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SEDAR-PW6-RD50

23 June 2014

Fisheries Research 108 (2011) 248–257

Contents lists available at ScienceDirect

Fisheries Research

journal homepage: www.elsevier.com/locate/fishres

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ARTICLE INFO

Article history:
Received 10 August 2010
Received in revised form
30 November 2010
Accepted 3 December 2010

Keywords:
Bycatch
Bycatch-reduction device
Florida
Roller frame
Shrimp
Trawl

ABSTRACT

High rates of fishery discards have been noted for penaeid shrimp fisheries worldwide and especially for the shrimp trawl fisheries of the southeastern U.S.A. Selective fishing gear, such as bycatch-reduction devices (BRDs), can significantly decrease bycatch and discards in shrimp trawl fisheries. The roller-frame trawl, a type of gear unique to Florida, is used in seagrass beds to harvest food shrimp and bait shrimp. No BRD is required for roller-frame trawls, although bycatch can be significant. We tested the effectiveness of two BRDs – the Florida fisheye (FFE) and the large-mesh extended-mesh funnel (EMF) – in reducing bycatch in roller-frame trawls. Tests were conducted at two Florida locations: the nearshore waters off Tarpon Springs, where food shrimp are harvested, and Biscayne Bay, where bait shrimp are harvested. At Tarpon Springs, each device was tested independently and with the addition of a stimulator cone; the cone was not tested at Biscayne Bay. We tested each BRD configuration using a paired trawl design; a BRD-equipped net was deployed off one side of the boat, and a control net with no BRD was deployed off the other side of the boat. The effectiveness of the BRD configurations in retaining shrimp while reducing bycatch varied considerably. Although some significant species-specific reductions were observed in the FFE, that BRD did not significantly reduce overall finfish bycatch, but it did retain shrimp. The EMF performed well, but only at Tarpon Springs. Bycatch reduction was significant, albeit low, and shrimp loss was low. At Biscayne Bay, both bycatch and shrimp loss were significantly reduced in the EMF. Use of the stimulator cone with the FFE and the EMF resulted in significant bycatch reduction but also significant shrimp loss. Modification of the gear may improve their performance in roller-frame trawls.

1. Introduction

The discard of bycatch (non-target species) in the world's fisheries is a serious issue being addressed from local to global scales. Kelleher (2005) recently updated estimates of fishery discards for the Food and Agriculture Organization of the United Nations (FAO), taking into account fishing area, fishing gear, and target species. Tropical shrimp (principally penaeid) fisheries accounted for more than 27% of the global discards. In the U.S.A., the Gulf of Mexico (gulf) shrimp–trawl fishery discarded more bycatch, by weight (nearly 500,000 tonnes), than any fishery in the FAO database, and its discard rate was 57%. The U.S.A. South Atlantic shrimp–trawl fishery had a discard rate of 83%, although its landings and bycatch by weight were much less than for the gulf fishery. Although discards can include prohibited individuals of the target species (due to size limits or reproductive status, for example), in shrimp fisheries most discards comprise finfish and other invertebrates. Thus, reducing bycatch decreases discards. In shrimp fisheries, significant reductions in bycatch have resulted from the use of selective fishing gear, including bycatch-reduction devices (BRDs) (Kelleher, 2005).

The use and performance of various BRDs for reducing bycatch in penaeid–shrimp fisheries was reviewed by Eayrs (2007). Eayrs advised that not all designs were optimal for different gear types, fishing locations, or expected bycatch species.

The roller-frame trawl is a type of gear used only in Florida, to harvest food shrimp and bait shrimp in seagrass beds (Fig. 1). A roller frame is a rectangular trawl equipped with metal rollers at the bottom of the frame. The rollers allow the trawl to roll over the ocean bottom and obstructions while being towed. Metal excluder bars extend vertically across the mouth of the net to reduce the amount of seagrass, larger finfish, and turtles that enter the net. In Florida, no more than two trawls per vessel may be fished within three miles of the west coast or within one mile of the east

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0165-7836/$ – see front matter
doi:10.1016/j.fishres.2010.12.004

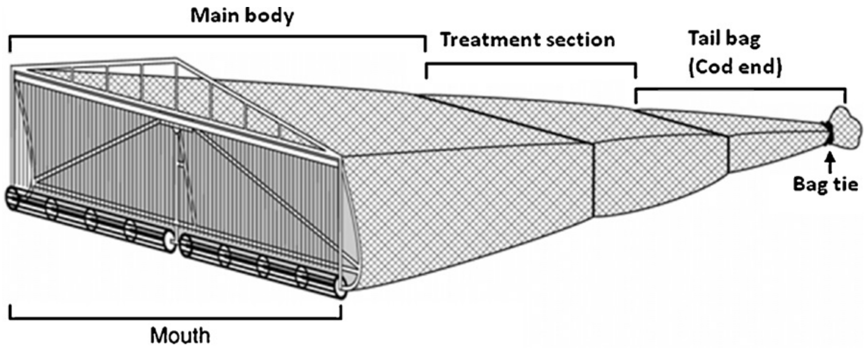

Fig. 1. Diagram of roller-frame trawl. The treatment section, where the bycatch-reduction devices (BRDs) were placed, is depicted in Fig. 3.

coast. Trawl duration is usually 15–30 min for bait-shrimp harvest (Meyer et al., 1999) but may be 60–90 min for food–shrimp harvest. Harvesting depths are 0.3–6.0 m. The pink shrimp, *Farfantepenaeus duorarum* (Burkenroad, 1939) is the principal species targeted for harvest using roller-frame trawls. The pink shrimp is nocturnal; therefore, trawling is done at night. During 2006, Florida shrimp harvesters reported using roller-frame trawls to land about 214,000 kg of food shrimp and 225,000 kg of bait shrimp (Florida Fish and Wildlife Conservation Commission [FWC] Marine Fisheries Information System); these landings data are probably underestimates because trawl type was not reported for many landings.

Bycatch-reduction devices are not required in roller-frame trawls in Florida, although bycatch can compose a considerable portion of the total catch. Bycatch in roller-frame trawls used in inshore and nearshore shrimp fisheries has included a wide variety of finfishes and invertebrates and has exhibited regional and seasonal variation in species composition and abundance (Coleman et al., 1991, 1992; Continental Shelf Associates, 1992). Coleman and Koenig (1998) also noted an apparent efficiency of this gear in capturing certain small size classes of finfishes. Therefore, the use of roller-frame trawls in seagrass beds, which serve as nurseries for numerous commercially and recreationally important finfishes, may result in the capture and subsequent mortality of many juveniles of such species.

BRDs have reduced the bycatch of certain species in the inshore and nearshore Florida shrimp fisheries using otter trawls (Steele et al., 2002) and skimmer trawls (Warner et al., 2004). Only limited tests of the effectiveness of BRDs in roller-frame trawls have been made, but some reductions in bycatch have been noted (Coleman et al., 1994, 1996). We investigated the use of BRDs in roller-frame trawls in seagrass habitats as a means of reducing bycatch. We chose study sites where roller-frame trawls are used in commercial harvest of both food shrimp and bait shrimp, in west-central Florida (offshore of Tarpon Springs) and southeast Florida (Biscayne Bay), respectively (Fig. 2).

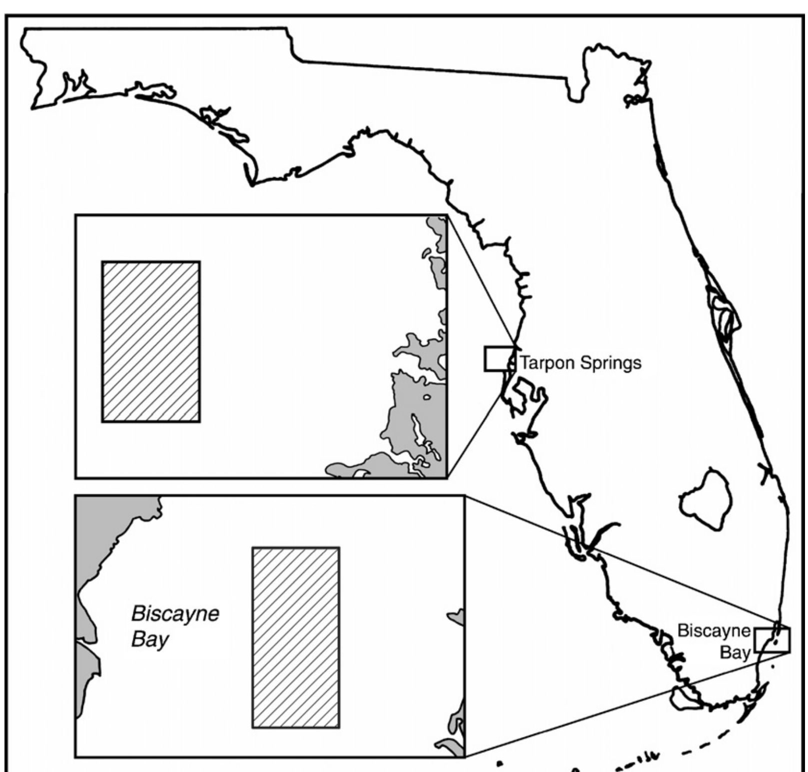

Fig. 2. Map of study sites at Tarpon Springs, Florida, and Biscayne Bay, Florida. Trawling was conducted at Tarpon Springs between 28.25°N–28.30°N and 82.75°W–82.80°W and in Biscayne Bay between 25.69°N–25.72°N and 80.19°W–80.22°W.

2. Materials and methods

We tested the effectiveness of roller-frame trawls for two types of BRDs, the Florida fisheye (FFE) and the large-mesh extended-mesh funnel (EMF) – the two BRDs approved for use in Florida's shrimp–trawl fisheries. We concentrated our efforts in the nearshore waters of Tarpon Springs because, there, we had unlimited access to an FWC vessel. At Biscayne Bay, sampling was conducted aboard a commercial roller-frame trawler, but only the basic sampling was conducted because our access to that vessel was limited. Field sampling at Tarpon Springs was conducted October 1997 (Fall 1997), March 1998 (Spring 1998), and October 1998 (Fall 1998). Sampling at Biscayne Bay was conducted during November–December 1999 (Fall 1999). Guidelines for the construction and placement of BRDs in roller-frame trawls had not yet been established, so staff of the National Marine Fisheries Service (NMFS) Harvesting Systems Team conducted diver surveys to determine the most effective positions of BRDs.

2.1. Gear specifications

Sampling was conducted aboard 35 ft diesel-powered trawlers with 12 ft outriggers from which 3.7 m × 0.8 m roller frames had been deployed. Each net consisted of three sections: the main body (No. 9 twine, 3.8 cm stretch-mesh); the treatment section (No. 18 twine, 3.2 cm stretch-mesh); and the cod-end section (No. 18 twine, 3.2 cm stretch-mesh). As required by Florida law, the nets did not exceed 45 m^2 (500 sq ft) maximum mesh area and were equipped with turtle excluder devices. All nets were the same size and dimensions; and within each location, the same nets were used throughout the project. The treatment section of the experimental net was equipped with a BRD and the control net was not equipped with a BRD (Fig. 3). In the nets used for sampling at Tarpon Springs, zippers were installed to connect the sections of the net to one another, facilitating BRD installation. The nets used for sampling at Biscayne Bay were privately owned and therefore were not altered with zipper connections.

The FFE was constructed of a 13 mm-diameter stainless-steel rod 30 cm long, with an opening of 15 cm diameter to allow fish to escape (Fig. 3B). The FFE was mounted at the top center of the treatment section of the net 90% of the way between the beginning of the treatment section and the cod-end tie-off rings. A 15 cm oval float was attached to the top of the opening. The EMF consisted of a funnel of nylon webbing (3.5 cm stretch-mesh) surrounded by an "escape section" (21 cm stretch-mesh) 1.4 m long (Fig. 3C). A plastic-coated hoop (2 m circumference) allowed the EMF to expand to the full circumference of the trawl.

The FFE and EMF are both devices that allow finfish to escape the net by swimming forward and out via the escape section. To further decrease finfish bycatch, both BRDs were modified in some trials with the insertion, directly behind the BRD, of a stimulator cone (C) constructed of nylon webbing (not shown in Fig. 3). The stimulator cone is designed to impede passage of finfish into the cod end and to increase water velocity through the trawl, facilitating finfish escape through the BRD while funneling shrimp to the tailbag. The stimulator cone is a part of the Jones–Davis BRD tested in otter trawls at the NMFS Harvesting Section Laboratory in Pascagoula, MS. All BRDs used in this project had been approved by representatives of the NMFS Harvesting Systems Team.

2.2. Sampling protocol

The sampling protocol was established in consultation with representatives of the NMFS Pascagoula Laboratory and the FWC Division of Marine Fisheries Management. At Tarpon Springs, we evaluated four BRD configurations: FFE, EMF, FFE + C, and EMF + C. At the Biscayne Bay study site, nets with only the FFE or EMF were tested.

Sampling was done at night. All paired tows were for 30 min at 2 knot, as determined by a Global Positioning System. The total number of tows ranged from 8 for the EMF + C to 33 for the FFE. The number of tows used for each BRD configuration depended on the time and resources available and the variability in catch among tows. Each sampling season, before the BRDs were installed, the paired nets were towed ten times to compare their catchability. Finfish and shrimp catches from each net were weighed separately and their weights were converted to catch per unit effort (CPUE, weight in grams caught per minute of trawling time and a relative estimator of biomass). For finfish and for shellfish, the mean CPUEs for the two nets were compared using paired *t*-tests. The nets were adjusted such that mean CPUEs did not differ significantly between paired nets. For each pair, a BRD was inserted into one trawl. The unaltered net served as the control for evaluating the BRD's effectiveness.

To test each BRD configuration, the BRD-equipped trawl was deployed off one randomly chosen side of the boat and its paired control net was deployed simultaneously off the other side in a double-rig trawl design, a net configuration commonly used in the Florida shrimp fishery. After half of the 10 test tows for each device were completed, the nets of each pair were switched to opposite sides of the boat to avoid bias due to possible differences in the fishing capabilities of the two sides of the boat.

Except for the shrimp caught in the FFE Tarpon Springs Fall 1997 sample, catches from the two nets (BRD and control) were processed separately for each tow. Each catch was sorted as shrimp, finfish bycatch, invertebrate bycatch (crabs, bay scallops, sponges, tunicates, and marine gastropods), seagrass, and trash (rocks, shells, anthropogenic trash, etc.). The shrimp were weighed and counted, and at least 20 randomly chosen individuals from each net were measured to the nearest mm to obtain a size–frequency distribution. Total length was measured at Tarpon Springs but carapace length was measured at Biscayne Bay, principally because it was faster to measure carapace length on the commercial boat. The finfish were sorted by species. For each species, 20 randomly selected individuals were measured to the nearest mm standard length (SL) and collectively weighed; remaining fish were counted and collectively weighed. If fewer than 20 fish of a species were captured, all were measured and collectively weighed. Samples that accounted for <1% of the total were not weighed. The crabs and bay scallops were counted, then all of the invertebrate bycatch, the seagrass, and the trash were weighed separately and all were discarded. In the event that the catch from the tows could not be processed on board, the finfish catch for each net and tow was labeled, bagged, and processed at the laboratory.

2.3. Statistical analyses

All weights were standardized to CPUE, and counts were standardized to number per unit effort (NPUE; number of individuals caught per minute of trawling time and a relative estimator of abundance). Statistical analyses were performed using the STATISTICA software package and following Sokal and Rohlf (1995). Most variables did not conform to the assumptions of normality (Shapiro–Wilk test) or homogeneity of variances (Levene test). Therefore, we used non-parametric statistics for all analyses.

The ability of each BRD net to retain shrimp while reducing finfish bycatch was assessed by comparing, for each pair of trawls, mean NPUE or CPUE of the shrimp and the finfish bycatch in the net equipped with a BRD with those analogous values in the control net. When the bycatch was subsampled in the field, the finfish data

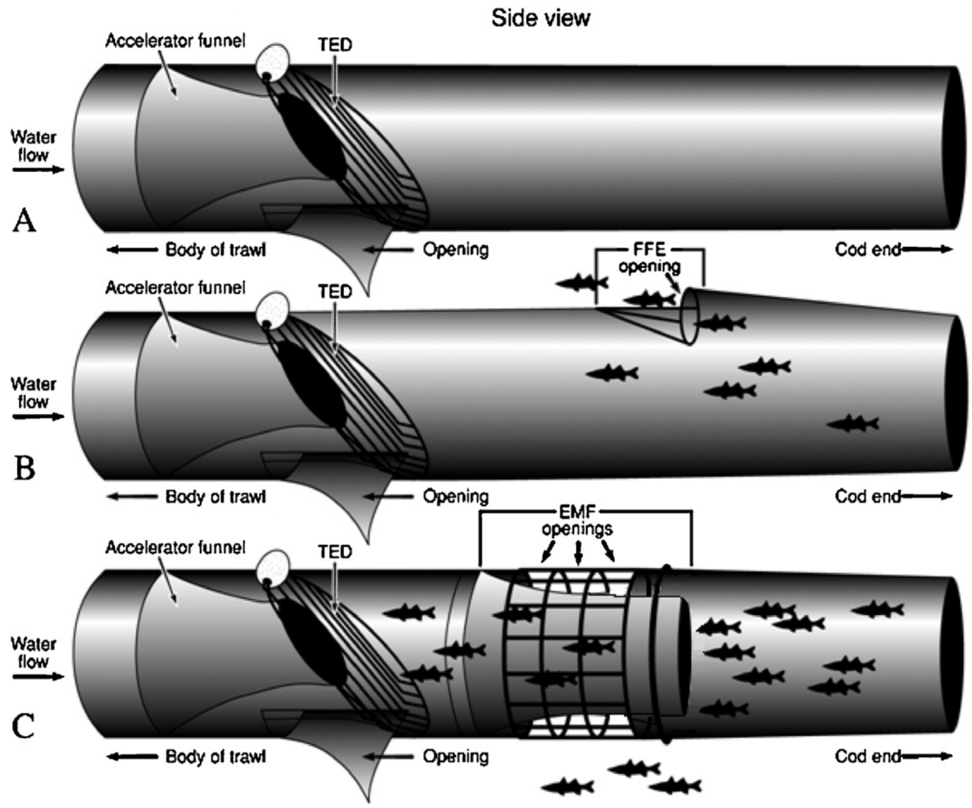

Fig. 3. Stylistic diagram of the treatment section of the bycatch-reduction devices (BRDs) used in this study: net with (A) no BRD (control), (B) Florida fisheye (FFE) and (C) extended-mesh funnel (EMF). When used, a stimulator cone (not shown) was installed in the foreward-most part of the cod end. TED: turtle excluder device.

were extrapolated following Steele et al. (2002) using the formula:

$$\text{Finfish biomass or number} = \text{Finfish subsample biomass or number} \times \left(\frac{\text{Total bycatch weight}}{\text{Subsample weight}}\right)$$

We used the Mann–Whitney *U*-test to compare shrimp-catch and bycatch NPUE and CPUE from each BRD net with the corresponding value from its control net. The percent reduction or increase in NPUE or CPUE was calculated using the formula (from Rogers et al., 1997a):

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

Differences in NPUE and CPUE between the catches of BRD-equipped nets and catches of control nets were assessed using a sign test. Mean sizes of the shrimp and the abundant finfish species were compared between catches from the BRD nets and their paired controls using the Kolmogrov–Smirnov two-sample test. Separate analyses were conducted for each season, location, and BRD configuration. A sign test was also used to determine whether there was a relationship between fish size and exclusion by the BRDs.

3. Results

3.1. Total catch

At Tarpon Springs, for all BRD configurations and seasons combined, shrimp composed 14% and 13% of the total biomass caught in BRD nets and control nets, respectively. Finfish bycatch was 51% and 59% of the total biomass caught in the respective nets. Additional bycatch biomass consisted principally of seagrass (15% in the BRD nets and 12% in the control nets), and bay scallops (*Argopecten irradians* (Lamarck); 9,470 individuals, 10% and 9% of the catch in, respectively, the BRD nets and control nets). Other invertebrate bycatch and trash composed 10% and 7%, respectively, of the total bycatch biomass harvested by the BRD nets and control nets. In addition to bay scallops, other invertebrate bycatch at Tarpon Springs consisted principally of blue crabs (*Callinectes sapidus* (Rathbun)), stone crabs (*Menippe* (Rathbun) spp.), and several different species of gastropods.

At Biscayne Bay, shrimp composed 20% and 26% and finfish composed 17% and 18% of the total biomass caught, respectively, in the BRD nets and control nets. Seagrass accounted for 63% of the total biomass in the BRD-net catch and 56% in the control-net catch. Invertebrate bycatch, composed principally of blue crabs, octopuses, mantis shrimp (Stomatopoda), and spiny lobsters (*Panulirus argus* (Latreille)), and trash were negligible.

3.2. Finfish bycatch composition

Overall, we caught 83 species of finfish as bycatch (Table 1). Twenty-five species were captured only at Tarpon Springs, and 27 were captured only at Biscayne Bay. The differences in finfish-bycatch species composition between the two areas were due principally to biogeographic differences; temperate species pre-

Table 1
Abundance (total count) and biomass (g) of finfish species collected from roller-frame trawls fished in Florida. Dashes: species not caught during the sampling period. A. Tarpon Springs. B. Biscayne Bay.

A. Common name	Scientific name	Tarpon Springs[a]					
		Fall 1997		Spring 1998		Fall 1998	
		Count	Biomass	Count	Biomass	Count	Biomass
Pinfish[b]	*Lagodon rhomboids* (Linnaeus)	16,374 (59.8)	116,573 (23.7)	21,557 (73.8)	218,036 (40.6)	22,426 (59.1)	301,923 (34.4)
Pigfish	*Orthopristis chrysoptera* (Linnaeus)	2,673 (9.8)	55,026 (11.2)	858 (2.9)	35,891 (6.7)	8,009 (21.1)	183,315 (20.9)
Gulf toadfish	*Opsanus beta* (Goode & Bean)	1,159 (4.2)	97,721 (19.8)	2,434 (8.3)	170,664 (31.8)	2,247 (5.9)	192,882 (21.9)
Spottail pinfish	*Diplodus holbrookii* (Bean)	2,601 (9.5)	30,532 (6.2)	432 (1.5)	6,067 (1.1)	365 (1.0)	10,731 (1.2)
Silver perch	*Bairdiella chrysoura* (Lacepède)	752 (2.8)	22,283 (4.5)	12 (<1)	–	1,567 (4.1)	36,984 (4.2)
White grunt	*Haemulon plumierii* (Lacepède)	1,222 (4.5)	12,332 (2.5)	775 (2.7)	6,946 (1.3)	10 (<1)	–
Scrawled cowfish	*Acanthostracion quadricornis* (Linnaeus)	428 (1.6)	21,092 (4.3)	662 (2.3)	27,612 (5.1)	12 (<1)	–
Barbfish	*Scorpaena brasiliensis* Cuvier	4 (<1)	–	453 (1.6)	5,075 (0.9)	417 (1.1)	11,891 (1.4)
Gulf flounder[b]	*Paralichthys albigutta* (Jordan and Gilbert)	8 (<1)	–	342 (1.2)	10,206 (1.9)	5 (<1)	–
Lane snapper[b]	*Lutjanus synagris* (Linnaeus)	301 (1.1)	12,190 (2.5)	–	–	9 (<1)	–
Grass porgy	*Calamus arctifrons* (Goode and Bean)	6 (<1)	–	297 (1.0)	7,541 (1.4)	20 (<1)	–
All other species combined[c]		1,857 (6.8)	124,937 (25.4)	1,405 (4.8)	49,390 (9.2)	2,899 (7.6)	141,330 (16.1)
Totals		27,385	492,686	29,227	537,428	37,986	879,056

B. Common name	Scientific name	Biscayne Bay[d]	
		Fall 1999	
		Count	Biomass
White grunt	*Haemulon plumierii* (Lacepède)	2,617 (24.4)	28,695 (16.2)
Gulf toadfish	*Opsanus beta* (Goode & Bean)	2,202 (20.5)	49,050 (27.6)
Fringed filefish	*Monocanthus ciliates* (Mitchill)	1,625 (15.1)	12,360 (7.0)
Silver jenny	*Eucinostomus gula* (Quoy & Gaimard)	886 (8.3)	7,830 (4.4)
Scrawled cowfish	*Acanthostracion quadricornis* (Linnaeus)	597 (5.6)	16,241 (9.2)
Pinfish[b]	*Lagodon rhomboids* (Linnaeus)	498 (4.6)	14,625 (8.2)
Redfin parrotfish	*Sparisoma rubripinne* (Valenciennes)	275 (2.6)	7,904 (4.4)
Lane snapper[b]	*Lutjanus synagris* (Linnaeus)	227 (2.1)	2,960 (1.7)
Bandtail puffer	*Sphoeroides spengleri* (Bloch)	189 (1.8)	3,520 (2.1)
Gray snapper[b]	*Lutjanus griseus* (Linnaeus)	185 (1.7)	2,305 (1.3)
Tomtate	*Haemulon aurolineatum* Cuvier	162 (1.5)	1,805 (1.0)
Yellowtail snapper[b]	*Ocyurus chrysurus* (Bloch)	158 (1.5)	1,805 (1.0)
Striped burrfish	*Chilomycterus schoepfii* (Walbaum)	117 (1.1)	6,215 (3.5)
All other species combined[e]		1,002 (9.3)	22,196 (12.5)
Totals		10,740	177,511

[a] Numbers in parentheses are percentages of the count or of the total biomass for each season.

[b] Economically important species.

[c] Only species comprising greater than 1% of the total bycatch (by count) in at least one set of samplings are listed. Species with less than 1% of the count during each sampling period, unless otherwise noted: *Achirus lineatus* (Linnaeus), *Aluterus schoepfii* (Walbaum), *Ancylopsetta dilecta* (Goode and Bean), *Ariopsis felis* (Linnaeus), *Centropristis striata* (Linnaeus), *Chaetodipterus faber* (Broussonet), *Chilomycterus schoepfii* (Walbaum), *Chloroscombrus chrysurus* (Linnaeus), *Cynoscion nebulosus* (Cuvier)[b], *Cynoscion nothus* (Holbrook)[b], *Dasyatis Americana* Hildebrand and Schroeder, *Diodon holocanthus* Linnaeus, *Diplectrum formosum* (Linnaeus), *Elops saurus* Linnaeus, *Eucinostomus gula* (Quoy & Gaimard), *Gymnothorax saxicola* Jordan and Davis, *Gymnura micrura* (Bloch & Schneider), *Haemulon aurolineatum* Cuvier (1997 and Spring 1998), *Harengula jaguana* Poey, *Hemiramphus brasiliensis* (Linnaeus)[b], *Hippocampus erectus* Perry, *Hypsoblennius hentz* (Lesueur), *Lachnolaimus maximus* (Walbaum), *Leiostomus xanthurus* Lacepède, *Lutjanus griseus* (Linnaeus), *Monocanthus ciliatus* (Mitchill) (1998 only), *Stephanolepis hispidus* (Linnaeus), *Monacanthus tuckeri* Bean, *Mycteroperca microlepis* (Goode & Bean)[b], *Nicholsina usta* (Valenciennes), *Oligoplites saurus* (Bloch and Schneider), *Ophichthus gomesi* (Castelnau), *Ophidion holbrookii* Putnam, *Pagrus pagrus* (Linnaeus), *Prionotus scitulus* Jordan and Gilbert, *Sciaenops ocellatus* (Linnaeus)[b], *Selene vomer* (Linnaeus), *Sphoeroides nefelus* (Goode & Bean), *Sphoeroides spengleri* (Bloch) (1997 only), *Symphurus plagiusa* (Linnaeus), *Syngnathus scovelli* (Evermann & Kendall), *Synodus foetens* (Linnaeus), *Trinectes maculates* (Bloch & Schneider), *Urophycis floridana* (Bean & Dresel).

[d] Numbers in parentheses are percentages of the count or of the total biomass.

[e] Only species comprising greater than 1% of the total bycatch (by count) are listed. Species with less than 1% of the count: *Acanthurus chirurgus* (Bloch), *Achirus lineatus* (Linnaeus), *Aluterus scriptus* (Osbeck), *Astrapogon alutus* (Jordan & Gilbert), *Balistes capriscus* Gmelin, *Bothus ocellatus* (Agassiz), *Calamus arctifrons* Goode and Bean, *Chaetodipterus faber* (Broussonet), *Chilomycterus antennatus* (Cuvier), *Chriodorus atherinoides* Goode and Bean, *Cosmocampus albirostris* (Kaup), *Cynoscion nebulosus* (Cuvier)[b], *Dactylopterus volitans* (Linnaeus), *Diodon holocanthus* Linnaeus, *Diodon hystrix* Linnaeus, *Diplectrum bivittatum* (Valenciennes), *Diplectrum formosum* (Linnaeus), *Equetus acuminatus* (Bloch and Schneider), *Eucinostomus argenteus* Baird and Girard, *Foetorepus agassizi* (Goode and Bean), *Gymnothorax saxicola* Jordan and Davis, *Hippocampus erectus* Perry, *Holocentrus adscensionis* (Osbeck), *Hypoplectrus puella* (Cuvier), *Lachnolaimus maximus* (Walbaum), *Lactophrys trigonus* (Linnaeus), *Monacanthus tuckeri* Bean, *Opistognathus* sp., *Orthopristis chrysoptera* (Linnaeus), *Paraclinus marmoratus* (Steindachner), *Paraclinus nigripinnis* (Steindachner), *Paralichthys albigutta* Jordan and Gilbert, *Paralichthys lethostigma* Jordan and Gilbert, *Pomacanthus paru* (Bloch), *Prinotus scitulus* Jordan and Gilbert, *Scorpaena brasiliensis* Cuvier, *Sparisoma radians* (Valenciennes), *Sphoeroides nefelus* (Goode and Bean), *Stephanolepis hispidus* (Linnaeus), *Syngnathus louisianae* Günther, *Syngnathus pelagicus* Linnaeus, *Syngnathus scovelli* (Evermann and Kendall), *Synodus foetens* (Linnaeus), *Trinectes maculates* (Bloch and Schneider).

dominated in the Tarpon Springs samples, whereas the Biscayne Bay samples also included tropical reef species.

In the Tarpon Springs samples, pinfish (*Lagodon rhomboides* (Linnaeus)) predominated in the finfish bycatch, accounting for 64% of the total number of finfish captured during all sampling periods (Table 1A); and they were five times more abundant as the second most common species, the pigfish (*Orthopristis chrysoptera* (Linnaeus)), which accounted for 12% of the total number of finfish. Nine other species each comprised more than 1% of the total number of finfish during at least one sampling period. In weight, pinfish also predominated, comprising 33% of the total finfish biomass, followed by gulf toadfish (*Opsanus beta* (Goode & Bean), 24%) and pigfish (14%). Some seasonal differences in finfish species composition were evident in the Tarpon Springs samples; all but one species caught during the Spring sampling period were also caught during the Fall, but 16 species were caught only during the Fall.

In the Biscayne Bay samples, the white grunt (*Haemulon plumieri* (Lacepède)), gulf toadfish, and fringed filefish (*Monocanthus ciliatus* (Mitchill)) comprised 25%, 21%, and 15%, respectively, of the total number of finfish in the bycatch (Table 1B). No other species comprised more than 10% of the total finfish abundance, but 13 species comprised more than 1%. Only the gulf toadfish (28%) and white grunt (16%) comprised more than 10% of the total finfish biomass; 16 species comprised 1–10%.

The pinfish, captured in great abundance and biomass at Tarpon Springs (Table 1A), is used as bait, principally in recreational fisheries. Other commercially and recreationally important finfish species were caught at relatively low frequencies or only occasionally at the two locations (Table 1A and B). These species included the gulf flounder (*Paralichthys albigutta* Jordan and Gilbert), lane snapper (*Lutjanus synagris* (Linnaeus)), gray snapper (*Lutjanus griseus* (Linnaeus)), yellowtail snapper (*Ocyurus chrysurus* (Bloch)), seatrouts (*Cynoscion nebulosus* (Cuvier), *C. nothus* (Holbrook)), ballyhoo (*Hemiramphus brasiliensis* (Linnaeus)), gag (*Mycteroperca microlepis* (Goode and Bean)), and red drum (*Sciaenops ocellatus* (Linnaeus)).

3.3. Effects of BRDs on NPUE and CPUE

3.3.1. FFE

Finfish bycatch was similar in both abundance and weight between FFE-net and control-net catches during nearly all sampling periods and at both locations (Table 2). The most abundant finfish species were not reduced by the FFE, but some species-specific differences were noted (Tables 1 and 3). At Tarpon Springs, for each of five species, NPUE and/or CPUE for FFE nets was significantly less (15–89% less) than for control nets (silver perch (*Bairdiella chrysoura* (Lacepède)), scrawled cowfish (*Acanthostracion quadricornis* (Linnaeus)), lane snapper, silver jenny (*Eucinostomus gula* (Quoy and Gaimard)), inshore lizardfish (*Synodus foetens* (Linnaeus)); Table 3). In contrast, the CPUE of sand perch (*Diplectrum formosum* (Linnaeus)) was 12% greater and the NPUE of gulf toadfish was 44% greater for FFE nets. At Biscayne Bay, gulf toadfish NPUE was similarly greater (40%) for FFE nets, whereas gray snapper CPUE was more than 50% less.

The CPUE of neither bay scallops nor other invertebrate bycatch in the FFE nets differed significantly from that in control nets at either Tarpon Springs or Biscayne Bay. However, at Biscayne Bay, overall seagrass CPUE was 157% greater for BRD nets than for control nets ($P < 0.001$).

Although the only significant difference in shrimp catch between the FFE nets and the control nets was a significantly higher shrimp NPUE in the FFE-net catch during Fall 1997 at Tarpon Springs (Table 2), overall, the catch of shrimp in the FFE net was significantly greater than that in the control net (sign test, NPUE and CPUE, $P < 0.05$).

Table 2
Comparison of mean catch from each roller-frame trawl net equipped with a bycatch-reduction device (BRD) and from its paired control net. FFE: Florida fisheye. EMF: extended-mesh funnel. FFE + C: FFE with a stimulator cone. EMF + C: EMF with a stimulator cone. Sampling periods (Sampl. per.): Tarpon Springs, Fall 1997 (TSF97), Spring 1998 (TSS98), Fall 1998 (TSF98), Biscayne Bay, Fall 1999 (BBF99). *n*: number of tows. NPUE: number of finfish captured per unit of effort. CPUE: biomass (grams) of finfish captured per unit of effort. Standard deviations are in parentheses. % Diff.: percentage difference in catch from the BRD-equipped net compared with its control net.

Net	Sampl. per.	*n*	Finfish NPUE			Finfish CPUE			Shrimp NPUE			Shrimp CPUE		
			BRD	Control	% Diff[a]	BRD	Control	% Diff	BRD	Control	% Diff	BRD	Control	% Diff
FFE	TSF97	33	10.2 (6.1)	10.2 (4.8)	−0.9	139.7 (87.2)	161.9 (71.3)	−13.7	6.9 (2.8)	5.3 (3.7)	+30.5 *	42.2 (21.4)	34.7 (20.4)	+21.8
	TSF98	20	10.0 (2.6)	9.6 (2.3)	+4.5	230.3 (37.4)	247.8 (68.0)	−7.0	12.2 (4.0)	10.7 (5.2)	+14.3	73.1 (27.7)	62.4 (26.4)	+17.1
	BBF99	20	7.2 (2.5)	6.8 (2.4)	+5.9	112.0 (31.7)	110.9 (28.2)	+0.9	17.2 (7.7)	14.6 (7.3)	+17.6	91.9 (38.4)	88.6 (39.3)	+3.8
EMF	TSS98	18	11.7 (5.1)	16.0 (6.9)	−26.8 *	205.8 (88.2)	308.8 (145.4)	−33.4 *	13.8 (7.3)	13.8 (7.7)	+0.5	77.4 (39.2)	85.1 (45.7)	−9.0
	TSF98	20	8.5 (1.5)	9.9 (1.9)	−14.0 *	187.8 (23.0)	222.8 (39.5)	−15.7 ***	12.0 (5.1)	13.7 (5.2)	−12.9	81.3 (34.6)	86.5 (33.2)	−6.0
	BBF99	20	1.8 (0.5)	2.6 (1.1)	−59.0 ***	19.8 (8.1)	53.2 (8.1)	−62.7 ***	22.6 (10.5)	42.8 (16.9)	−47.3 ***	127.8 (58.8)	239.3 (99.6)	−46.6 ***
FFE + C	TSS98	18	8.2 (3.1)	15.0 (4.5)	−44.7 ***	107.0 (29.0)	274.6 (89.2)	−61.0 ***	7.6 (3.2)	14.6 (6.3)	−48.1 ***	46.6 (18.2)	84.9 (34.1)	−45.2 ***
EMF + C	TSF97	9	8.7 (3.3)	17.0 (4.5)	−49.1 **	101.8 (42.7)	191.5 (56.4)	−46.8 **	4.6 (1.5)	8.2 (2.4)	−44.5 **	36.2 (13.5)	50.9 (13.8)	−28.9 *

[a] Asterisks show significance: *$P \leq 0.05$; **$P \leq 0.01$; ***$P \leq 0.001$.

Table 3
Proportional differences in finfish bycatch between each BRD-equipped roller-frame trawl net and its paired control net. Only statistically significant comparisons are included. Percentage differences are approximate due to rounding. Sampl. per.: sampling period. FFE: Florida fisheye. EMF: Extended-mesh funnel. FFE + C: FFE with a stimulator cone. EMF + C: EMF with a stimulator cone. NPUE: number of finfish captured per unit of effort. CPUE: biomass (grams) of finfish captured per unit of effort.

Net/Sampl. per.[a]	Common name[b]	NPUE			CPUE		
		BRD	Control	% Diff. [c]	BRD	Control	% Diff.
FFE							
TSF97	Silver perch (5)[d]	0.26	0.43	−41.2*	4.35	9.05	−51.9**
	Scrawled cowfish (7)	0.15	0.21	−28.1*	4.98	6.67	−25.3*
	Lane snapper (9)	0.12	0.14	−15.1*	2.55	3.75	−32.1*
	Silver jenny (13)				0.09	0.80	−89.3*
	Inshore lizardfish (low)				1.40	4.38	−68.0*
	Sand perch (low)				0.80	0.72	12.0*
TSF98	Gulf toadfish (3)	0.76	0.53	44.4*			
BBF99	Gulf toadfish (*2*)	1.65	1.18	40.2**			
	Gray snapper (*10*)				1.08	2.38	−54.4**
EMF							
TSS98	Pinfish (1)	8.89	12.40	−28.3*			
	Pigfish (2)	0.36	0.55	−34.3*			
	Gulf toadfish (3)	0.80	1.10	−27.4*			
	Silver perch (5)	0.04	0.13	−67.1*	1.09	5.34	−79.6*
TSF98	Pinfish (1)	5.29	6.33	−16.4*	70.12	88.12	−20.4***
	Spottail pinfish (4)	0.05	0.11	−54.4**	1.61	3.45	−53.4*
	Silver perch (5)	0.19	0.36	−46.8***	4.25	8.74	−51.4***
	Striped burrfish (19)				8.08	2.84	185.0*
BBF99	White grunt (1)	0.10	0.37	−73.5*			
	Fringed filefish (3)	0.15	0.32	−53.1*	1.59	3.13	−49.2**
	Silver jenny (4)	0.06	0.26	−77.8*	1.18	4.86	−75.8**
	Pinfish (6)	0.02	0.07	−65.9*			
	Bandtail puffer (9)	0.03	0.12	−77.8***	0.48	2.48	−80.5***
	Tomtate (11)				0.53	1.93	−72.3*
	Trunkfish (low)	0.13	0.25	−49.3**	2.14	8.47	−74.7***
	Planehead filefish (low)				0.39	1.40	−72.0*
	Hogfish (low)	0.01	0.04	−80.0*			
FFE + C							
TSS98	Pinfish (1)	5.52	10.76	−48.7***	8.03	110.30	−92.7***
	Pigfish (2)				9.40	17.90	−47.5*
	Gulf toadfish (3)				52.87	94.08	−43.8**
	Spottail pinfish (4)	0.14	0.28	−49.7**			
	White grunt (6)	0.34	0.62	−45.4**	2.84	6.14	−53.8**
	Barbfish (8)	0.18	0.28	−36.2**			
	Gulf flounder (10)	0.17	0.24	−32.1*			
	Fringed filefish (12)	0.12	0.04	210.0*			
	Planehead filefish (low)	0.05	0.15	−64.6***			
	Southern puffer (low)	0.02	0.04	−57.9*			
EMF + C							
TSF97	Pinfish (1)	5.59	11.73	−52.4***	31.71	61.32	−48.3**
	Spottail pinfish (4)	0.37	1.01	−63.6**	4.20	12.18	−65.5***
	Silver perch (5)	0.03	0.16	−81.0**	0.42	4.31	−90.2***
	Grass porgy (11)	0.19	0.37	−49.5*			
	Silver jenny (13)	0.11	0.26	−58.0*			
	Tomtate (17)	0.10	0.16	−39.5*	0.74	2.00	−63.2*
	Southern puffer (low)				0.32	2.63	−88.0*

[a] Defined in Table 2.
[b] Finfish scientific names are given in Table 1.
[c] Significance level: $^{*}P \leq 0.05$; $^{**}P \leq 0.01$; $^{***}P \leq 0.001$.
[d] Species rank, as determined by species abundance in the bycatch, for each location (see Table 1); species listed as (low) contributed <1% to total abundance.

3.3.2. EMF

At both sampling locations, the overall finfish bycatch with EMF nets was significantly less (sign test, $P = 0.02$) than with control nets (Table 2). The decrease in NPUE and CPUE ranged from 14% to 33% for the Tarpon Springs samples. The decrease was even more marked for the Biscayne Bay samples: overall finfish NPUE was 59% less with EMF nets than with control nets, and CPUE was 63% less.

In the Tarpon Springs samples, species released by the EMF included pinfish, pigfish, gulf toadfish, silver perch, and spottail pinfish (*Diplodus holbrooki* (Bean)) (Table 3). Only the catch of striped burrfish (*Chilomycterus schoepfi* (Walbaum)) increased significantly; CPUE for this species was 185% greater with EMF nets than with control nets. In the Biscayne Bay EMF-net samples, the NPUE and/or CPUE for nine species was significantly less (49–81%) than for control-net samples. The EMF was consistently effective in discharging pinfish and silver perch. NPUE and/or CPUE of pinfish was 16–66% less with EMF nets than with control nets, and for the Tarpon Springs samples, the NPUE of silver perch was 47–67% less and CPUE was 53–80% less than for control nets.

At Tarpon Springs, the NPUE of bay scallops with EMF nets did not differ significantly from that with control nets. However, the combined invertebrate CPUE was 28% greater ($P < 0.05$) with EMF nets than with control nets during Spring 1998, but this was not true for Fall 1998. In the Biscayne Bay samples, neither invertebrate-bycatch NPUE nor CPUE differed between the catches of the EMF nets and control nets.

In the Tarpon Springs EMF-net samples, shrimp NPUE and CPUE did not differ significantly from that of the control-net samples. In notable contrast, in the Biscayne Bay shrimp samples, NPUE and

Table 4
Comparison of mean standard lengths (mm) of finfish caught in each roller-frame trawl equipped with a bycatch-reduction device (BRD) and finfish caught in its paired control net; only statistically significant comparisons are included. FFE: Florida fisheye. EMF: Extended-mesh funnel. FFE + C: FFE with a stimulator cone. EMF + C: EMF with a stimulator cone. *n*: number of fish measured. SD: standard deviation.

Net/sampling period[a]	Species[b]	Treatment	
		BRD mean ± SD (*n*)	Control mean ± SD (*n*)
FFE			
TSF97	Pigfish (2)[c]	81 ± 17**[d] (578)	78 ± 13 (612)
	Spottail pinfish (4)	61 ± 9** (576)	59 ± 5 (607)
	White grunt (6)	52 ± 18* (409)	53 ± 21 (374)
	Silver jenny (13)	44 ± 14*** (60)	65 ± 26 (60)
	Lined sole (low)	63 ± 20* (13)	115 ± 95 (21)
TSF98	Gulf toadfish (3)	145 ± 29** (332)	155 ± 32 (291)
	Silver perch (5)	94 ± 15** (258)	99 ± 17 (268)
BBF99	Scrawled cowfish (5)	62 ± 36* (191)	68 ± 41 (182)
EMF			
TSS98	Pinfish (1)	70 ± 15* (400)	68 ± 11 (400)
	Gulf toadfish (3)	134 ± 33** (343)	141 ± 34 (352)
	White grunt (6)	62 ± 10* (113)	65 ± 11 (120)
	Grass porgy (11)	87 ± 15* (61)	82 ± 14 (74)
TSF98	Pinfish (1)	70 ± 15* (399)	74 ± 15 (400)
	Silver perch (5)	94 ± 14** (116)	99 ± 15 (218)
BBF99	Scrawled cowfish (5)	52 ± 26** (76)	69 ± 41 (150)
FFE + C			
TSS98	Gulf toadfish (3)	139 ± 34* (335)	143 ± 30 (331)
	White grunt (6)	65 ± 9 * (180)	68 ± 11 (279)
EMF + C			
TSF97	Spottail pinfish (4)	64 ± 5*** (96)	71 ± 18 (158)
	Silver jenny (13)	62 ± 10**(29)	65 ± 20 (76)

[a] Defined in Table 2.
[b] Finfish scientific names are given in Table 1.
[c] Species rank, as determined by species abundance in the bycatch, for each location (see Table 1); species listed as (low) contributed <1% to total abundance.
[d] Significance level: *$P \leq 0.05$; **$P \leq 0.01$; ***$P \leq 0.001$.

CPUE were significantly less (29–48%) with the EMF nets than with the control nets (Table 2).

3.3.3. *FFE + C and EMF + C*

The addition of a stimulator cone (C) to either the FFE net or EMF net resulted in a significant decrease in NPUE and CPUE for both finfish and shrimp (Table 2). The bycatch of bay scallops and other invertebrates was not affected. Seagrass CPUE in the catch from FFE + C nets was 55% less than that from control nets ($P < 0.01$); but seagrass CPUE in the catch from the EMF + C nets was 92% greater than that from control nets ($P < 0.05$).

3.4. *Size comparisons*

Of the 113 comparisons of mean finfish SL between BRD-net and control-net samples, only 19 tests for 10 species showed significant differences and, of those, only 10 were significant at the more conservative 0.01 level (Table 4). In 15 of those tests and in 9 of the 10 highly significant tests, the mean SL of fish in BRD-net samples was less than that in control-net samples. A significant sign test ($P < 0.02$) indicated that the BRDs preferentially discharged larger fish. Most differences in mean SL were minor, exceeding 10 mm for only four species – gulf toadfish, scrawled cowfish, silver jenny, and lined sole (*Achirus lineatus* (Linnaeus)).

Compared with controls, mean SL differed significantly for eight species in the FFE-net samples and for six species in the EMF-net samples (Table 4). The greatest difference was for lined sole in the Fall 1997 FFE-net samples; mean SL was 63 mm, compared with 115 mm in the control-net samples. In contrast, mean SL in samples taken with FFE + C and EMF + C nets differed significantly from that in samples taken with control nets only twice for each type of gear; in all four instances, mean SL was less in the BRD-net samples. Most of the significant differences in SL between BRD-net samples and control-net samples occurred in the Tarpon Springs samples. In the Biscayne Bay samples, the mean SL of only the scrawled cowfish differed significantly between the BRD-net samples and control-net samples.

For shrimp, only the FFE-net samples did not differ significantly in mean size from controls (Table 5). In the Tarpon Springs EMF-net samples, mean shrimp size was significantly larger than in control-

Table 5
Comparison of mean lengths (mm) of shrimp caught in each roller-frame trawl equipped with a bycatch-reduction device (BRD) and its paired control net. FFE: Florida fisheye. EMF: Extended-mesh funnel. FFE + C: FFE with a stimulator cone. EMF + C: EMF with a stimulator cone.

BRD	Sampling period[a]	Treatment	
		BRD mean ± SD (*n*)	Control mean ± SD (*n*)
FFE	TSF98	92 ± 19 (377)	91 ± 20 (405)
	BBF99	29 ± 6 (181)	29 ± 6 (170)
EMF	TSS98	91 ± 12 (446)	92 ± 12 (506)
	TSF98	95 ± 20***[b] (423)	90 ± 21 (398)
	BBF99	31 ± 4 (200)	30 ± 5 (202)
FFE + C	TSS98	95 ± 10* (391)	93 ± 11 (319)
EMF + C	TSF97	97 ± 20* (379)	95 ± 18 (582)

[a] Defined in Table 2.
[b] Asterisks denote significant differences in mean length of shrimp from BRD-equipped nets compared with those from control nets (*$P \leq 0.05$; ***$P \leq 0.001$).

net samples during Fall 1998 but not during Spring 1998. In both the FFE + C- and EMF + C-net samples, mean shrimp size was larger than in control-net samples. Overall, significant size differences were relatively minor, only 2–5 mm.

4. Discussion

Overall, we found some encouraging reductions in bycatch reduction in our studies, but the results were inconsistent between sites and among species within gears. The EMF tended to reduce bycatch better than the FFE, but the EMF also reduced (sometimes greatly) the catch of shrimp, the targeted species. In general, our study provides additional evidence that BRDs should be required in roller frame fisheries and that the BRDs we tested, particularly the EMF, can reduce bycatch, but that customized alterations may be needed and the choice of BRD may differ depending on the benthic habitat being trawled.

4.1. Bycatch reduction

The efficacy of the FFE in reducing finfish bycatch in shrimp trawls has been demonstrated in numerous studies (Whitaker et al., 1992; Wallace and Robinson, 1994; Rogers et al., 1997a; Steele et al., 2002; Warner et al., 2004). In this study, the FFE failed to decrease overall bycatch, but a significant reduction occurred for a few species. Surprisingly, relative abundances of the most common species (pinfish at Tarpon Springs, white grunt at Biscayne Bay) were not significantly reduced, contrary to the results of other studies in which reduction rates were more proportional to abundance (Rogers et al., 1997a; Steele et al., 2002; Warner et al., 2004). Results for our EMF tests were the opposite of those for the FFE; all nets equipped with EMFs significantly reduced finfish bycatch, especially that of the most abundant species. Similar decreases have been observed in tests of other mesh-funnel BRDs (Brewer et al., 1998; Garcia-Caudillo et al., 2000; Courtney et al., 2006). The reduction of finfish bycatch in BRDs equipped with the stimulator cone was more marked than in BRDs equipped with the FFE or EMF alone and included a broad range of finfish species, suggesting that the cone was valuable in reducing bycatch. However, the concomitant large losses of shrimp negated the cone's usefulness for reducing bycatch under our field conditions.

Broadhurst (2000) described considerations for maximizing a BRD's ability to reduce bycatch while retaining shrimp catch: trawl size and method of handling, location and characteristics of trawl grounds, species to be expelled and their sizes, and the extent to which behavior of target and bycatch species is known. Rogers et al. (1997a), after comparing several BRD configurations at three coastal Louisiana locations, reported that gear efficiencies depended on local species composition and size distributions. Our results concurred; we saw both seasonal and spatial differences in bycatch reduction. In addition, in our study, the two study sites differed greatly in the amount of seagrass present, which differentially affected the efficiency of the BRDs.

Modifications and re-evaluation may be necessary to optimize a BRD to a particular location or fishery (Broadhurst, 2000). Several authors have stressed the need to evaluate BRDs as they are used in commercial fisheries and not only during research trials. For example, Broadhurst (2000) noted that BRDs performed differently during research trials conducted in weather bad enough to keep the commercial fleet in port than in trials conducted during good weather. Richards and Hendrickson (2006) reported that bycatch reduction was 35% less on commercial vessels than on research vessels, but Hannah and Jones (2007) saw no difference. We recommend that the BRDs used here be tested in the commercial fleet.

Mean size of retained finfish species was smaller in BRD-net samples than in control-net samples for 15 of the 19 significant tests. This preferential release of larger fish has been noted previously (Whitaker et al., 1992; Coleman and Koenig, 1998; Garcia-Caudillo et al., 2000; Steele et al., 2002; Warner et al., 2004; Courtney et al., 2006). The FFE and EMF devices were designed to take advantage of behavioral differences between shrimp and finfish (Broadhurst, 2000). Shrimp are weak swimmers and tend to be flushed through a net into the cod end. Fish, in general, are stronger swimmers. Wardle (1993) described the optomotor response of fish in a trawl; initially, many fish swim along within the mouth of a trawl until they tire, at which point they turn and swim into the net toward the cod end. Constriction of the netting increases water flow, stimulating positive rheotaxic behavior in the fish: they orient themselves against the current, again facing the trawl mouth (Watson, 1988). Variations in a trawl's netting, such as a BRD opening, produces changes in water flow that induce fish to swim away from the cod end and out through the escape holes. Swimming speed and endurance are size-dependent in many fish, and small fish cannot hold position as long as larger fish and cannot swim against strong water flow. Thus, larger fish are more likely to escape from BRDs such as the FFE and EMF. Size-specific rates of retention and escape ultimately depend on the size-specific anatomy, physiology, and behavior of a species.

4.2. Shrimp catch

Retention of shrimp is a major reason that fisherman have accepted BRDs (Broadhurst, 2000). In this study, shrimp catch with BRD nets varied with BRD type and with location when compared with that of control nets. Although in only one case – the FFE in Fall 1997 at Tarpon Springs – did shrimp catch increase significantly with BRD use, use of the FFE consistently resulted in greater shrimp catches. This pattern of no shrimp loss, and even slight shrimp gain, bodes well for the industry's acceptance of BRDs in roller-frame trawls. In other studies testing the FFE and similar fisheye BRDs, shrimp retention generally has been good (Whitaker et al., 1992; Wallace and Robinson, 1994; Brewer et al., 1998; Steele et al., 2002; Warner et al., 2004), although Rogers et al. (1997a) reported significantly, albeit not drastically, smaller shrimp catches (−16% in numbers, −14% in biomass) from their FFE nets. Both Whitaker et al. (1992) and Rogers et al. (1997a) noted better retention of white shrimp (*Litopenaeus setiferus*) than brown shrimp (*Farfantepenaeus aztecus* (Ives)) and suggested that species-specific shrimp behaviors may account for the differences in gear efficiency.

Our EMF-net results showed shrimp loss in all but one comparison. Some degree of shrimp loss has been noted for this BRD in locations as varied as Florida (Steele et al., 2002), the Gulf of California (Garcia-Caudillo et al., 2000), and Australia (Courtney et al., 2006). However, although Brewer et al. (1998) reported significantly diminished shrimp catches from nets equipped with the Australian equivalent of the EMF (radial escape section) during bad weather, they recorded slightly greater catches during good weather, and Rogers et al. (1997b) noted low shrimp loss when using an EMF net. In our study, the single increase in shrimp abundance (0.5%, for EMF-net catches in Fall 1998 at Tarpon Springs) was statistically negligible. More striking was the nearly 50% reduction in shrimp abundance and biomass in the EMF-net catches at Biscayne Bay. Soft BRDs tend to catch more seaweed and seagrass than rigid BRDs (Broadhurst, 2000). Such debris may alter flow rates through a trawl and affect BRD performance (Rogers et al., 1997a) by clogging the trawl openings and nets. More than 50% of the bycatch biomass at Biscayne Bay was seagrass, which may have hampered the fishing of the EMF net, allowing shrimp to escape. Similar large rates of shrimp loss were observed when a stimulator cone was used in conjunction with either the FFE or EMF. However, since the FFE + C and EMF + C were fished only at Tarpon Springs, seagrass was probably not a factor in their shrimp-escapement rates. Shrimp losses as great as those observed with the EMF at Biscayne Bay and BRD + C gears at Tarpon Springs would undoubtedly be unacceptable to industry; shrimpers consider losses greater than 3% to be unacceptable.

Shrimp size did not seem to be a factor in the shrimp exclusion or retention properties of the different BRD types. Mean shrimp sizes at Tarpon Springs ranged from 90 to 97 mm total length. Using a conversion equation for pink shrimp derived by Fontaine and Neal (1968), we estimated mean total lengths for shrimp captured at Biscayne Bay to be 68–74 mm. Although there was a trend toward slightly larger shrimp in the BRD-net catches, the lack of consistent significant size differences between the shrimp harvest from the BRD nets and that from the control nets for all BRD types indicated that trawling conditions probably affected both the larger food shrimp and smaller bait shrimp similarly and that these conditions were little influenced by use of a BRD. The retention of slightly larger shrimp in FFE nets and EMF nets has been noted in other studies (Rogers et al., 1997a,b).

4.3. Roller frames, BRDs, and fishery management

Roller-frame trawls are not used by a large portion of the shrimping fleet, but they are operated in sensitive seagrass environments. The roller-frame trawl itself has been reported to have minimal impact on seagrass habitat, at least in the short term (Meyer et al., 1999). However, the biological and population effects of bycatch capture and potential mortality are intensified in this environment because seagrass beds are nursery areas for many estuarine and marine finfishes and for invertebrates with estuarine-dependent juvenile phases (Continental Shelf Associates, 1992; Coleman et al., 1993; Coleman and Koenig, 1998; Meyer et al., 1999; Baum et al., 2003). Due to their lesser swimming abilities, small and juvenile fish are more susceptible to being captured by a trawl than are larger fish; they are also are more susceptible to trawl-induced mortality (Meyer et al., 1999). Although there are BRDs designed to separate finfish species from the shrimp by size (Broadhurst, 2000), most of the finfish in our bycatch samples were similar in size to the targeted shrimp; thus, size-selective gear will not work in this fishery.

The roller-frame trawl is the only one of the three major trawl types used in Florida (the other two being the otter and skimmer trawls) for which it is not required that a BRD be installed in the net. This and other studies have demonstrated that roller-frame trawls produce considerable bycatch (Meyer et al., 1999; Continental Shelf Associates, 1992), indicating that seagrass communities would benefit from the introduction of BRDs into this fishery. None of the types of gear tested in this study produced consistent and significant reductions in bycatch in conjunction with improved shrimp retention. The EMF worked well at Tarpon Springs, with significant – albeit relatively small – reductions in bycatch and only slight shrimp loss, but it worked poorly at Biscayne Bay. Optimization of BRD performance in these and other locations is necessary if BRDs are to be considered for mandatory use in the roller-frame trawl fishery. Modifications and re-evaluation of BRDs at these and other locations are necessary for such optimization.

Acknowledgements

Thanks to the field crews that participated in this study, especially S. Levett, K. Johnston, S. Geiger, D. Warner, and participating fishermen. We also thank two helpful anonymous reviewers. This study was funded in part by the U.S. Department of Commerce National Oceanographic and Atmospheric Administration, through Cooperative Agreement NA67FIO118 to the Florida Fish and Wildlife Conservation Commission. The views expressed herein are solely those of the authors and do not necessarily reflect the views of the funding agencies.

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