Efficiency of bycatch reduction devices in small otter trawls used in the Florida shrimp fishery

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Abstract–Two bycatch reduction devices (BRDs)—the extended mesh funnel (EMF) and the Florida fisheye (FFE)—were evaluated in otter trawls with net mouth circumferences of 14 m, 17 m, and 20 m and total net areas of 45 m^2. Each test net was towed 20 times in parallel with a control net that had the same dimensions and configuration but no BRD. Both BRDs were tested at night during fall 1996 and winter 1997 in Tampa Bay, Florida. Usually, the bycatch was composed principally of finfish (44 species were captured); horseshoe crabs and blue crabs seasonally predominated in some trawls. Ten finfish species composed 92% of the total finfish catch; commercially or recreationally valuable species accounted for 7% of the catch. Mean finfish size in the BRD-equipped nets was usually slightly smaller than that in the control nets. Compared with the corresponding control nets, both biomass and number of finfish were almost always less in the BRD-equipped nets but neither shrimp number nor biomass were significantly reduced. The differences in proportions of both shrimp and finfish catch between the BRD-equipped and control nets varied between seasons and among net sizes, and differences in finfish catch were specific for each BRD type and season. In winter, shrimp catch was highest and size range of shrimp was greater than in fall. Season-specific differences in shrimp catch among the BRD types occurred only in the 14-m, EMF nets. Finfish bycatch species composition was also highly seasonal; each species was captured mainly during only one season. However, regardless of the finfish composition, the shrimp catch was relatively constant. In part as a result of this study, the State of Florida now requires the use of BRDs in state waters.

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Commercial fishermen use a variety of gears to harvest shrimp in southeastern U.S. waters, but they have predominantly used the otter trawl since the 1940s. The otter trawl is an unselective gear that commonly has an associated catch of untargeted organisms (e.g. finfish, miscellaneous invertebrates) that are referred to as “bycatch.” Numerous definitions for the term “ bycatch” have been proposed (Allsopp, 1982; Caddy, 1982; Saila, 1983). The most comprehensive, suggested by Alverson et al. (1994), refers to nontargeted species retained, sold, or discarded for any reason.

An estimated average of 27.0 million metric tons (t) (range=17.9–39.5 million t) of bycatch are discarded annually by the world’s marine fishing fleets (Alverson et al., 1994). Shellfish fisheries compose 14 of the top 20 fisheries worldwide in quantity of bycatch discards (Alverson et al., 1994) and account for 9.5 million t of discards annually. Because the harvest of bycatch often exceeds that of the targeted species, the issue of bycatch in marine fisheries has become a global concern.

In the southeastern United States, the penaeid shrimp fishery often ranks first in value of all fisheries for commercially harvested marine species. In 1996, total landings were 98 million kg and were valued at approximately $434 million, ex-vessel price (size-specific price per unit volume paid to the fisherman for the catch) (NMFS[1]). The Gulf of Mexico (referred to as “Gulf” in this study) shrimp fishery accounted for 90% of this volume and 87% of this value. In U.S. waters, the Gulf and the southeast U.S. Atlantic (referred to as “South Atlantic”) shrimp trawl fisheries ranked 5th and 9th, respectively. Their ratios of kg finfish bycatch to kg shrimp were 10.3:1 for the Gulf, and 8.0:1 for the South Atlantic (Alverson et al., 1994). However, the Gulf and South Atlantic Fisheries Development Foundation (GSAFDF[2]) estimated that the ratio of finfish bycatch to shrimp harvest was 4.2:1 for the Gulf shrimp fishery and 2.8:1 for the South Atlantic shrimp fishery. Thus, using the more conservative ratios reported by GSAFDF and the 1996 shrimp landings for the Gulf fishery (88 million kg) and the south Atlantic fishery (9.9 million kg; NMFS[1]), the estimated total finfish bycatch for these two fisheries is 370 million kg and 28 million kg, respectively.

In 1996, approximately 11.3 million kg of shrimp were landed along the Florida Gulf coast and 1.8 million kg of shrimp were landed along the Florida Atlantic coast (NMFS[1]). Ratios of finfish bycatch to shrimp for the Florida Gulf coast ranged from 2.3:1 (fish-

[1] NMFS (National Marine Fisheries Service). 1997. Bycatch in the southeast shrimp trawl fishery. A data summary report. National Marine Fisheries Service, Southeast Science Center, 75 Virginia Beach Drive, Miami, FL 33149, 197 p.

[2] GSAFDF (Gulf and South Atlantic Fisheries Development Foundation). 1997. Bycatch and its reduction in the Gulf of Mexico and South Atlantic shrimp fishery. Final report to the National Oceanic and Atmospheric Administration (award NA57 FF0285). GFSFDF, Suite 997, Lincoln Center, 5401 West Kennedy Boulevard, Tampa, FL 33609, 27 p.

ing depth >10 fathoms [fm]) to 2.5:1 (fishing depth < 10 fm) (NMFS[1]); thus total finfish bycatch can be estimated at 26.0–28.3 million kg for the Florida Gulf shrimp fishery. With the finfish-to-shrimp ratio of of 2.8:1 for the South Atlantic fishery and the current landings information for Florida, the finfish bycatch for the Florida Atlantic shrimp fishery can be estimated at 5.0 million kg. Since 1990, considerable research has been conducted to characterize bycatch composition and to develop methods to reduce bycatch in the Gulf and the South Atlantic shrimp fisheries (Nance, 1992, 1993; GSAFDF[2,3]; Nichols et al.[4]; NMFS[5]). In addition, numerous fishery-independent surveys examining bycatch characterization and the efficiency of bycatch reduction devices (BRDs) have been conducted by state and private organizations throughout the southeastern U.S.A. (Burrage et al.[6]).

In 1990, the Florida Marine Fisheries Commission (FMFC; now Florida Fish and Wildlife Conservation Commission) began to develop a shrimp fishery management plan that included a mandate to reduce the bycatch of total finfish biomass in shrimp trawls by 50%. Responding to this policy decision, a bycatch-characterization study of the inshore Florida shrimp fishery was conducted statewide (Coleman et al.[7]; Coleman et al.[8]). Field studies comparing the efficiencies of two types of BRDs (Florida fish eye [FFE], large-mesh extended-mesh funnel [EMF]) in otter trawls and rollerframe trawls were also conducted (Continental Shelf Associates Inc.[9]; Coleman and Koenig[10]; Coleman et al.[11]).

The issue of bycatch in the Florida shrimp trawl fishery has exacerbated conflicts between conservationists and recreational and commercial fishermen over the allocation of marine resources. Relevant issues include the following: 1) the high mortality rates of economically important juvenile finfish caught in shrimp trawls, which could reduce harvestable finfish stocks; 2) the high mortality rates of nonharvested species caught in shrimp trawls, which could alter the overall health of the marine environment; and 3) the perceived waste of bycatch species that are discarded.

This controversy was partly responsible for the passage of a Florida constitutional amendment (Article X, Section 16) that reduced the size of shrimp trawl nets used in the coastal shrimp fishery to 500 sq. ft. (45 m^2) of mesh area per net and limited the number of nets to two per vessel. In previous studies conducted in Florida to examine the efficiency of BRDs in shrimp trawls (Coleman and Koenig[10]), net sizes greatly exceeding that authorized by the amendment were tested. The goal of our study was to test how efficiently the FFE and EMF excluded finfish in small otter trawls (overall mesh area=45 m^2) of various mouth-perimeter sizes. This information can be used by fisheries managers when considering the use of BRDs in inshore and nearshore shrimp fisheries.

Materials and methods

Tampa Bay is located on the west-central coast of Florida (Fig. 1) and is the largest open-water estuary in the state (Lewis and Estevez, 1988). The bay is a subtropical estuary that has patches of fringing seagrass meadows (Lewis et al., 1981), but fine sand is the predominant seabottom type (Brooks[12]).

Gear specifications

Conventional semiballoon otter trawls (Fig. 2) are used to harvest pink shrimp (*Farfantepenaeus duorarum*) in Tampa Bay. Otter trawls are typically used on unvegetated, sandy-bottom areas. We tested the effectiveness of

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3 GSAFDF (Gulf and South Atlantic Fisheries Development Foundation). 1993. Organization and management of a Gulf of Mexico and south Atlantic Ocean fishery bycatch management program (year 2). Final report to National Marine Fisheries Service (award NA37FD0032). GSAFDF, Suite 997, Lincoln Center, 5401 West Kennedy Boulevard, Tampa, FL 33609, 65 p.

4 Nichols, S., A. Shah, G. J. Pellegrin Jr., and K. Mullin. 1990. Updated estimates of shrimp fleet bycatch in the offshore waters of the U.S. Gulf of Mexico, 1972–1989. Report to the Gulf of Mexico Fishery Management Council, The Commons at Rivergate 3018 U.S. Highway 301 N., Tampa, FL 33619.

5 NMFS (National Marine Fisheries Service). 1995. Cooperative research program addressing finfish bycatch in the Gulf on Mexico and south Atlantic shrimp fisheries: a report to Congress. National Marine Fisheries Service, Southeast Fisheries Center, Southeast Regional Office, 9721 Executive Center Drive, St. Petersburg FL 33702, 68 p.

6 Burrage, D. D., S. G. Branstetter, G. Graham, and R. K. Wallace. 1997. Development and implementation of fisheries bycatch monitoring programs in the Gulf of Mexico. Report to the U. S. Environmental Protection Agency (report MX-994717-95-0). Mississippi State University, P.O. Box 5325, Mississippi State, MS 39762, 103 p.

7 Coleman, F. C., C. C. Koenig, and W. F. Herrnkind. 1991. Survey of the Florida inshore shrimp trawling bycatch and preliminary tests of bycatch reduction devices. First annual report to the Florida Department of Natural Resources. National Marine Fisheries Service MARFIN grant NA37FF0051. Institute for Fishery Resource Ecology, Florida State Univ., Tallahassee, FL 32306, 25 p.

8 Coleman, F. C., C. C. Koenig, and W. F. Herrnkind. 1992. Survey of the Florida inshore shrimp trawling bycatch and preliminary tests of bycatch reduction devices. Second annual report to the Florida Department of Natural Resources. National Marine Fisheries Service, MARFIN Grant NA37FF0051. Institute for Fishery Resource Ecology, Florida State Univ., Tallahassee, FL 32306, 21 p.

9 Continental Shelf Associates, Inc. 1992. Commercial food shrimp fishery impacts on by-catch in the lower St. Johns River, Florida. Draft final report C-7238. Continental Shelf Associates, Inc., 759 Parkway Street, Jupiter, FL 33477, 35 p.

10 Coleman, F. C., and C. C. Koenig. 1994. Florida inshore shrimping: experimental analysis of bycatch reduction. Final report. National Marine Fisheries Service, MARFIN grant NA37FF0051. Institute for Fishery Resource Ecology, Florida State Univ., Tallahassee, FL 32306, 63 p.

11 Coleman, F. C., P. Steele, and W. Teehan. 1996. Use of bycatch reduction devices in small trawls of sizes set by the net ban. Final Report. Florida Department of Environmental Protection contract MR081. Florida Dep. Environ. Protection, 100 8th Avenue S.E., St. Petersburg, FL 33701, 75 p.

12 Brooks, H. K. 1974. Geological oceanography. *In* Summary of knowledge, eastern Gulf of Mexico (J. I Jones, R. R Ring, M. O. Rinkel, and R. E. Smith, eds.), p. IIE1-50. Fla. State Univ. Syst. Inst. Oceanogr., St. Petersburg, FL.

two BRDs, the FFE and the EMF (Fig. 3) in three sizes of otter trawls in Tampa Bay during October–December 1996 (fall) and February–April 1997 (winter). Both BRDs are standard devices that have been recommended by NMFS, are used by the commercial fishing sector, and have been extensively tested in offshore and inshore waters throughout the southeastern United States (Murray et al., 1992; Watson et al., 1993; Rogers et al., 1997; Coleman et al.[7] Christian et al.[13]; McKenna and Monaghan[14]).

The otter trawl dimensions were as follows: 1) 14-m net: mouth circumference = 14.0 m, float-line length = 6.3 m, lead-line length = 6.9 m; 2) 17-m net: mouth circumference = 17.0 m, float-line length = 6.9 m, lead-line length = 7.8 m; 3) 20-m net: mouth circumference = 20.0 m, float-line length = 8.1 m, lead-line length = 9.4 m. The nets were of appropriate lengths to conform to the 45-m^2 total-mesh-area rule. Net perimeters were chosen after consultation with commercial shrimpers and personnel from the NMFS Laboratory Harvesting Section, Pascagoula, Mississippi. All net bodies were constructed of no. 9 twine and had a stretch-mesh size of 3.8 cm; the tailbag was constructed of no. 18 twine and had a stretch-mesh size of 3.2 cm. The FFE was constructed of 13-mm-diameter stainless steel rods. It had an overall length of 30 cm and a 15-cm × 15-cm opening to allow fish to escape. The FFE was mounted at the top center of the tailbag at 70% of the distance between the tie-off rings and the beginning of the codend (Watson et al., 1993; Christian et al.[13]), creating an area of reduced water flow directly behind the FFE, which would allow fish to escape. The EMF had an overall length of 121 cm and a circumference of 120 meshes; it consisted of a web funnel (3.5-cm stretch-mesh size) surrounded by a larger-mesh "escape" section (21-cm stretch-mesh size) held open by a plastic-coated hoop. One side of the funnel was extended to form a lead panel that created an area of reduced water flow on the back side of the funnel, similar to that created by the FFE.

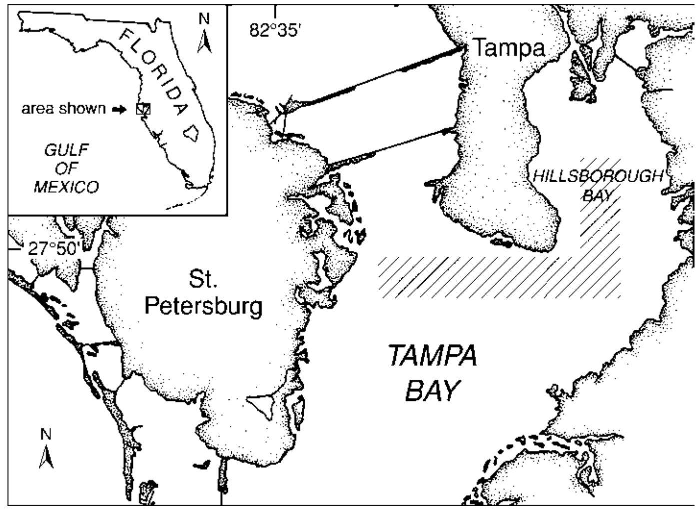

Figure 1

Tampa Bay, Florida. Hatched region shows sampling area.

To conform to federal regulations, each net was equipped with a turtle excluder device (TED) placed near the mouth of the tailbag (Fig. 2). The standard super-shooter TED 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 (Watson et al., 1993). Sewn in front of the TED was a section of webbing (3.2-cm stretch-mesh) that formed an accelerator funnel (Fig. 3A), which increased the velocity of water and entrained organisms both through the TED and into the net tailbag. The tailbag section and the combined TED and accelerator-funnel section could be zipped to any trawl body, regardless of size. The zipper ensured random pairing of trawl body and tailbag and enabled the experimental and control nets to be easily exchanged throughout the project. The BRDs and TEDs used during this project were approved by the NMFS Laboratory Harvesting Section, Pascagoula, Mississippi.

Both types of BRDs were tested in each net size. For each net size, one net of a matched pair was equipped with either the FFE or the EMF and served as the experimental net and the other, unaltered net served as the control. In the experimental net, the FFE or EMF was installed behind the TED-accelerator funnel section. The net with the BRD was deployed off a randomly chosen side of the boat and its paired control net was deployed simultaneously off the other side in a double-rig trawl towed from 3.5-m outriggers. Each net was spread by two 123-cm × 62-cm wooden trawl doors linked by a tickler chain.

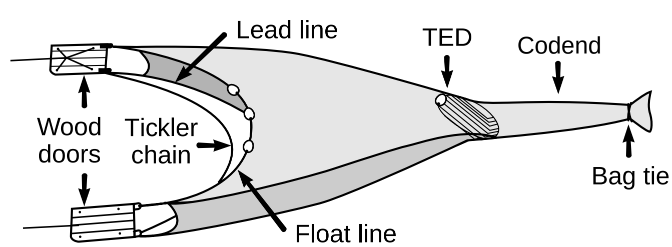

Figure 2

Components of a semiballoon otter trawl equipped with a super shooter turtle excluder device (TED). The TED is required in all shrimp nets in Florida.

[13] Christian, P. A., D. L. Harrington, D. R. Amos, R. G. Overman, L. G. Parker, and J. B. Rivers. 1993. Final report on the reduction of finfish capture in south Atlantic shrimp trawls. Final report to National Marine Fisheries Service (award NA27FD 0070-01). Univ. Georgia, 715 Bay Street, Brunswick, GA 31520, 83 p.

[14] McKenna, S. A., and J. P Monaghan Jr. 1993. Gear development to reduce bycatch in the North Carolina trawl fisheries. Completion report to Gulf and South Atlantic Fisheries Development Foundation (cooperative agreement NA90AA-H-SK052). North Carolina Div. Mar. Fish., 3441 Arendell Street,Morehead City, NC 28557, 79 p.

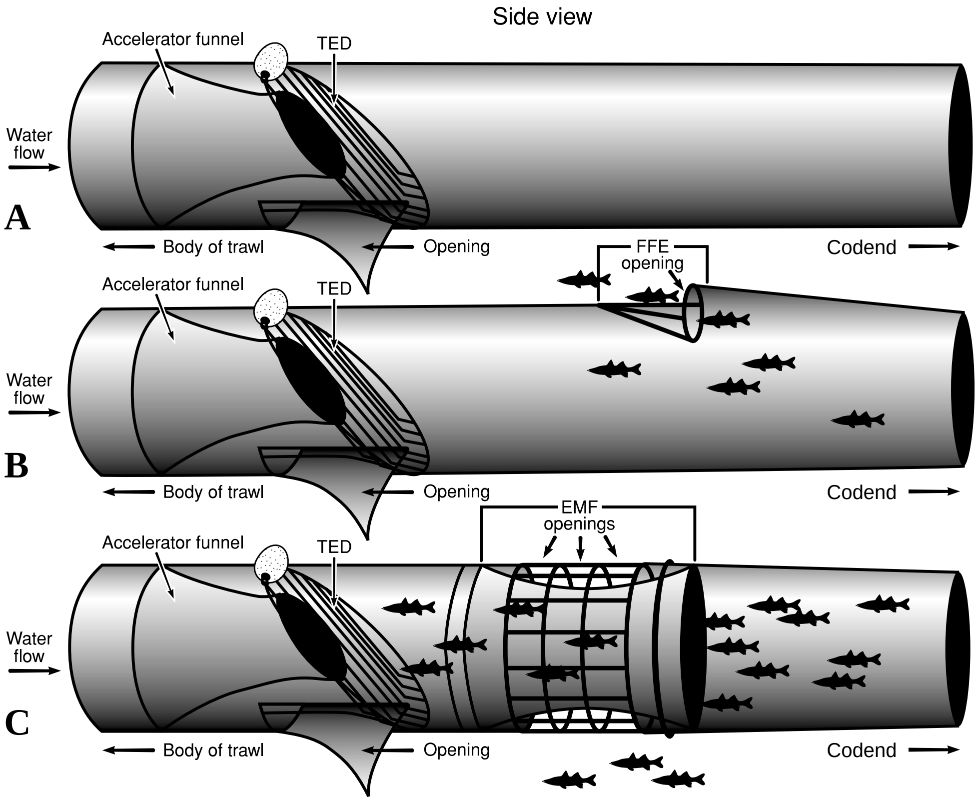

Figure 3

Stylistic diagram of the bycatch reduction devices used in this study: (**A**) Control net equipped with an accelerator funnel in front of the TED; (**B**) net with Florida fisheye (FFE), the device is inserted into the tailbag behind the TED; (**C**) net with large-mesh extended-mesh funnel (EMF) inserted directly behind the TED.

Sampling protocol

Our sampling protocol was established in consultation with representatives from the NMFS Pascagoula Laboratory and the FMFC. Coleman and Koenig[9] established that TEDs did not work as finfish excluder devices in inshore waters; therefore we did not test their exclusion efficiencies.

Sampling was conducted aboard a 35-ft, diesel-powered, Bruno & Stillman trawler boat, modified with outriggers. The nets were deployed and retrieved with a hydraulic powered system. Prior to installing and testing the BRDs, we equipped all pairs of nets of each size with the combined TED and accelerator-funnel sections and tested them for comparable catchability.

To test each BRD type in each size of net, we conducted twenty paired tows at night during a three-week sampling period in each season. Each pair of nets was towed 10 times within a two-week time period. To minimize any potential bias inherent to a particular net or side of the boat, the two nets of each pair were switched to opposite sides of the boat after 10 tows were completed. All paired nets were towed in water depths of 3.5 to 5.0 m for 30-min bottom time at an average speed of 2.5 kn; speed was determined through use of the global positioning system (GPS). All trawling was conducted in areas where the commercial shrimp fishery operates.

The catches from the paired nets (BRD and control) were maintained separately and were sorted onboard the vessel. After each tow, the shrimp, finfish, invertebrates (horseshoe crabs, portunid crabs, sponges, tunicates) and “trash” (seagrass, rocks, shells, anthropogenic debris, etc.) from each net were separated. The large invertebrates (horseshoe crabs, blue crabs, etc.) and trash were weighed separately, the invertebrates were counted, and both the invertebrates and the trash were discarded. The total catch of shrimp and finfish from each net was weighed separately. The shrimp were counted, sex was determined for 10 randomly chosen individuals, and their carapace lengths (CL) were measured to the nearest 0.1 mm. These measurements from the 20 replicate tows were combined to obtain length-frequency distributions for the shrimp. The remaining bycatch, composed of finfish and small invertebrates, was weighed. If the total weight of the bycatch was less than or equal to 4.5 kg, the entire sample was kept; if the weight of the sample exceeded 4.5 kg, a subsample weighing a total of 4.5 kg + 20% of the total bycatch weight was kept. All species of vertebrates and invertebrates from each bycatch sample or subsample were identified; finfish that could not be identified onboard were labeled and returned to the laboratory for identification. All individuals of each finfish species were counted and the finfish bycatch sample or subsample was weighed. To obtain an estimate of the size-frequency distribution for each species of finfish, we measured the standard length (SL) to the nearest 1 mm of 20 randomly selected individuals of each species from each tow and combined the measurements from the 20 replicate tows. If fewer than 20 individuals were caught in a tow, all individuals captured in that tow were measured.

All weights were standardized to grams per minute towed to estimate CPUE (biomass). All counts of individual species were standardized to number per minute towed (NPUE).

Statistical analyses

Statistical analyses followed Sokal and Rohlf (1995). Parametric statistics were applied when the data conformed to the parametric assumptions of normality (Shapiro-Wilk test) and homogeneity of variances (Levene's test). Variables that did not conform to parametric assumptions were transformed to log (biomass or number)+1. Nonparametric statistics were employed only after appropriate methods were deemed unsuccessful in transforming the data to meet parametric assumptions. Both parametric and nonparametric statistical analyses were completed by using the STATISTICA software package (Statsoft Inc, 1999). Using *t*-tests, we evaluated the performance of the paired nets prior to the addition of the BRDs and compared the catchability of the BRD-equipped net to its control. Because we used a paired-tow design for field testing, we analyzed each net size and type of BRD separately; net sizes and BRDs were not directly compared with each other but were always compared with the controls. The ability of a BRD-equipped trawl to retain shrimp while reducing bycatch was assessed by comparing the CPUE (biomass) and NPUE of finfish and shrimp and by comparing the CPUE and the NPUE of the 10 most abundant finfish species in the BRD-equipped net with CPUE and NPUE data for its paired control net. The CPUE and NPUE of shrimp caught, calculated as described above, were based on actual weight and numbers of shrimp caught in each trawl. When the bycatch was subsampled, the finfish biomass or number was estimated using the formula

$$\textit{Finfish biomass} \text{ or } \textit{number} = \frac{\textit{Finfish subsample CPUE} \text{ or } \textit{NPUE} \times \textit{Total bycatch weight}}{\textit{Subsample weight}}.$$

Because our sampling period ranged over two seasons, we considered the interactive effects of season and net type (BRD-equipped or control) for each net size by using analysis of variance (ANOVA). We then used the least-squares difference (LSD) *post hoc* test to locate the significant differences. Differences between the net with the BRD and its paired control net in the size-frequency distribution of the 10 most abundant fish species were assessed by using the Kolmogorov-Smirnov two-sample test. To determine the percent reduction or increase in the biomass and number of each of the top ten finfish species, we compared the BRD-equipped nets with the control nets by using the untransformed mean CPUE and NPUE data for shrimp and finfish and the total number of individuals subsampled. Percent reduction for either CPUE or NPUE was then calculated (from Rogers et al., 1997) as

$$\textit{Percent difference} = \frac{(\textit{CPUE} \text{ or } \textit{NPUE of BRD net} - \textit{CPUE} \text{ or } \textit{NPUE of control net}) \times 100}{\textit{CPUE} \text{ or } \textit{NPUE of control net}}.$$

Results

No significant differences were found in total weight of the finfish or shrimp catch between nets of equal size prior to the addition of the BRDs. Similarly, the total weight of finfish or shrimp was not significantly affected by trawl position. The standardized mean ratio of finfish bycatch to shrimp biomass for all control net sizes combined was 5.3:1 (range 2.9:1–11.3:1). The standardized mean ratio for the BRD-equipped nets (3.8:1; range 2.5:1–4.9:1) was not significantly different but was substantially lower than that of the control nets.

CPUE and NPUE

In contrast to results with the control nets, there were no significant differences in either biomass or number of shrimp captured in the 17-m net or the 20-m net equipped with either BRD (Table 1). In winter, the biomass and the number of shrimp captured in the 14-m net equipped with either BRD were significantly lower than these quantities captured in the corresponding control net (FFE: P=0.025; EMF: P=0.008). On the contrary, both the biomass and number of finfish were significantly and notably lower in most of the BRD-equipped nets than they were in the control nets (for significant differences, P range for the FFE= 0.025–0.001 and P range for the EMF= 0.027–<0.001). The only exception was in the number of finfish caught in winter by nets equipped with either BRD.

Significant seasonal differences always occurred in shrimp CPUE (FFE: P<0.001 for all tests; EMF P range: 0.003–<0.001) and nearly always occurred in shrimp NPUE (FFE P range: 0.003–<0.001; EMF P range: 0.002–0.001; exception: NPUE for the 17-m EMF-equipped net) and accounted for most of the variation in CPUE observed for each net size. Nearly all significant differences in shrimp CPUE and NPUE between seasons were due to a larger catch of shrimp in winter. The only significant interactive

Table 1

Comparison of percentage differences in shrimp and finfish biomass (CPUE) and number (NPUE) from the 14-m, 17-m, and 20-m nets equipped with the Florida fisheye (FFE) and extended mesh funnel (EMF) bycatch reduction devices (BRDs). CPUE is the mean weight (grams) caught per minute towed, and NPUE is the mean number of individuals caught per minute towed. Significance levels of ≤0.05 are denoted by asterisks.

		Shrimp						Fish					
		CPUE			NPUE			CPUE			NPUE		
		BRD	control	% diff.	BRD	control	% diff.	BRD	control	% diff.	BRD	control	% diff.
FFE													
Fall 1996	14-m net	29	31	–6	2	2	–5	99	154	–35*	3	4	–34*
	17-m net	21	21	4	2	1	7	70	105	–33*	2	3	–41*
	20-m net	17	16	6	1	1	11	176	196	–11	3	5	–39
Winter 1997	14-m net	36	45	–20*	2	2	–16*	113	132	–14	4	4	3
	17-m net	55	59	–6	4	4	–5	119	124	–4	12	12	5
	20-m net	42	38	11	2	2	14	114	130	–12	7	6	28
EMF													
Fall 1996	14-m net	32	33	–5	2	2	–5	90	168	–46*	3	5	–39*
	17-m net	23	25	–9	2	2	–11	60	151	–60*	2	4	–60*
	20-m net	12	12	0	1	1	0	116	174	–33*	3	5	–28*
Winter 1997	14-m net	42	60	–29*	2	3	–25*	106	130	–18	7	6	28
	17-m net	31	39	–18	2	2	–21	86	121	–28*	8	7	7
	20-m net	25	22	18	1	1	17	133	169	–21	5	4	12

effect between season and BRD type occurred in shrimp CPUE for the 14-m, EMF-equipped net (P=0.027).

Similarly, finfish CPUE differed seasonally for most net sizes (FFE P range: 0.009–< 0.001; EMF P for all tests: <0.001; exceptions: 14-m and 17-m, EMF-equipped nets), and NPUE differed seasonally for all net sizes (FFE P for all tests: <0.001; EMF P range: <0.001–0.000). However, the season in which the largest catch was harvested differed between net sizes and between BRD types. Both finfish CPUE and NPUE were significantly higher during winter than during fall in the 14-m and 17-m FFE-equipped nets but finfish CPUE and NPUE were significantly lower during fall than during winter in the 20-m FFE-equipped net. For the EMF-equipped nets, finfish CPUE differed seasonally only in the 20-m nets; CPUE in winter was higher than in fall. Finfish NPUE values for the EMF-equipped nets were always significantly higher in winter (P for all tests: <0.001).

Percent reduction

Differences in the percentage of shrimp in the BRD-equipped versus the control nets varied with season, net size, and BRD type. Although many of these differences were not significant (Table 1), patterns in shrimp loss or retention were apparent. Other than the 17-m, FFE-equipped net in fall, the addition of a BRD to a 14-m or 17-m net resulted in a reduction in shrimp CPUE and NPUE, regardless of BRD type. However, the reductions were significant only for the 14-m nets in winter. In contrast, shrimp CPUE and NPUE usually were slightly higher in the 20-m BRD-equipped nets than in the control nets.

Finfish CPUE was always less in BRD-equipped nets than in control nets (Table 1). The reduction in finfish bycatch CPUE was nearly always significant in fall, and most reductions were dramatic (20–60%). Reductions in finfish NPUE also had a strong seasonal component. For all net sizes, finfish bycatch NPUE in the BRD-equipped nets was notably (and nearly always significantly) less than that in the control nets in fall, whereas more (but not significantly more) finfish were captured in the BRD-equipped nets than in the control nets in winter.

Catch composition

Most of the biomass in both the BRD-equipped and the control nets usually was composed of finfish (30–70%). The remainder of the catch consisted of shrimp (15–20%), horseshoe crabs (*Limulus polyphemus*) and blue crabs (*Callinectes sapidus*) (15–58%), and miscellaneous invertebrates such as ctenophores, portunid crabs, sponges, and gastropods (<25%). When the catch of arthropods (principally horseshoe crabs) was large, the finfish catch was generally small. The shrimp catch was relatively stable even when the bycatch composition fluctuated.

Horseshoe crabs were the most abundant invertebrate bycatch species. A total of 2867 horseshoe crabs were caught during the two sampling seasons; largest catches occurred during fall. Although the catch of horseshoe crabs caught in the BRD-equipped nets was generally smaller than the catch in the corresponding control nets, only in the 14-m FFE-equipped net and the 20-m EMF-equipped net was the number of horseshoe crabs caught significantly lower than the number of horseshoe crabs caught in the corresponding control nets (P=0.001 and P=0.05, respectively). Blue crabs were the second most abundant invertebrate bycatch species. A total of 544 blue crabs were caught during the two sampling seasons; the largest catches occurred during winter. Although fewer blue crabs were caught in the BRD-equipped nets, only in the 14-m EMF-equipped net was the number of blue crabs significantly lower than that in the corresponding control net (P=0.005 for both seasons).

A total of 44 species of finfish were caught during our study (Table 2). Numerically, ten finfish species composed more than 92% of the total finfish count, and a single species, the leopard searobin (*Prionotus scitulus)*, composed over 40%. Abundance differed greatly between seasons for nearly all fishes (Table 2). The silver jenny (*Eucinostomus gula*), hardhead catfish (*Arius felis*), gafftopsail catfish (*Bagre marinus*), sand seatrout (*Cynoscion arenarius*), and silver perch (*Bairdiella chrysoura*) predominated in the catch during fall. These were replaced during winter by the leopard searobin (*Prionotus scitulus),* blackcheek tonguefish (*Symphurus plagiusa*), southern kingfish (*Menticirrhus americanus*), pinfish (*Lagodon rhomboides*), and spadefish (*Chaetodipterus faber*).

Ten of the finfish species that we captured are important to the recreational or commercial fishing sectors. These are the southern kingfish (*Menticirrhus americanus*), scaled sardine (*Harengula jaguana*), striped anchovy (*Anchoa hepsetus*), bay anchovy (*Anchoa mitchelli*), spot (*Leiostomus xanthurus*), spotted seatrout (*Cynoscion nebulosus*), gulf menhaden (*Brevoortia patronus*), gulf flounder (*Paralichthys albigutta*), pompano (*Trachinotus carolinus*), and permit (*Trachinotus falcatus*). These species each accounted for less than 1% of the total finfish count, except for the southern kingfish, which accounted for 4.6%.

For the species captured principally in fall, the overall proportion of the bycatch excluded by the 14-m and 17-m BRD-equipped nets was similar, and both sizes of nets tended to exclude high percentages of these fishes (Fig. 4). The 20-m BRD-equipped net was not as effective in reducing the numbers of these species. For the species captured principally in winter, the efficiency with which the BRD-equipped nets excluded these fishes varied among net sizes and BRD types. For some species (e.g. the leopard searobin and blackcheek tonguefish), BRD-equipped nets retained more individuals than did the corresponding control nets.

Size distribution

Shrimp size-frequency distributions for pooled trawls (BRD-equipped net and its corresponding control) had significant seasonal variation (P<0.001, t=16.1, df=2,416). In fall, mean carapace length was 23.4 mm (SD=4.7 mm) and the range was 11.2–40.4 mm, whereas in winter, the mean was 27.0 mm (SD=6.5 mm) and the range was 7.3–43.8 mm.

Mean sizes of the 10 most abundant finfish species differed significantly between the BRD-equipped nets and their corresponding controls in approximately 25% of the trawls with the FFE-equipped nets and in 30% of the trawls with the EMF-equipped nets (Table 3). The differences in mean sizes of individuals were usually small regardless of statistical significance. Nevertheless, the ratio of comparisons in which mean size of fish from BRD-equipped nets was smaller than that of fish from control nets to comparisons in which the mean size of fish from BRD-equipped nets was larger than that of fish from control nets was 2:1 for the trawls with the FFE-equipped net and 3:1 for the trawls with the EMF-equipped net. The only net size and BRD-type combination for which the mean size of individuals from the BRD-equipped net was always smaller than that from the control net was the 14-m FFE-equipped net.

Discussion

Shrimp catch

Although most BRD-equipped nets retained less biomass and fewer numbers of shrimp than did their corresponding control nets, the difference in these measures between the BRD-equipped nets and their controls was significant only for the 14-m net in winter. Indeed, shrimp biomass and number in the 20-m BRD-equipped net slightly exceeded biomass and number in the corresponding control net. In previous studies, researchers evaluating the efficiency of BRDs also found that the shrimp catch in BRD-equipped nets tended to be higher than in control nets. They attributed the increase in shrimp catch in their BRD-equipped net to a greater net spread caused by a reduction in the amounts of bycatch and drag (Rogers et al., 1997; Coleman and Koenig[10]) and to an increase in the volume of water filtered through the net due to the position of the BRD (Christian et al.[13]).

The numbers of shrimp retained in all BRD-equipped nets and in nearly all control nets were greater in winter than in fall. In the Tampa Bay region, adult female shrimp migrate out of the bay to spawn during spring and fall and juvenile shrimp are recruited into the bay during summer and winter (Eldred et al., 1965). The increase in abundance and the larger size range of shrimp that we caught during winter support this finding.

Finfish bycatch

Overall, both BRDs proved to be highly effective in reducing finfish bycatch without greatly reducing shrimp catch. The reduction in bycatch was usually significant in the 14-m and 17-m BRD-equipped nets. The mean ratio of finfish biomass to shrimp biomass in our BRD-equipped nets was within the range of ratios reported by others who tested the BRD-equipped nets in the Gulf (Alverson et al., 1994; GSAFDF[2]). Branstetter (1997) and Watson et al.[15]

[15] Watson, J., A. Shah, and D. Foster. 1997. Report on the status of bycatch reduction device (BRD) development. National Marine Fisheries Service, Mississippi Laboratories, P.O. Drawer 1207, Pascagoula, MS, 39568.

Table 2

Percentage contribution of individual finfish species subsampled from catches of otter trawls towed in Tampa Bay during fall 1996 and winter 1997. All tows have been pooled and incorporate both BRD-equipped and control nets for all three trawl-net sizes. Seasonal percentages are calculated for each species.

Common name	Species	Total number of sampled fish	% (Total)	% (Fall)	% (Winter)
Leopard searobin	*Prionotus scitulus*	28,299	41.02	6.6	93.4
Silver jenny	*Eucinostomus gula*	9134	13.24	86.2	13.8
Gafftopsail catfish	*Bagre marinus*	6658	9.65	83.5	16.5
Blackcheek tonguefish	*Symphurus plagiusa*	4613	6.69	35.6	64.4
Sand seatrout	*Cynoscion arenarius*	3365	4.88	80.6	19.4
Southern kingfish	*Menticirrhus americanus*	3193	4.63	44.0	56.0
Hardhead catfish	*Arius felis*	2949	4.27	88.0	12.0
Silver perch	*Bairdiella chrysoura*	2463	3.57	64.1	35.9
Pinfish	*Lagodon rhomboides*	1503	2.18	0.8	99.2
Spadefish	*Chaetodipterus faber*	1487	2.16	10.7	89.3
Bighead searobin	*Prionotus tribulus*	759	1.10	12.9	87.1
Scaled sardine	*Harengula jaguana*	642	0.93	59.4	40.6
Hogchocker	*Trinectes maculatus*	538	0.78	37.7	62.3
Striped anchovy	*Anchoa hepsetus*	524	0.76	25.5	74.5
Southern puffer	*Sphoeroides nephelus*	346	0.50	5.2	94.8
Southern hake	*Urophycis floridana*	337	0.49	0.0	100.0
Bay anchovy	*Anchoa mitchelli*	320	0.46	1.3	88.7
Pigfish	*Orthopristis chrysoptera*	274	0.40	3.7	96.3
Inshore lizardfish	*Synodus foetens*	237	0.34	76.4	23.6
Lined sole	*Achirus lineatus*	160	0.23	26.8	73.2
Lookdown	*Selene vomer*	138	0.20	100.0	0.0
Atlantic bumper	*Chloroscombrus chysurus*	135	0.20	97.7	2.3
Striped burrfish	*Chilomycterus schoepfi*	128	0.19	2.3	97.7
Ocellated flounder	*Ancylopsetta quadrocellata*	93	0.13	1.1	98.9
Spot	*Leiostomus xanthurus*	89	0.13	0.0	100.0
Crested blenny	*Hypleurochilus geminatus*	82	0.12	1.2	98.8
Rough silverside	*Membras martinica*	78	0.11	24.4	75.6
Planehead filefish	*Monacanthus hispidus*	76	0.11	15.7	84.3
Threadfin herring	*Opisthonema oglinum*	72	0.10	38.8	61.2
Scrawled cowfish	*Lactophrys quadricornis*	64	0.09	3.2	96.8
Crevalle jack	*Caranx hippos*	47	0.07	100.0	0.0
Sheepshead	*Archosargus probatocephalus*	46	0.07	97.8	2.2
Spotted seatrout	*Cynoscion nebulosus*	43	0.06	100.0	0.0
Orange filefish	*Aluterus schoepfi*	22	0.03	9.1	90.9
Gulf menhaden	*Brevoortia patronus*	19	0.03	68.4	31.6
Gulf toadfish	*Opsanus beta*	15	0.02	13.4	86.6
Harvestfish	*Peprilus alepidotus*	10	0.01	50.0	50.0
Leatherjacket	*Oligoplites saurus*	6	0.01	100.0	0.0
Shrimp eel	*Ophichthus gomesi*	5	0.01	80.0	20.0
Gulf flounder	*Paralichthys albigutta*	5	0.01	40.0	60.0
Gulf butterfish	*Peprilus burti*	4	0.01	50.0	50.0
Striped mojarra	*Diapterus plumieri*	1	0.00	100.0	0.0
Pompano	*Trachinotus carolinus*	1	0.00	100.0	0.0
Permit	*Trachinotus falcatus*	1	0.00	100.0	0.0

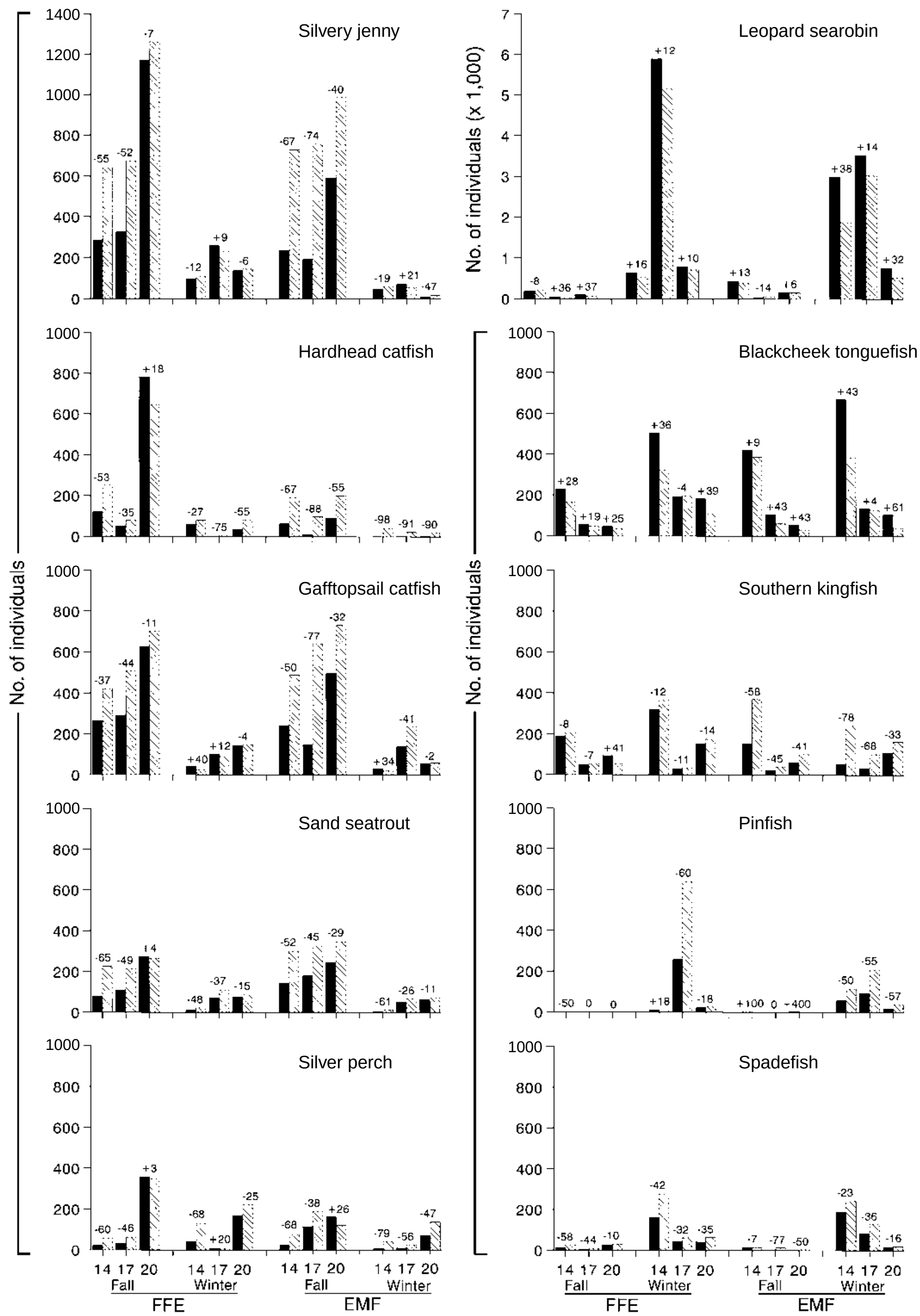

Figure 4

Comparisons of species-specific seasonal catch and retention rates for the 10 finfish species most commonly captured in the three sizes of period bycatch reduction device (BRD)-equipped nets (black bars) and control shrimp-trawl nets (hatched bars). Each vertical bar represents the total number of fish captured in 20 tows. Numbers over pairs of bars are the percent losses or gains in numbers of individuals captured by the BRD-equipped net versus the paired control net. FFE = Florida fisheye BRD; EMF = extended mesh funnel BRD. Column 1 shows species captured principally in fall; column 2 shows species captured principally in winter.

Table 3

Comparison of mean standard length measurements (mm) of the most abundant species caught in nets equipped with either the Florida fisheye (FFE) or the extended mesh funnel (EMF) bycatch reduction device (BRD) and their corresponding control nets. The three nets of different sizes used are denoted by the measurements of their perimeters: 14 m, 17 m, and 20 m. Significance levels are ≤0.05(*). Values represent mean and standard deviation, and sample sizes (*n*) are shown in parentheses. Dashes indicate that no fish were captured.

		Fall			Winter		
		14 m	17 m	20 m	14 m	17 m	20 m
Common name	Treatment	Mean, SD (*n*)	Mean, SD (*n*)	Mean, SD (*n*)	Mean, SD (*n*)	Mean, SD (*n*)	Mean, SD (*n*)
Florida fisheye bycatch reduction device							
Leopard searobin	BRD	103, 26 (191)	83, 13 (47)	98, 22 (85)	94*, 22 (327)	78, 17 (400)	97, 17 (309)
	Control	108, 24 (204)	90, 26 (30)	100, 22 (63)	96, 19 (317)	77, 13 (400)	97, 16 (325)
Silver jenny	BRD	66*, 09 (259)	75, 14 (286)	76, 08 (340)	82*, 07 (99)	73, 09 (180)	86, 07 (123)
	Control	69, 09 (394)	75, 10 (371)	76, 08 (339)	84, 09 (113)	82, 09 (189)	88, 12 (136)
Gafftopsail catfish	BRD	123*, 10 (203)	134, 13 (267)	124*, 10 (317)	143, 30 (43)	154, 26 (103)	147, 19 (131)
	Control	132, 10 (302)	131, 08 (347)	123, 16 (326)	136, 11 (26)	152, 23 (88)	147, 17 (140)
Blackcheek tonguefish	BRD	115*, 16 (214)	123, 20 (58)	121, 20 (48)	117, 15 (374)	155, 16 (185)	115*, 16 (160)
	Control	119, 16 (154)	125, 18 (47)	122, 19 (36)	120, 18 (293)	115, 18 (180)	119, 16 (111)
Sand seatrout	BRD	135*, 29 (78)	150*, 30 (110)	150, 33 (226)	177, 30 (12)	167, 29 (71)	174*, 22 (71)
	Control	146, 29 (217)	157, 26 (213)	155, 30 (225)	159, 27 (23)	169, 18 (71)	181, 30 (88)
Southern kingfish	BRD	137, 34 (185)	158, 14 (50)	135, 33 (93)	154*, 22 (275)	149, 33 (31)	170*, 21 (146)
	Control	138, 34 (202)	143, 35 (54)	136, 34 (55)	153, 24 (311)	142, 33 (35)	164, 20 (171)
Hardhead catfish	BRD	94*, 30 (120)	109, 48 (54)	94, 29 (325)	196, 88 (58)	180, 127 (2)	158, 79 (34)
	Control	101, 37 (224)	99, 32 (80)	99, 41 (304)	206, 80 (79)	199, 66 (8)	173, 73 (83)
Silver perch	BRD	88, 16 (23)	84, 17 (33)	89, 15 (224)	114, 11 (42)	94, 05 (10)	108, 07 (162)
	Control	90, 10 (58)	92, 17 (61)	89, 14 (235)	110, 11 (131)	97, 15 (9)	109, 11 (224)
Pinfish	BRD	90 (1)	— —	86, 23 (2)	93, 17 (11)	79, 07 (159)	84, 14 (23)
	Control	103, < 1 (2)	— —	97, 23 (2)	96, 11 (9)	78, 06 (194)	84, 13 (27)

continued

investigated the effectiveness of BRD designs that were similar to ours in offshore waters of the Gulf and the south Atlantic. They reported reductions in finfish biomass of 4–46% for the FFE and 18–35% for the EMF and respective reductions in shrimp biomass of 0–16% and 0–4%.

Our biomass reduction ratios of finfish to shrimp ranged broadly and unpredictably among net sizes and between BRD types and seasons, and our percentages of change in both biomass and numbers of finfish ranged widely between the BRD-equipped nets and their corresponding controls. In our study, the proportion of finfish to invertebrates and the species compositions and size distributions of these two groups influenced the ratio of finfish to shrimp. Bycatch reduction and shrimp retention have also

Table 3 (continued)

		Fall			Winter		
		14 m	17 m	20 m	14 m	17 m	20 m
Common name	Treatment	Mean, SD (*n*)	Mean, SD (*n*)	Mean, SD (*n*)	Mean, SD (*n*)	Mean, SD (*n*)	Mean, SD (*n*)
Extended mesh funnel bycatch reduction device							
Leopard searobin	BRD	104, 23 (317)	80, 26 (43)	99, 21 (110)	91, 22 (391)	86, 20 (359)	101, 14 (155)
	Control	108, 19 (310)	92, 26 (50)	95, 22 (121)	91, 21 (383)	85, 19 (359)	100, 15 (152)
Silver jenny	BRD	67*, 09 (217)	76*, 09 (187)	74, 09 (360)	81, 07 (51)	76*, 07 (70)	87, 08 (10)
	Control	70, 09 (379)	78, 09 (381)	74, 08 (375)	80, 09 (62)	82, 12 (58)	95, 12 (19)
Gafftopsail catfish	BRD	129*, 12 (167)	132*, 12 (119)	125*, 18 (309)	147, 28 (32)	139*, 19 (139)	149, 19 (57)
	Control	124, 09 (343)	129, 19 (385)	121, 10 (394)	137, 15 (21)	148, 33 (185)	154, 17 (58)
Blackcheek tonguefish	BRD	115*, 15 (315)	126, 19 (107)	124, 18 (45)	122, 18 (346)	111, 20 (134)	114, 17 (99)
	Control	118, 16 (318)	129, 23 (61)	124, 17 (31)	122, 18 (273)	117, 19 (127)	117, 15 (41)
Sand seatrout	BRD	141*, 24 (144)	142, 29 (179)	145, 31 (227)	163, 37 (5)	159, 34 (51)	154*, 50 (57)
	Control	149, 32 (274)	146, 31 (289)	147, 28 (328)	144, 52 (13)	169, 22 (69)	179, 29 (60)
Southern kingfish	BRD	139, 28 (154)	127, 43 (22)	143, 27 (60)	153, 23 (54)	155, 29 (33)	167, 17 (85)
	Control	139, 25 (311)	138, 34 (40)	141, 29 (99)	155, 26 (210)	157, 26 (103)	173, 16 (120)
Hardhead catfish	BRD	100*, 25 (65)	103, 44 (12)	100*, 38 (86)	94 (1)	301, 52 (2)	150, 50 (2)
	Control	95, 27 (193)	100, 38 (98)	103, 50 (167)	242, 72 (41)	227, 74 (22)	234, 54 (21)
Silver perch	BRD	91, 10 (25)	82*, 14 (116)	87, 12 (106)	104,* 12 (9)	98, 08 (12)	113, 10 (73)
	Control	93, 11 (78)	87, 14 (189)	82, 14 (121)	112, 09 (42)	103, 23 (27)	111, 10 (126)
Pinfish	BRD	84 (1)	— —	130, 35 (4)	79, 05 (49)	76*, 06 (81)	82, 09 (16)
	Control	— —	— —	— —	79, 06 (108)	79, 07 (102)	81, 08 (38)

varied greatly in other studies. This variation has been attributed to temporal and spatial diversity in size and species composition of the finfish and shrimp within a trawling area; changes in bottom substrate; water depth; BRD type, placement, and size; trawl dynamics; and speed, and duration of tow (Branstetter, 1997; Fuls and McEachron[16]).

[16] Fuls, B. E., and L. W. McEachron. 1998. Evaluation of bycatch reduction devices in Aransas Bay during the 1997 spring and fall commercial bay-shrimp season. Corpus Christi Bay National Estuary Program Publication CCBNEP-33, 6300 Ocean Drive, Corpus Christi, TX 78412, 33 p.

Although most of the nets tested in these other studies were considerably larger than the nets tested in our study, some of these attributes probably contributed to the variation that we observed. In addition, and most notably, the efficiency of our BRDs was greatly reduced when large numbers of horseshoe crabs were captured or when large numbers of spiny fishes became entangled in the nets.

Although the number and weight of finfish captured were greatly reduced in the FFE-equipped nets, finfish bycatch reduction rates were even higher with the nets equipped with the EMF, particularly the 17-m net, which had the highest overall reduction rate of all BRD and net-size combinations. Similar, comparatively high reduction rates for nets equipped with an EMF have been reported elsewhere (Fuls and McEachron[16]).

Both BRDs reduced (usually notably and significantly) the biomass of finfish in all net sizes during both seasons. However, the number of fish in the BRD-equipped nets compared with the control nets varied markedly between seasons. In fall, the number of fish in the BRD-equipped nets was nearly always much lower than the number in the corresponding control nets; but in winter, the number in the BRD-equipped nets was generally slightly higher than the number in the corresponding control nets. This increase was due to the sizable influx of juvenile leopard searobins in the finfish catch in winter. The long pectoral-fin rays on these fish became entangled in the nets (and in the BRD) and prevented the fish from escaping.

The detailed analysis of species-specific change in numbers of fish in the BRD-equipped nets compared with their corresponding control nets revealed additional interesting patterns. The number of silver jennys was reduced in all BRD-equipped nets, except in the 17-m BRD-equipped net during winter. The numbers of hardhead catfish, sand seatrout, silver perch, and southern kingfish were always reduced in the BRD-equipped nets except in the 20-m FFE-equipped net during fall. The number of leopard searobins and blackcheek tonguefish nearly always increased in the BRD-equipped nets, regardless of season. With some exceptions, larger fish were more likely to escape than smaller fish, probably because swimming ability is positively associated with size in fishes (Wardle, 1993). However, fish (particularly large individuals) of species with protruding bony scutes or long fin rays (e.g. gafftopsail catfish, leopard searobin, southern kingfish) became entangled in the nets and thus could not escape. The potential for large individuals of these types of fish to become entangled in the net may have increased because of the restricted net circumference, caused by the presence of the EMF. Thus, for these types of species, mean size of individuals retained in the BRD-equipped nets was frequently larger than mean size of individuals retained in the corresponding control nets.

A number of factors other than morphological features, such as pointed, projecting body structures, influence the ability of fish to escape from trawl nets equipped with BRDs. The behavior of fish in response to trawls has been described as a combination of optomotor response and rheotactic reaction, both of which contribute to a fishes' ability to escape capture in a trawl (Watson[17]). When ambient light conditions and water clarity allow for sufficient contrast between the trawl and the background, many, but not all, fishes orient their heads toward the mouth of trawl and maintain swimming speeds comparable to the trawling speed. Thereby, a fish can align itself with the in-trawl current. This optomotor response is usually associated with the well-developed lateral line system found in pelagic schooling species and is usually absent in demersal species (Pavlov, 1969). However, this response is considerably diminished during nighttime and in turbid water, and both of these conditions existed during our trawling. Thus, fishes with well-developed optomotor responses probably required additional stimuli to escape from our nets, even if they were in close proximity to an escape opening. Most of these fishes may have escaped the trawl through the BRD when the trawl speed was reduced during trawl haul-back (Watson[17]). The rheotactic response allows demersal fish to detect turbulent water flows and associated pressure gradients through the lateral line even when substantial visual cues are not available (Wardle, 1993). Areas of disturbed water exist within a moving trawl, especially near objects such as BRDs, which interrupt water flow. Demersal fishes with well-developed rheotactic responses can sense these areas of reduced velocity, align themselves behind these areas, and eventually escape through the exit provided by the BRD while the trawl is being towed. The finfish species with the largest percentage reductions in numbers in our BRD-equipped nets compared with the corresponding control nets were demersal and most likely used this response to assist in their escape.

[17] Watson, J. W. 1988. Fish behavior and trawl design: potential for selective trawl development. *In* Proceedings of the world symposium on fishing gear and fishing vessel design, (S. G. Fox and J. Huntington, eds.), p. 25–29. Newfoundland and Labrador Institute of Fisheries and Marine Technology, P.O. Box 4920, St. John's, Newfoundland A1C 5R3.

BRDs and fishery management

Both the FFE and EMF are standard bycatch reduction devices recommended by NMFS and used by the shrimp industry. The effectiveness of these two BRDs in reducing finfish bycatch without greatly reducing shrimp catches has been well documented for the Gulf and the South Atlantic shrimp fisheries. (Captiva and Rivers, 1960; Gutherz and Pellegrin, 1988; Murray et al., 1992; Watson et al., 1993; Branstetter, 1997; Rogers et al., 1997; Coleman et al.[7]; Christian et al.[13]; McKenna and Monaghan[14]; Watson et al.[15]; our study). The FFE is now required in all shrimp trawls used in the federal Exclusive Economic Zone along the South Atlantic and in the Gulf.

The policy set forth by the FMFC in 1990 to reduce the overall finfish bycatch in the Florida shrimp fishery has been addressed in our study. In part as a result of this study, Florida is the first state bordering on the Gulf of Mexico to require the use of BRDs in state waters. BRDs not only serve to conserve natural marine resources, in the Florida shrimp fishery they provide additional benefits to the shrimp fishermen. Reducing bycatch decreases drag during tow times, which, in turn, lowers fuel consumption thereby reducing fuel costs, diminishes wear and tear on the trawl gear, decreases culling time by the deck crew, and produces a better shrimp product. From a cost-benefit perspective, BRDs clearly provide conservational, economic, and sociological benefits that far outweigh their actual costs.

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