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# The Efficiency of a Bycatch Reduction Device Used in Skimmer Trawls in the Florida Shrimp Fishery

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*Abstract.*—Of principal concern to those who regulate shrimp harvesting gear are the quantity and composition of nontargeted species (bycatch) harvested by any allowable gear type. The use of skimmer trawls in the Florida shrimp fishery is a contested issue, in part because little bycatch characterization data exist for this gear. We characterized skimmer trawl bycatch and evaluated the efficiency of the Florida Fisheye (FFE) bycatch reduction device in a skimmer trawl typically used by commercial fishermen in Apalachicola Bay, Florida, an area with an active fishery for white shrimp *Litopenaeus setiferus* (also known as *Penaeus setiferus*). In general, the finfish bycatch in a 4.9-m-long × 3-m-wide skimmer trawl net equipped with an FFE was significantly lower than that in an identical net towed simultaneously but without the FFE; the two nets, however, did not differ in the quantity of shrimp retained. The magnitude of the reduction in bycatch in the FFE-equipped net varied between seasons (spring and fall) and among finfish species and, in the case of silver seatrout *Cynoscion nothus* and Atlantic croaker *Micropogonias undulatus*, between size- (i.e., age-) groups. Preliminary tests of FFEs in skimmer trawls in North Carolina also show a reduction in bycatch; we provide further details on how bycatch reduction devices work in skimmer trawls. Overall, our results indicate that skimmer trawls equipped with FFEs should compare favorably with other allowable shrimping gear.



The penaeid shrimp fishery often ranks higher in value than any other commercial fishery in the southeastern United States (Klima 1989; NMFS 1997), but the greatest amounts of nontargeted organisms (e.g., finfish and miscellaneous invertebrates) are also harvested in this fishery because shrimp trawls harvest nonselectively (Alverson et al. 1994). The catches of these nontargeted organisms, also known as bycatch, often exceed those of the targeted species. For example, in the southeastern U.S. shrimp trawl fisheries, the total weight of bycatch is frequently two to four times the total weight of the shrimp catch and can be as high as ten times the total weight (Alverson et al. 1994; Wallace and Robinson 1994; GSAFDF 1997). Thus, the capture of bycatch in shrimp trawls is an important concern for fishermen, fishery managers, and environmentalists (Alverson and Hughes 1996). Recently, researchers have focused on various ways to reduce the amount of bycatch, including the development and evaluation of various bycatch reduction devices attached to shrimp nets (McKenna and Monaghan 1993; Rogers et al. 1997a, 1997b; Broadhurst 2000; Steele et al. 2002).

The skimmer trawl is a type of shrimping gear that is commonly used in the North Carolina and Louisiana shrimp fisheries (Hines et al. 1993; Estrada et al. 2000). This gear is similar to a wing net in that the net is held open by a rigid frame and deployed amidships of the towing vessel. The skimmer trawl is different from the commonly used otter trawl in that this shallow water gear fishes the entire water column and is pushed through the water instead of being pulled. The skimmer trawl has several advantages over other types of shrimping gear. For example, the skimmer trawl is more effective at reducing bycatch and increasing shrimp catch than the otter trawl, and captured finfish bycatch species have higher survival probabilities after being released from the net (Hines et al. 1993; Coale et al. 1994).

The use of skimmer trawls in the Florida shrimp fishery is limited and relatively recent. Florida fishermen first expressed an interest in using skimmer trawls to harvest white shrimp *Litopenaeus setiferus* (also known as *Penaeus setiferus*) in the Apalachicola region (Figure 1) in 1993. At that time, skimmer trawls were approved for use in Florida only under a special activities license and within a restricted fishing zone in Apalachicola Bay. However,

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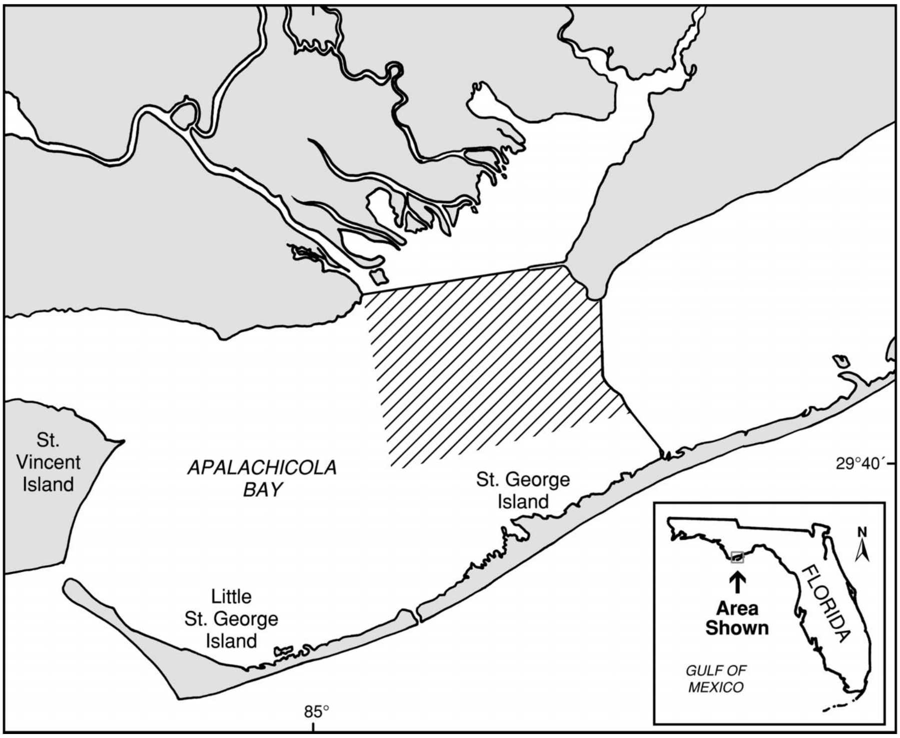


FIGURE 1.—Map of Apalachicola Bay, Florida. The hatched region is the area where sampling was conducted, which was also the only area in Florida where the use of skimmer trawls was allowed until 2002.



in 2002, skimmer trawls were classified as allowable shrimp-harvesting gear throughout the Northwest Florida Shrimping Region (Northwest Region Food Shrimp Production Gear Specifications 2002).

The principal concerns of those who regulate shrimp-harvesting gear are the quantity and composition of the bycatch species harvested by the gear. To our knowledge, only three papers have been published on skimmer trawls in general (Hines et al. 1993; Coale et al. 1994; Hines et al. 1999), and no detailed information has been published on the efficiency of bycatch reduction devices in skimmer trawls. Furthermore, little bycatch characterization data exist for the skimmer trawl in Florida waters. In May 1994, Felicia Coleman (Florida State University, Tallahassee, unpublished data) conducted an initial survey of skimmer trawl bycatch. However, her shrimp catch was small, and she was unable to determine catch rates of finfish and shrimp from the data. Thus, a more comprehensive characterization of skimmer trawl bycatch in Florida waters was needed.

The goal of our study was to characterize the bycatch captured by skimmer trawls and to evaluate the efficiency of the Florida Fisheye (FFE) bycatch reduction device (BRD) in reducing the capture of nontarget species and retaining shrimp. This information should assist fishery managers when they consider the use of skimmer trawls and the FFE bycatch reduction device.

## Methods

*Gear specifications.*—We conducted our sampling on a commercial shrimp boat (12.5 m long × 4.9 m wide and powered by a General Motors 8-71 engine) equipped with paired skimmer trawls identical to the type used in the Florida commercial shrimp fishery (Figure 2). The skimmer trawls consisted of rigid aluminum frames (4.9 m wide × 3.0 m high) that were suspended off each side of the boat and hinged to the base of an A-frame located 60% of the way aft of the bow. This allowed the trawls to be raised and lowered (Hines et al. 1993). A ‘‘shoe’’ (30.5 cm × 91.4 cm) attached to the bottom of the vertical arm slid along the sea floor when the trawls were fishing. Commercial food-shrimp nets (no. 9 twine) with a stretch-mesh size of 3.8 cm were attached to the frames; accordingly, the mouths of the nets were

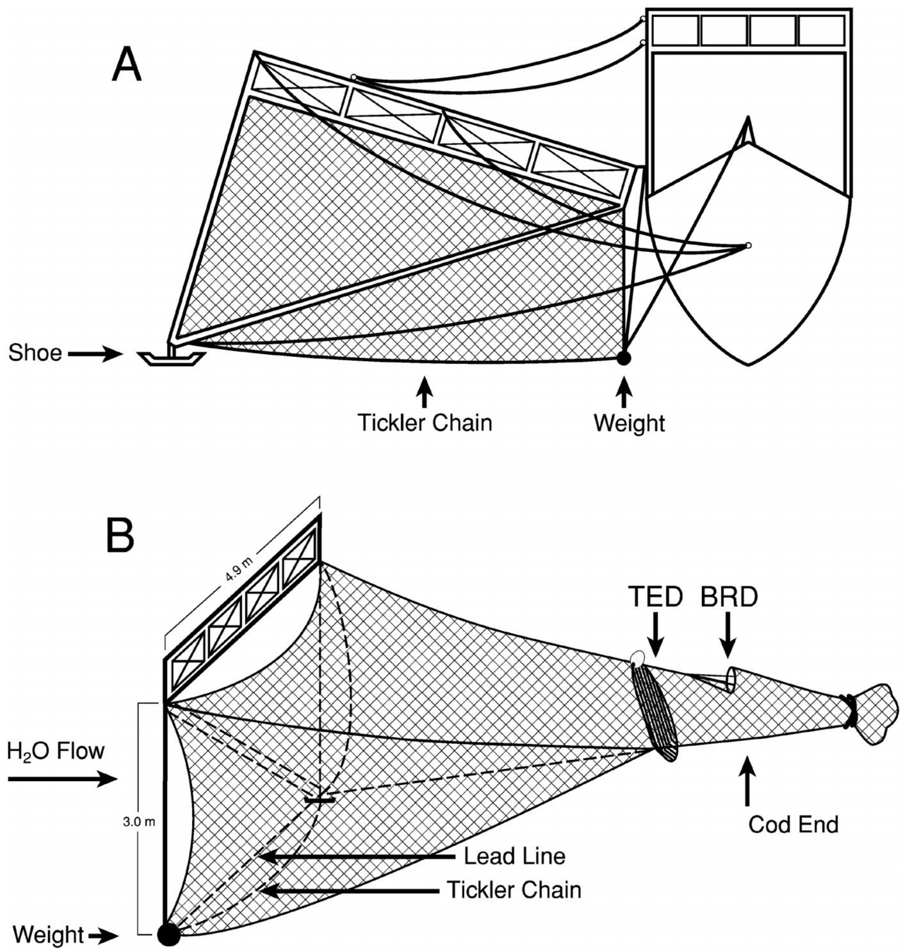


FIGURE 2.—Diagram showing **(A)** the skimmer trawl frame and **(B)** the components of the net. Both the Turtle Excluder Device (TED) and the Florida Fisheye Bycatch Reduction Device (BRD) were attached to the shrimp net.

the same dimensions as the frames. The tail bags (3.35 m long) were made of no. 21 twine and had a stretch-mesh size of 3.5 cm. For each net, a 113-kg weight tied to an inboard line spread open the bottom of the net, and a tickler chain was connected between the shoe and the weight.

Each net was equipped with a Super Shooter Turtle Excluder Device (TED). The TED was attached to the net according to federal regulations and consisted of a metal grid of seven aluminum bars with a 9-cm interbar distance; the grid was set at a 45° angle to direct turtles downward toward the escape opening. Each net was also equipped with an FFE. The FFE was mounted at the top center of the tail bag approximately halfway between the tie-off rings and the beginning of the cod end. The FFE was constructed of 13-mm-diameter stainless steel rods. It was 30 cm in length and had a 15-cm × 15-cm opening to allow fish to escape. The FFE has been tested in other types of shrimping gear (Whitaker et al. 1992; Rogers et al. 1997a; Steele et al. 2002) and is an approved BRD for the Florida shrimp fishery.

*Sampling protocol*.—We conducted our study in Apalachicola Bay, a 549-km$^2$ estuary located in northwestern Florida (Figure 1). An active fishery for penaeid shrimp, principally the white shrimp, is located in the bay. At the time of this study, shrimp fishing with skimmer trawls in the bay was restricted to a designated fishing area (Figure 1) that had an average water depth of about 3 m. We sampled only within this area.

During each sampling period (spring [May 2001] and fall [September 2001]), we trawled at night when commercial fishermen were actively fishing. The trawls were towed at a speed of 2.5 knots (1 knot = 0.514 m/s), as determined by the global positioning system. We conducted a total of forty 30-min tows using paired trawls, one attached to each side of the boat. The first 10 tows were used as a preliminary study to determine whether the biomass catchability of the two trawls was equivalent; thus, they were conducted with the BRDs in both nets sewn shut. The subsequent 30 experimental tows were conducted with the BRD in one trawl sewn shut (control net) and the BRD in the other trawl left open (BRD-equipped net). To reduce any bias associated with differences in the catch related to the side of the boat on which we placed the BRD-equipped net, we performed 15 experimental tows with the BRD-equipped net on the port side of the boat and then changed the position of the BRD-equipped net to the starboard side for the remaining 15 tows.

All samples were processed onboard the boat immediately after each tow. For the preliminary study, only the total weights of shrimp plus bycatch were recorded for each tow. For each of the experimental tows, the shrimp were separated from the bycatch and the bycatch was separated by species. The total shrimp catch was weighed and counted to determine the count per gram. Twenty randomly chosen shrimp (or all shrimp if $n < 20$) were measured (total length [TL]) to obtain a size distribution. Similarly, for each bycatch species, the total catch was weighed and 20 randomly chosen individuals (or all individuals if $n < 20$) were measured (TL). Miscellaneous debris and organisms (turtle grass *Thalassia testudinum*, manatee grass *Syringodium filiforme*, rocks, shells, sponges, tunicates, anthropogenic garbage, etc.) were separated out of each tow.

*Statistical analyses.*—Statistical analyses followed the methods of Sokal and Rohlf (1995) and were performed using the STATISTICA software package (Statsoft, Inc. 1999). A significance level of 0.05 was used for all tests. Most variables did not conform to parametric assumptions of normality (Shapiro−Wilk test) or homogeneity of variances (Levene's test), even after log transformation. Thus, appropriate nonparametric tests were used for all analyses, as detailed below.

We calculated the number per unit effort (NPUE) as the number of individuals caught per minute of trawling time and the catch per unit effort (CPUE) as biomass (g) caught per minute of trawling time. We report large weights as kilograms for simplicity. All comparisons of NPUE and CPUE were made between the BRD-equipped net and its corresponding control net for each season separately. We compared mean NPUE and CPUE values using the Mann–Whitney $U$-test. We also calculated the percent difference in mean NPUE or CPUE between the BRD-equipped and control nets using the method of Rogers et al. (1997a), namely,

$$\text{Percent difference} = \left(\frac{\text{BRD value} - \text{control value}}{\text{control value}}\right) \times 100.$$

Number per unit effort and CPUE comparisons were done separately for shrimp, total finfish bycatch, total invertebrate bycatch (excluding sponges and tunicates) as well as for each finfish bycatch species in an ''abundant'' category, which we defined as those that collectively composed 95% of the finfish bycatch in terms of numbers or biomass. Although relatively small individuals of some species may have passed through our nets, we used all finfish species in our analyses, including small species such as anchovies *Anchoa* spp., scaled sardine *Harengula jaguana*, and Atlantic silversides *Menidia menidia*, because they contributed relatively large proportions of the overall bycatch NPUE and CPUE in both seasons (Tables 1, 2).

We used the Kolmogorov−Smirnov two-sample test to determine whether there were shifts in the size distributions of the shrimp captured in the BRD-equipped net and the control net. This test was also used to determine whether there were significant differences in the size distributions of the finfish bycatch species in the abundant category captured in the BRD-equipped net and those captured in the control net. However, the sizes of certain large species that were rarely captured (i.e., longnose gar, cownose ray, and blacktip shark) were not evaluated because sample sizes were small.

## Results

The shrimp catch consisted principally of white shrimp with occasional pink shrimp *Farfantepenaeus duorarum*. For this study we did not separate these two species during data collection.

The catchability rates of the net on the port side of the boat and that on the starboard side were similar when no BRDs were used. The differences between the port and starboard nets in catchability rate (total biomass) were 0.8% in the spring ($U =$

TABLE 1.—Composition (number) of finfish bycatch species captured in a skimmer trawl net equipped with a bycatch reduction device (BRD) and skimmer trawl net without a BRD (control) in Apalachicola Bay, Florida, during the spring and fall of 2001. Only species that collectively contributed to 95% of the total catch are identified in the table; the remaining species are listed in the footnotes. The acronym NPUE refers to the number of fish captured per minute of towing. Crosses denote species important to commercial or recreational fisheries. Asterisks represent significant differences in catch between the BRD-equipped and control nets ($P < 0.05$*, $P < 0.01$**, $P < 0.001$***).

| Species | Total count (%) | NPUE in control net | NPUE in BRD net | Percent difference |
|---|---|---|---|---|
| **Spring** | | | | |
| Striped anchovy† *Anchoa hepsetus* | 6,964 (37.1) | 3.55 | 4.43 | 24.8* |
| Atlantic croaker *Mircopogonias undulatus* | 3,913 (20.9) | 2.16 | 2.31 | 7.0 |
| Atlantic bumper† *Chloroscombrus chrysurus* | 2,734 (14.6) | 1.66 | 1.54 | −7.4 |
| Star drum *Stellifer lanceolatus* | 1,165 (6.2) | 0.70 | 0.64 | −9.2 |
| Gulf menhaden† *Brevoortia patronus* | 977 (5.2) | 0.78 | 0.34 | −57.2* |
| Atlantic silverside† *Menidia menidia* | 885 (4.7) | 0.54 | 0.49 | −9.9 |
| Harvestfish† *Peprilus alepidotus* | 608 (3.3) | 0.34 | 0.37 | 8.4 |
| Hardhead catfish† *Arius felis* | 315 (1.7) | 0.20 | 0.17 | 12.2 |
| Scaled sardine† *Harengula jaguana* | 254 (1.4) | 0.19 | 0.10 | −45.4** |
| Caribbean pomfret *Brama caribbaea* | 203 (1.1) | 0.12 | 0.11 | −9.3 |
| Other finish combined[a] | 717 (3.8) | 0.41 | 0.41 | 0.4 |
| **Fall** | | | | |
| Gulf menhaden† | 39,789 (68.3) | 33.39 | 11.71 | −64.9*** |
| Scaled sardine† | 7,166 (12.3) | 4.95 | 3.37 | −32.0 |
| Silver perch† *Bairdiella chrysoura* | 4,387 (7.5) | 2.69 | 2.43 | −9.7 |
| Bay anchovy† *Anchoa mitchilli* | 1,852 (3.2) | 0.94 | 1.21 | 29.7 |
| Spot† *Leiostomus xanthurus* | 1,783 (3.1) | 1.25 | 0.83 | −33.9* |
| Atlantic bumper† | 1,323 (2.3) | 0.31 | 1.14 | 267.6 |
| Other finfish combined[b] | 1,938 (3.3) | 0.95 | 1.29 | 36.3 |

[a] Other finish bycatch species captured in spring 2001 (in order of relative abundance) are as follows: Atlantic thread herring† *Opisthonema oglinum*, pinfish† *Lagodon rhomboids*, leatherjack *Oligoplites saurus*, Atlantic spadefish† *Chaetodipterus faber*, Spanish mackerel† *Scomberomorus maculates*, bluestriped grunt† *Haemulon sciurus*, bonnethead† *Sphyrna tiburo*, bighead searobin *Prionotus tribulus*, ladyfish† *Elops saurus*, sapphire eel *Cynoponticus savanna*, Atlantic needlefish† *Strongylura marina*, blackcheek tonguefish *Symphurus plagiusa*, spotted whiff *Citharichthys macrops*, hogchoker *Trinectes maculates*, spiny butterfly ray *Gymnura altavela*, reef shark *Carcharhinus perezi*, southern flounder† *Paralichthys lethostigma*, southern stingray† *Dasyatis Americana*, and stippled clingfish *Gobiesox punctulatus*.

[b] Other finfish bycatch species captured in fall 2001 (in order of relative abundance) are as follows: striped anchovy†, Atlantic silverside†, silver seatrout† (*Cynoscion nothus*), Caribbean pomfret, Atlantic thread herring†, banded rudderfish† *Seriola zonata*, pinfish†, spotfish mojarra† *Eucinostomus argenteus*, spotted seatrout† *Cynoscion nebulosus*, leatherjack, lookdown† *Selene vomer*, bluntnose jack *Hamicaranx amblyrhynchus*, Atlantic spadefish†, Spanish mackerel†, bluestriped grunt†, Atlantic moonfish† *Selene setapinnis*, bonnethead, inshore lizardfish *Synodus foetens*, bighead searobin, ladyfish†, cownose ray† *Rhinoptera bonasus*, gray snapper† *Lutjanus griseus*, Atlantic needlefish†, blackcheek tonguefish, sand seatrout† *Cynoscion arenarius*, striped burrfish *Chilomycterus schoepfi*, bandtail puffer *Sphoeroides spengleri*, hogchoker, king mackeral† *Scomberomorus cavalla*, Atlantic stingray† *Dasyatis Sabina*, crevalle jack† *Caranx hippos*, gulf kingfish† *Menticirrhus littoralis*, remora *Remora remora*, sand perch† *Diplectrum formosum*, smalltail shark *Carcharhinus porosus*, southern puffer† *Sphoeroides nephelus*, and tripletail† *Lobotes surinamensis*.



49.0, df = 18, $P = 0.940$) and 0.9% in the fall ($U = 30.5$, df = 18, $P = 0.377$). The shrimp biomass captured in the two nets (spring: 13.0%; fall: 8.7%) differed to a greater degree than did the finfish bycatch biomass (spring: 0.6%; fall: 0.0%), but none of the differences were statistically significant (spring shrimp: $U = 33.5$, df = 18, $P = 0.212$; fall shrimp: $U = 37.5$, df = 18, $P = 0.791$; spring finfish: $U = 46.5$, df = 18, $P = 0.791$; fall finfish: $U = 33.0$, df = 18, $P = 0.508$). In addition, the net on one side of the boat did not have a consistently higher or lower catch rate than the net on the other side of the boat. The biomass of the invertebrate bycatch was too small for reliable statistical tests.

In the experimental study, the total biomass captured in the BRD-equipped net and the control net (all data combined for each net type) in the spring consisted of 84.1% and 87.3% finfish bycatch, respectively, and 11.8% and 10.1% shrimp. The remainder of the catch consisted of invertebrate bycatch (<2.0% of the total biomass in each net) and miscellaneous debris (<2.5% of the total biomass in each net). Of the total biomass captured in the

TABLE 2.—Composition (biomass) of finfish bycatch species captured in a skimmer trawl net equipped with a bycatch reduction device (BRD) and a skimmer trawl net without a BRD (control) in Apalachicola Bay, Florida, during the spring and fall of 2001. Only species that collectively contributed to 95% of the total catch are identified in the table; the remaining species are listed in the footnotes to Table 1. The acronym CPUE refers to the biomass of fish captured per minute of towing. Crosses denote species important to commercial or recreational fisheries. Asterisks represent significant differences in catch between the BRD-equipped and control nets ($P < 0.05$*, $P < 0.01$**, $P < 0.001$***).

| Species | Total biomass (g) (% of catch) | CPUE in control net | CPUE in BRD net | Percent difference |
|---|---|---|---|---|
| **Spring** | | | | |
| Hardhead catfish† | 93,650 (14.0) | 59.69 | 51.26 | −14.1 |
| Gulf menhaden† | 85,870 (12.9) | 64.88 | 34.37 | −47.0** |
| Atlantic croaker | 68,470 (10.3) | 35.58 | 42.75 | 20.2 |
| Striped anchovy† | 65,400 (9.8) | 36.69 | 39.20 | 6.9 |
| Atlantic bumper† | 51,770 (7.8) | 29.91 | 30.55 | 2.1 |
| Gafftopsail catfish† *Bagre marinus* | 46,250 (6.9) | 39.12 | 13.73 | −64.9 |
| Star drum | 43,940 (6.6) | 26.21 | 24.33 | −7.2 |
| Harvestfish† | 34,480 (5.2) | 19.28 | 20.73 | 7.5 |
| Atlantic silverside† | 32,630 (4.9) | 19.98 | 17.99 | −10.0 |
| Atlantic midshipman *Porichthys plectrodon* | 22,440 (3.4) | 13.25 | 12.71 | −4.1 |
| Silver perch† | 17,270 (2.6) | 10.59 | 9.65 | −8.8 |
| Banded rudderfish† | 16,280 (2.4) | 10.85 | 8.14 | −25.0 |
| Blacktip shark† *Carcharhinus limbatus* | 16,050 (2.4) | 12.32 | 5.67 | −54.0 |
| Scaled sardine† | 15,700 (2.4) | 12.47 | 5.66 | −54.6** |
| Silver seatrout† | 10,410 (1.6) | 7.70 | 4.33 | −43.8 |
| Cownose ray† | 8,100 (1.2) | 9.70 | 0.00 | −100.0 |
| Spotted seatrout† | 7,750 (1.2) | 3.94 | 5.00 | 26.8 |
| Other finfish combined | 30,380 (4.4) | 17.49 | 17.27 | −1.3 |
| **Fall** | | | | |
| Gulf menhaden† | 435,300 (61.6) | 365.10 | 131.12 | −64.1*** |
| Silver perch† | 82,860 (11.7) | 51.35 | 45.41 | −11.6 |
| Scaled sardine† | 56,840 (8.0) | 38.18 | 27.55 | −27.8 |
| Spot† | 42,070 (6.0) | 29.53 | 19.84 | −32.8* |
| Longnose gar *Lepisosteus osseus* | 31,400 (4.4) | 21.07 | 15.94 | −24.4 |
| Atlantic croaker | 10,410 (1.5) | 3.94 | 7.75 | 96.6 |
| Gafftopsail catfish† | 9,220 (1.3) | 4.15 | 6.74 | 62.4 |
| Hardhead catfish† | 7,370 (1.0) | 3.77 | 4.58 | 21.5 |
| Other finfish combined | 32,230 (4.5) | 19.80 | 16.54 | −16.5 |

fall, the BRD-equipped net contained 91.6% finfish bycatch and 8.0% shrimp; the control net contained 95.0% finfish bycatch and 4.4% shrimp. The invertebrate bycatch and debris was less than 1% of the total biomass in each net.

### *Effects of the BRD on NPUE and CPUE*

In the spring, the NPUE of the finfish bycatch in the BRD-equipped net did not differ significantly from that in the control net, but the CPUE did differ significantly ($U = 278.0$, df = 58, $P = 0.011$; Figure 3A, B). The finfish bycatch CPUE in the BRD-equipped net (343.3 ± 84.9 g/min [mean ± SD]) was 20% lower than that in the control net (429.7 ± 193.5 g/min). The discrepancy between the NPUE and CPUE results was partially due to the decrease in the catch of relatively small numbers of large fish such as the gafftopsail catfish, blacktip shark, and cownose ray in the BRD-equipped net. The presence of only one or a few of these fish in a net strongly influenced the overall CPUE. Notable decreases in the number or biomass of smaller fish, such as the gulf menhaden, scaled sardine, and silver seatrout, also contributed to the reduction in CPUE (Tables 1, 2).

In the fall, both NPUE ($U = 210.0$, df = 58, $P < 0.001$) and CPUE ($U = 184.0$, df = 58, $P < 0.001$) of the finfish bycatch were approximately 50% lower in the BRD-equipped net than in the control net (Figure 3A, B). These differences were due to the capture of fewer gulf menhaden in the BRD-equipped net than in the control net. The gulf menhaden composed 68% and 62% of the finfish-bycatch NPUE and CPUE, respectively; these measures were 65% and 64% lower, respectively, in the BRD-equipped net than in the control net. When gulf menhaden were omitted from the analyses, neither NPUE nor CPUE differed signifi-

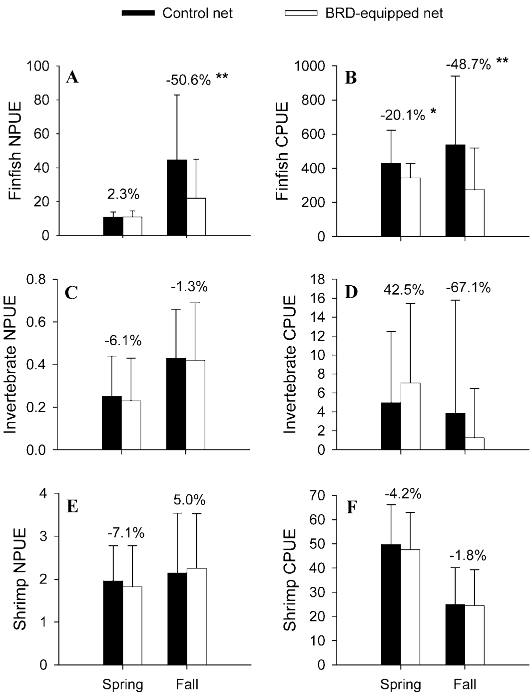


FIGURE 3.—Comparisons of the mean number captured per minute of towing (NPUE) and the mean biomass captured per minute of towing (CPUE) of **(A, B)** finfish bycatch, **(C, D)** invertebrate bycatch, and **(E, F)** shrimp in a skimmer trawl net equipped with a bycatch reduction device (BRD) and one without a BRD (control) in Apalachicola Bay, Florida, during the spring and fall of 2001. The numbers above the bars are the percentage differences between the control and BRD-equipped nets; $P < 0.01$*, $P < 0.001$**. The error bars represent standard deviations.

cantly between the BRD-equipped and control nets, despite relatively large percentage reductions of some of the less prevalent species (Tables 1, 2).

Equipping the skimmer trawl net with the FFE did not significantly reduce either the NPUE or CPUE of invertebrate bycatch during either season (Figure 3C, D). The differences in NPUE between the performances of the two nets were relatively small, but the differences in CPUE were large and were principally due to the occasional capture of a large blue crab *Callinectes sapidus* or cannonball jellyfish *Stomolophus meleagris* in either the BRD-equipped or the control net during a particular trawl. As a result, the high variances precluded statistical significance.

Except for NPUE in the fall, the shrimp harvest in the BRD-equipped net was slightly lower in both number and biomass than that in the control net. However, differences in the NPUE and CPUE of shrimp harvested in the BRD-equipped and control nets were not significant in either season (Figure 3E, F).

## *Bycatch Composition*

Overall, we captured 58 species of finfish (Tables 1, 2) and 6 species of invertebrates. Twenty-six of the finfish species were common to both the spring and the fall sampling periods.

In the spring, we captured a total of 37 finfish bycatch species. Only 10 species composed 96.2% of the 18,735 finfish caught (Table 1). The striped anchovy was the most common; the number of striped anchovy collected was nearly twice that of the second most common species, the Atlantic croaker. The Atlantic bumper was also relatively common. In biomass, no single species notably predominated (Table 2); total biomass was well distributed among the species captured. In total biomass, 29 species contributed small percentages (<5%).

The invertebrate bycatch in the spring consisted of squid (family Loliginidae) and blue crabs. We caught 322 squid, which composed 76% of the total number of bycatch invertebrates, and 99 blue crabs. Due to their small size, we did not weigh the squid. The blue crabs had a total biomass of about 10.0 kg.

The species composition of our finfish bycatch in the fall was highly diverse (47 species). Gulf menhaden were predominant in both numbers and biomass (Tables 1, 2). Scaled sardine and silver perch were also relatively common. Together, these three species accounted for 88.1% of the count and 81.3% of the biomass of the finfish bycatch.

The invertebrate bycatch was also speciose in the fall. Squid (600 individuals; 81% of total invertebrate bycatch numbers) and comb jellies *Mnemiopsis* spp. (100 individuals; 14%) were the most abundant species, followed by mantis shrimp *Squilla empusa* (17 individuals; 2%), blue crab (12 individuals; 2%), and cannonball jelly (8 individuals; 1%). Cannonball jelly predominated in the invertebrate bycatch biomass (4.0 kg).

A number of the finfish species harvested are commercially or recreationally important as baitfish, food fish, or sport fish (Tables 1, 2). The presence of a BRD in a net greatly reduced the harvest of some of these species (e.g., the gulf menhaden, scaled sardine, spot, and to a lesser extent, Atlantic silverside) but increased the harvest of others; however, these increases were significant for only one case (the NPUE of striped anchovy in spring).

TABLE 3.—Mean total lengths (mm) of the finfish commonly captured in a skimmer trawl net equipped with a bycatch reduction device (BRD) and a skimmer trawl net without a BRD (control) during spring and fall 2001 in Apalachicola Bay, Florida; $n$ = the number of fish measured. Asterisks denote significant differences between BRD-equipped and control nets ($P < 0.05$*, $P < 0.01$**). Comparisons of species with high biomass per minute of towing and low numbers per minute of towing were not made due to small sample sizes.

| | Spring | | | | Fall | | | |
|---|---|---|---|---|---|---|---|---|
| | Control net | | BRD net | | Control net | | BRD net | |
| Species | $n$ | Mean ± SD | $n$ | Mean ± SD | $n$ | Mean ± SD | $n$ | Mean ± SD |
| Striped anchovy | 600 | 58.7 ± 4.8 | 600 | 58.0 ± 5.3** | 180 | 81.2 ± 12.1 | 241 | 81.5 ± 11.4 |
| Atlantic croaker | 548 | 63.7 ± 10.9 | 560 | 62.3 ± 9.1** | 59 | 128.8 ± 30.2 | 66 | 113.5 ± 31.0* |
| Atlantic bumper | 529 | 63.3 ± 5.3 | 532 | 63.7 ± 6.0 | 128 | 41.12 ± 12.9 | 197 | 38.8 ± 10.2 |
| Star drum | 434 | 84.1 ± 14.6 | 422 | 84.4 ± 14.3 | 0 | | 0 | |
| Atlantic silverside | 423 | 90.3 ± 6.4 | 390 | 89.3 ± 7.6 | 1 | 75.0 | 2 | 81.0 ± 14.1 |
| Gulf menhaden | 546 | 122.9 ± 52.0 | 266 | 119.3 ± 55.0 | 584 | 85.6 ± 14.6 | 604 | 85.3 ± 16.3 |
| Harvestfish | 295 | 74.6 ± 8.1 | 287 | 75.0 ± 9.5 | 0 | | 0 | |
| Hardhead catfish | 167 | 218.3 ± 61.0 | 148 | 218.8 ± 53.0 | 29 | 162.4 ± 60.4 | 31 | 170.3 ± 63.6 |
| Scaled sardine | 168 | 87.5 ± 9.2 | 90 | 86.7 ± 7.5 | 582 | 74.8 ± 9.1 | 559 | 74.6 ± 8.5 |
| Caribbean pomfret | 107 | 52.1 ± 7.1 | 93 | 51.9 ± 6.7 | 55 | 48.7 ± 9.1 | 56 | 49.7 ± 15.0 |
| Silver seatrout | 80 | 81.1 ± 42.2 | 84 | 61.5 ± 27.1** | 148 | 103.4 ± 25.7 | 154 | 104.3 ± 54.5 |
| Silver perch | 67 | 109.6 ± 12.3 | 61 | 111.46 ± 10.9 | 571 | 94.6 ± 29.0 | 557 | 93.9 ± 12.6 |
| Bay anchovy | 0 | | 0 | | 531 | 52.0 ± 4.5 | 549 | 52.4 ± 4.7 |
| Spot | 0 | | 0 | | 529 | 94.1 ± 14.5 | 446 | 93.1 ± 10.4 |
| Gafftopsail catfish | 13 | 340.1 ± 75.0 | 12 | 323.3 ± 100.0 | 30 | 168.6 ± 76.3 | 25 | 172.2 ± 96.8 |
| Atlantic midshipman | 77 | 134.1 ± 16.9 | 91 | 132.3 ± 16.7 | 0 | | 0 | |
| Banded rudderfish | 30 | 155.6 ± 9.6 | 33 | 156.8 ± 10.0 | 18 | 75.8 ± 17.0 | 9 | 64.6 ± 24.4 |
| Spotted seatrout | 9 | 208.0 ± 22.4 | 10 | 209.2 ± 21.6 | 8 | 199.9 ± 27.4 | 25 | 110.6 ± 45.3** |

*Size Distribution*

We made 31 comparisons of the mean size of finfish species caught in the BRD-equipped net with that of those caught in the control net, and only five of those comparisons were statistically significant (Table 3); in all five of these cases, the mean size of fish in the control net was significantly larger than the mean size of fish in the BRD-equipped net. However, only three of these were notable—silver seatrout in the spring and Atlantic croaker and spotted seatrout in the fall (Table 3). Two size-classes of both the silver seatrout and the Atlantic croaker were captured (Figure 4); in both cases, the BRD-equipped net retained more fish in smaller size-classes and fewer fish in larger size-classes than did the control net. In additional analyses, we grouped the size-classes of these species into ‘‘small individuals’’ (silver seatrout: 30–99 mm TL; Atlantic croaker: 80–119 mm TL) and ‘‘large individuals’’ (silver seatrout: 110–189 mm TL; Atlantic croaker: 120–199 mm TL) and compared the NPUE between the BRD-equipped and control nets for these size groupings using the Mann–Whitney $U$-test. The NPUE of large-sized silver seatrout was significantly lower in the BRD-equipped net than it was in the control net ($U$ = 309.0, df = 162, $P$ = 0.037). A Wilcoxon's signed-ranks test showed further support for this pattern; the BRD-equipped net captured significantly fewer large-sized fish than did the control net for both silver seatrout ($P$ = 0.008) and Atlantic croaker ($P$ = 0.039).

The shrimp size-frequency distributions did not differ significantly between the BRD-equipped and control nets in either the spring or the fall. In the spring ($n$ = 1,182), mean total length was 109.9 mm (SD = 24.3) in the BRD-equipped net and 111.5 mm (SD = 23.0) in the control net. In the fall ($n$ = 1,163), mean total length was 94.5 mm (SD = 20.3) in the BRD-equipped net and 94.3 mm (SD = 20.1) in the control net.

## Discussion

*Shrimp Catch*

Shrimp biomass was a small component of the total biomass that we caught in our nets, and the presence of a BRD had no significant effect on the NPUE, CPUE, or mean size of shrimp harvested. However, the NPUE of shrimp harvested in the BRD-equipped net was 5% greater than that in the control net during the fall season. Moreover, the proportion of shrimp biomass relative to the total finfish biomass was nearly twice as high in the BRD-equipped net than in the control net during the fall season. The higher proportion of shrimp in the BRD-equipped net in the fall was due to the notably large (50%) decrease in finfish bycatch in the BRD-equipped net. Other studies of the effi-

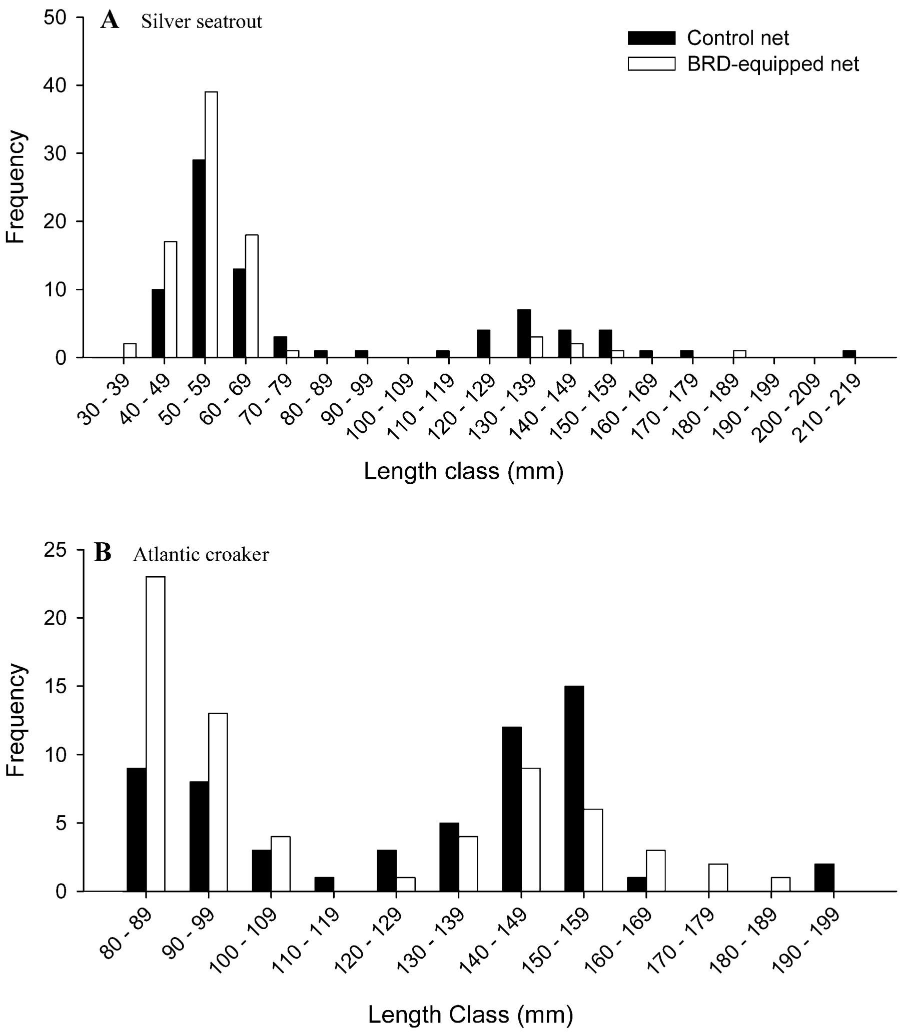


FIGURE 4.—Size-frequency distributions of the two finfish bycatch species that differed significantly and notably in size between the net equipped with a bycatch reduction device (BRD) and the control net: **(A)** silver seatrout in the spring and **(B)** Atlantic croaker in the fall.

ciency of bycatch-reduction devices have also shown that BRD-equipped trawl nets retain more shrimp than do control nets (Steele et al. 2002). The reduction in the amount of bycatch and, consequently, the drag in the BRD-equipped net may allow the net to spread and cover a proportionally larger area than a net without a BRD. Thus, more shrimp could be caught because an increased volume of water is filtered through the net (Christian et al. 1993; Coleman and Koenig 1994; Rogers et al. 1997a; Steele et al. 2002).

*Bycatch Reduction*

In general, the FFE was successful in reducing finfish bycatch and retaining shrimp. The magnitude of the reduction in bycatch varied between seasons and among finfish species. The seasonal differences in BRD efficiency were most likely due to seasonal differences in species composition and abundance. For example, in the fall, gulf menhaden made up more than 60% of the total count and biomass and were responsible for the large reduction (~50%) in both bycatch NPUE and CPUE between the BRD-equipped net and control net. In Louisiana waters, the Authement-Ledet BRD also effectively reduces bycatch when gulf menhaden are abundant (Rogers et al. 1997a). Rogers et al. (1997a) note that the capability of a BRD to reduce finfish bycatch depends on the species assemblage present, which could vary among seasons and locations. In our study, the FFE performed well during the fall when gulf menhaden were abundant, but its performance was reduced during the spring when the species composition differed.

The lower number of finfish in the BRD-equipped net was probably due to a combination of behavioral and optomotor responses of fish to moving shrimp trawls (Watson 1988; Wardle 1993). The ability of fish to respond to and escape from shrimp nets can vary with species, size, swimming ability, physiological condition, and environmental conditions (Watson 1988). Many fishes tend to swim at speeds similar to that of the trawling gear and to align themselves with the in-trawl currents by orienting their heads toward the mouth of the net. In dark conditions, like those present during our study, many fishes sense the netting via their lateral lines and maintain fixed distances from the net while swimming with the gear (Watson 1988; Wardle 1993). Fish may respond to holes in the netting because these areas contrast in color or structure with the rest of the net (Watson 1988). Thus, a hole or a BRD in the net may stimulate the fish to escape. In addition, BRDs disturb the water currents within the trawl. Many species with well-developed rheotactic responses sense these areas and eventually escape through the BRD (Watson 1988). The variation in bycatch reduction among the finfish species that we observed probably can be attributed to a combination of these factors. An additional concern, however, is the ability of finfish to survive after they have escaped through the BRD (Rulifson et al. 1992). Fish are sometimes injured when escaping through a BRD and therefore may become susceptible to disease or predation. Nevertheless, it seems likely that fish that have escaped through a BRD will still have a greater probability of survival than fish that are captured in nets without BRDs. Experimental studies of postescape survival of finfish bycatch are needed to address this concern.

In contrast to finfish, penaeid shrimp are relatively weak swimmers and are unable to maintain their orientation in the currents generated by the trawl (Watson 1988); thus, they probably rarely escape through the BRD.

The differences between the BRD-equipped net and the control net in the harvested quantities of at least two species (silver seatrout and Atlantic croaker) were size-class specific. The two size-classes of silver seatrout and Atlantic croaker probably represent two age-groups: age 0 and age 1 and above. Large individuals of these species were retained more frequently in the control net than in the BRD-equipped net, possibly because they are more likely to escape through the FFE than small individuals are. In fish, swimming ability and size are positively associated (Blaxter and Dickson 1958; Wardle 1993). Studies of other types of trawling gear (such as the otter trawl) and BRDs also report higher capture rates of small fish in BRD-equipped nets than in control nets (e.g., Steele et al. 2002). Because of the potentially detrimental effects of harvesting finfish in the early life stages, more research on the effect of BRDs on the size-specific capture of fish is warranted.

### *Skimmer Trawls, BRDs, and Fishery Management*

The capture of commercially or recreationally important finfish species in shrimp trawl nets has been a major concern of fishermen and fishery managers (Hendrickson and Griffin 1993). In our study, some of the species that were captured in high quantities are important food fish, baitfish, or sport fish. The harvest of some of these species was greatly reduced by the presence of a BRD in the net. The harvest of other such species was somewhat higher in the BRD-equipped net. These increases and decreases of finfish species bycatch in the BRD-equipped net demonstrate that BRD efficiency was species specific. However, almost none of the increases in bycatch in the BRD-equipped net were statistically or biologically significant; an increase in bycatch in the BRD-equipped net was significant for only one case (striped anchovy in spring). Thus, the use of the FFE in skimmer trawl nets is an effective way of reducing the bycatch mortality of several economically important finfish species.

The results of our study are consistent with those of preliminary tests of FFEs in skimmer trawls in North Carolina, which also reported a reduction of bycatch (Hines et al. 1993). However, we found that the performance of the FFE varied seasonally and depended on the composition of the finfish bycatch. The shrimp catch, however, was not significantly influenced by the presence of the FFE during either season. Thus, the FFE in a skimmer trawl not only serves to reduce bycatch but also provides other benefits to shrimp fishermen. Reducing bycatch decreases drag during tow times, which, in turn, decreases fuel consumption, wear on the trawl gear, and culling time by the deck crew. Consequently, from the perspective of fishermen and fishery managers, skimmer trawls equipped with FFEs should compare favorably with other allowable shrimping gear.

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