and D. M. Cupka. 1974. The southeast shrimp fishery: historical catch statistics. South Carolina Marine Resources Center Technical Report 5:86–160.

Grosslein, M. D. 1969. Groundfish survey of BCF Woods Hole. U.S. National Marine Fisheries Service Commercial Fisheries Review 31(8–9):22–35.

Gutherz, E. J., and G. J. Pellegrin. 1988. Estimate of the catch of red snapper, *Lutjanus campechanus*, by shrimp trawlers in the U.S. Gulf of Mexico. U.S. National Marine Fisheries Service Marine Fisheries Review 50(1):17–25.

Holland, B. F., Jr. 1989. Evaluation of certified trawl efficiency devices (TEDS) in North Carolina's nearshore ocean. Final report to U.S. National Marine Fisheries Service, Southeastern Regional Office, St. Petersburg, Florida.

Keiser, R. K., Jr. 1976. Species composition, magnitude, and utilization of the incidental catch of the South Carolina shrimp fishery. South Carolina Marine Resources Center Technical Report 16.

Keiser, R. K., Jr. 1977. The incidental catch from commercial shrimp trawlers of the South Atlantic States. South Carolina Marine Resources Center Technical Report 26.

Knowlton, C. J. 1972. Fishes taken during commercial shrimp fishing in Georgia's close inshore ocean waters. Georgia Game and Fish Commission, Coastal Fisheries Office, Contribution Series 21, Atlanta.

Latham, F. P. 1951. Evidence of fish loss due to shrimping in Pamlico Sound. Appendix B *in* G. R. Lunz, J. L. McHugh, E. W. Roelofs, R. E. Tiller, and C. E. Atkinson. Destruction of small fish by the shrimp trawlers in Pamlico Sound, North Carolina. Final Report to Atlantic States Marine Fisheries Commission, Washington, D.C.

Low, R. A., Jr., G. F. Ulrich, and F. Blum. 1982. Development potential of under utilized trawl fish in the South Atlantic Bight. South Carolina Marine Resources Center Technical Report 52.

Low, R. A., Jr., G. F. Ulrich, J. W. McCord, and N. C. Jenkins. 1990. Incidental finfish catch by South Carolina shrimp trawlers. Final report to National Marine Fisheries Service, Southeastern Regional Office, St. Petersburg, Florida.

Lunz, G. R., J. L. McHugh, E. W. Roelofs, R. E. Tiller, and C. E. Atkinson. 1951. The destruction of small fish by the shrimp trawlers in Pamlico Sound, North Carolina. Final Report to Atlantic States Marine Fisheries Commission, Washington, D.C.

Murray, J. D., J. J. Bahen, and R. A. Rulifson. 1992. Management considerations for by-catch in the North Carolina and southeast shrimp fishery. Fisheries (Bethesda) 17(1):21–26.

National Marine Fisheries Service. 1991. Shrimp trawl bycatch research requirements. National Oceanographic and Atmospheric Administration Publication, Washington, D.C.

Parkinson, E. A., J. Berkowitz, and C. J. Bull. 1988. Sample size requirements for detecting changes in some fisheries statistics from small trout lakes. North American Journal of Fisheries Management 8:181–190.

Pearce, K. B., D. W. Moye, and S. K. Strasser. 1989. Evaluation of trawl excluder devices in the Pamlico Sound shrimp fishery. Final Report 88-07 to U.S. Environmental Protection Agency and North Carolina Department of Natural Resources and Community Development, Morehead City, North Carolina.

Pellegrin, G., Jr. 1982. Fish discards from the southeastern United States shrimp fishery. Pages 51–54 *in* Technical consultation on shrimp bycatch utilization. Fish bycatch . . . bonus from the sea. Report of a technical consultation on shrimp bycatch utilization held in Georgetown, Guyana, 27–30 October 1981. International Development Research Center, Ottawa.

Powers, J. E., G. P. Goodyear, and G. P. Scott. 1987. The potential effect of shrimp fleet bycatch on fisheries production of selected fish stocks in the Gulf of Mexico. National Marine Fisheries Service, Southeast Fisheries Center, Coastal Resource Division, Contribution CRD-87/88-0., Miami.

Roe, R. B. 1969. Distribution of royal red shrimp, *Hymenopenaeus robustus*, on three potential commercial grounds off the southeastern United States. U.S. Fish and Wildlife Service, Bureau of Commercial Fisheries, Fishery Industrial Research 5:161–174.

Roelofs, E. W. 1951. Observations on the capture of small fish by the shrimp trawls. Appendix A *in* G. R. Lunz, J. L. McHugh, E. W. Roelofs, R. E. Tiller, and C. E. Atkinson. Destruction of small fish by the shrimp trawlers in Pamlico Sound, North Carolina. Final Report to Atlantic States Marine Fisheries Commission, Washington, D.C.

Rothmayr, C. M. 1965. Review of industrial bottom fishery in northern Gulf of Mexico, 1959–63. Commercial Fisheries Review 27(1):1–6.

Struhsaker, P. 1969. Demersal fish resources: composition, distribution and commercial potential of the continental shelf stock off the southeastern United States. U.S. Fish and Wildlife Service, Bureau of Commercial Fisheries, Fishery Industrial Research 4:261–300.

Webster, R. P., H. R. Beatty, and E. L. Wenner. 1989. Results of trawling efforts in the coastal habitat of the South Atlantic Bight. Final SEAMAP-SA report to National Marine Fisheries Service, Southeastern Regional Office, St. Petersburg, Florida.

Wenner, C. A. 1987. Results of tests conducted on two different trawl efficiency devices (TED) in South Carolina coastal waters. Final Report to Sport Fishing Institute, Washington, D.C.

Wenner, C. A., C. A. Barans, B. W. Stender, and F. H. Berry. 1979. Results of MARMAP otter trawl investigations in the South Atlantic Bight. III. Summer, 1974. South Carolina Marine Resources Center Technical Report 41.

Wenner, C. A., C. A. Barans, B. W. Stender, and F. H. Berry. 1980. Results of MARMAP otter trawl investigations in the South Atlantic Bight. V. Summer, 1975. South Carolina Marine Resources Center Technical Report 45.

Wenner, C. A., and G. R. Sedberry. 1989. Species composition, distribution, and relative abundance of fishes in the coastal habitat off the southeastern United States. NOAA (National Oceanographic Atmospheric Administration) Technical Report NMFS (National Marine Fisheries Service) 79:1–49.

Wenner, E. L., and C. A. Wenner. 1989. Seasonal composition and abundance of decapod and stomatopod crustaceans from coastal habitats, southeastern United States. U.S. National Marine Fisheries Service Fisheries Bulletin 87:155–176.

Whitaker, J. D., L. B. DeLancey, and J. E. Jenkins. 1989. A study of the experimental closure of South Carolina's sounds and bays to commercial trawling. South Carolina Marine Resources Center Technical Report 72.

Wolff, M. 1972. A study of North Carolina scrap fishery. North Carolina Department of Natural Resources and Community Development Special Scientific Report 20:1–29.