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EVALUATIONS OF TURTLE EXCLUDER DEVICES (TEDs) WITH REDUCED BAR SPACING IN THE INSHORE PENAEID SHRIMP FISHERY OF THE NORTHERN GULF OF MEXICO

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ABSTRACT

Turtle Excluder Devices (TEDs) have been required in the southeastern United States penaeid shrimp trawl fishery since 1989 to reduce the mortality of sea turtles associated with shrimp trawling. TEDs are metal sorting grids placed in the trawl forward of the codend. Larger animals, such as sea turtles, are directed to an escape opening in the trawl, while smaller ones, including shrimp, pass through the grid bars and into the codend. Federal TED requirements set the maximum bar spacing for the TED grid at 4 inches (10.2 cm) due to the size range of sea turtles that were encountered when the regulation was enacted. To explore the additional bycatch reduction benefit that may be achieved by reducing the maximum TED bar spacing, the NOAA Southeast Fisheries Science Center (SEFSC) conducted a series of experiments to evaluate TEDs with bar spacing of 2-inches (5.1 cm). Two prototype TED designs, a 2-inch and a 2-inch staggered bar (SB) TED, were compared to identical TED designs with 4-inch bar spacing (controls) during paired trials conducted in the inshore shrimp fishery of the northern Gulf of Mexico. The results of the study show that the 2-inch and the 2-inch SB TED, reduce the targeted shrimp catch by a statistically significant amount, 8.8% and 4.5% respectively. Both experimental TED designs reduced the bycatch of croaker (Micropogonias undulates), the most abundant bycatch species. However, only the 2-inch TED showed a significant reduction (30.7%, p <0.001). The reduction rate of sharks with the 2-inch and 2-inch SB TED was 83.9% and 55.2% respectively, with significance being detected for the 2–inch TED. The observed reduction in rays was statistically significant for both experimental TED designs with a mean reduction of 82.5% and 65% for the 2-inch and 2-inch SB TED, respectively.

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INTRODUCTION

Background

Tropical shrimp trawl fisheries generate a higher proportion of discards than any other fishery in the world (Alverson et al. 1994). This non-targeted catch in fisheries is commonly referred to as bycatch. In the southeastern United States (SEUS), otter trawls have traditionally been the primary method of harvesting penaeid shrimp (family Penaeidae) in the Gulf of Mexico and southeast U.S. Atlantic, although skimmer trawls have become a common gear type in Louisiana, Mississippi, Alabama, and North Carolina. Skimmer trawls are used in shallow coastal waters throughout the southeastern U.S. as an alternative to traditional bottom otter trawls (Price & Gearhart, 2011).

An early estimate of discards to shrimp ratio for the Gulf of Mexico shrimp fishery was 10.3:1 (Alverson et al., 1994). However, a more recent estimate for the Gulf shrimp fishery is 2.5:1 (Scott-Denton et.al, 2012). This bycatch in the shrimp trawl fishery is primarily comprised of finfish, which includes commercially and recreationally important species such as red snapper. In addition, shrimp trawls capture protected species such as endangered or threatened sea turtles (Henwood and Stuntz, 1987; Epperly and Stokes, 2012).

To address the sea turtle mortalities associated with shrimp trawl fisheries, the National Marine Fisheries Service (NMFS) developed the Turtle Excluder Device (TED). TEDs are mechanical sorting devices that are placed in the trawl forward of the codend. They generally consist of a metal grid placed in the trawl at an angle. In the capture process, small animals such as shrimp and small fish pass between the bars of the grid and enter the trawl codend. Animals too large to pass between the bars are directed by the water flow and the grid angle to an escape opening strategically placed in the trawl (Watson and Seidel, 1980). TEDs are not only effective at excluding sea turtles, but also exclude other large animals (mega-fauna) such as large fish and elasmobranchs (Brewer et al., 1998; Willems et al., 2016). TEDs became compulsory in the southeastern US offshore otter trawl shrimp fishery in 1989 and the requirements were expanded in 1992 to include the inshore otter trawl fishery. Based on sea turtle stranding and capture data available at the time of development, the maximum bar spacing of TEDs was set at 4 inches (10.4 cm) to ensure optimal balance of shrimp retention and turtle exclusion.

Bycatch that is similar in size to the targeted shrimp, pass between the bars and are not excluded. Consequently, the reduction of this component of the bycatch requires means other than mechanical sorting. Engaas et al. (1999) reported that the most efficient bycatch reduction devices will need to exploit the differences in behavior between target and bycatch species to achieve catch separation. Bycatch reduction devices (BRDs) developed for use in the shrimp trawl fishery exploit these behavioral differences to reduce bycatch. In response to the mandates of the Magnuson-Stevens Fishery Conservation and Management Act, BRDs have been required in the SE US EEZ since 1997. Under the BRD certification criterion, BRDs must successfully demonstrate a minimum 30% reduction in total weight of finfish bycatch to be certified for use in the fishery. BRDs that achieve a 25% reduction can be provisionally certified for two years. The provisional certification serves as an opportunity for further industry development and testing of the prototype BRD (see 50 CFR 622.53).

There are currently five bycatch reduction devices fully certified for use in the Gulf of Mexico; the fisheye, the Jones-Davis, modified Jones-Davis, and two configurations of the composite panel BRD. One additional BRD design, the Extended Funnel, is allowed in the Atlantic. However, with a bycatch to shrimp ratio of 2.5:1, there is clearly a need to reduce bycatch even further.

In the current study, we examine the potential for improving the proportion of bycatch reduction that is being accomplished through mechanical sorting by reducing the spacing between the TED bars.

Objectives

The objectives of this study are to quantify the bycatch reduction shrimp retention achieved using two prototype reduced bar spacing (RBS) TEDs.

Experiment One - Catch comparison between 2-inch bar spacing TED vs. 4-inch bar spacing TED

- Quantify the differences in the **shrimp** catch rates between a top-opening TED with a 2-inch bar spacing (experimental) to an identical TED with 4-inch bar spacing (control).
- Quantify the differences in the **bycatch** catch rates between a top-opening TED with a 2-inch bar spacing (experimental) to an identical TED with 4-inch bar spacing (control).

Experiment Two - Catch comparison between 2-inch **staggered bar** (SB) TED vs. 4-inch bar spacing TED

- Quantify the differences in the **shrimp** catch rates between a top-opening TED with staggered bars spaced 2 inches apart (experimental) to a non-staggered bar TED with a 4-inch bar spacing (control).
- Quantify the differences in the **bycatch** catch rates between a top-opening TED with staggered bars spaced 2 inches apart (experimental) to a non-staggered bar TED with 4-inch bar spacing (control).

MATERIALS AND METHODS

Evaluations were conducted aboard the commercial shrimp trawler *F/V Fair Maiden,* a 63 foot (19.2 m), steel-hulled shrimp trawler. The boat is home ported in Ocean Springs, MS and operates in the inshore waters of Mississippi and Louisiana, including Mississippi Sound (inland of the barrier Islands), Breton Sound, Chandeleur Sound, and Lake Borgne, LA (Figure 3). The vessel is a twin trawler (one net on each side of the vessel) and tows “Mississippi-style” nets equipped with a bib. Each trawl had a 25 foot (7.62 m) headrope and a 32 foot (9.75 m) footrope. The trawls were spread by 6 foot (1.83 m) by 40 inch (101.6 cm) wooden trawl doors. Towing speeds averaged 2.2 knots and ranged from 1.75-2.5 knots.

In the study, the performance of a standard flat-bar TED with 4-inch bar spacing (control) was compared to two versions of flat-bar TEDs constructed with 2-inch bar spacing (experimental). The control and experimental TEDs constructed for the experiments were of the size typically used in this fishery, with overall dimensions of 40 inches (101.6 cm) high by 33 inches (83.8 cm) wide. The outer frames were made from 1.25 inch (31.7 mm), outside diameter aluminum pipe. The grid bars were constructed from 0.25 inch (6.35 mm) thick x 1.5 inch (38 mm) wide aluminum flat-bars attached to an outer frame of aluminum tubing. TEDs were bent-bar style with a bend placed in the bars (approximately 45^{o}), adjacent to the escape opening. The bent bar style is designed to allow weeds and other bycatch (including turtles) to slide out of the TED more effectively. Bent bars also help to prevent the TED from becoming clogged with debris.

In the initial trial, the design of the experimental 2-inch flat-bar grid TED was the same as the control TED, with the exception of bar spacing (Figure 1). In the second trial, a variation of the 2-inch bar TED was tested, where the TED was constructed with alternating bent and straight bars (Figures 2A and 2B). This staggered-bar configuration results in the straight bars being recessed by up to 3.2 inches (8.13cm) from the face of the bent bars.

Figure 1. Curved bottom flat-bar TED with 2-inch bar spacing. Bars made from 0.25-inch x 1.5 inch aluminum flat-bar.

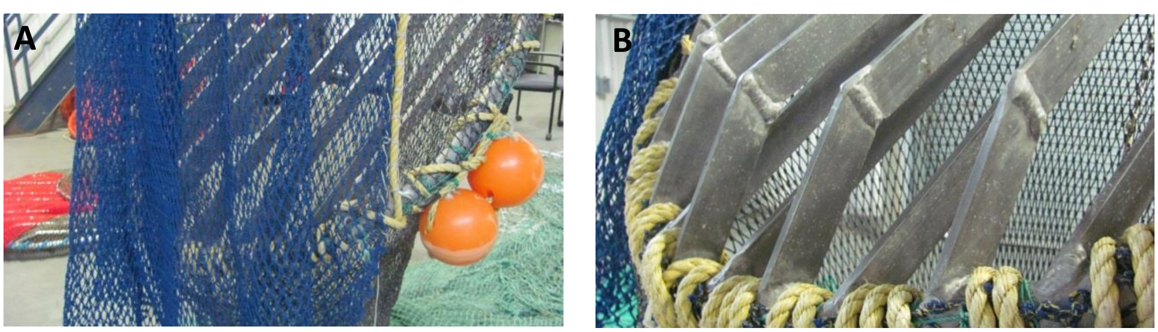

Figure 2. (A) Picture depicting a 2-inch staggered bar (SB) TED made from aluminum flat-bar. (B) Photo showing staggered grid bar configuration with flap pulled back for viewing bars.

TEDs were installed into extensions made from 1 5/8 inch (41.3 mm) Sapphire webbing, 140 meshes in circumference and 58 meshes in length. All TEDs had rib-lines made from ½ inch polypropylene rope which began at the grid and extended forward 42 inches (106.7 cm). The escape opening type were double-cover flaps which were made from heat-set and depth-stretched polyethylene webbing. The flaps were constructed from two pieces of 29 mesh x 55 mesh polypropylene webbing which had a 16 mesh overlap in the center and a 17 inch (43.2 cm) overhang beyond the posterior end of the grid. TEDs were installed in a top-opening orientation and were installed at 54 degrees from the horizontal. The 2-inch staggered bar (SB) TED was equipped with four 5 inch (12.7 cm) hard plastic floats to counteract the weight of the additional deflector bars. No floats were used on the 4-inch TED.

Prior to evaluations, TEDs were installed by Fisheries Methods and Equipment Specialists from the NMFS, SEFSC, Harvesting Systems Unit. All nets and TEDs were measured to ensure they were identical in all aspects except bar spacing. BRDs were not installed in either of the nets and were not required in any of the areas fished. All catch data were collected by fisheries biologists from the NMFS, SEFSC, Mississippi Laboratories. All efforts were made to emulate normal fishing practices, as the captain was given the flexibility to operate when and where desired. Paired tows were conducted with a control TED installed in one trawl and the experimental TED installed in the other. TEDs were switched between trawls at least one time during each trip to minimize the effects of potential side bias. Trip lengths ranged from two-nine days.

Tow duration was determined by the captain and based upon fishing conditions at the time. After each tow, observers inspected the gear for equipment and operational malfunctions related to the performance of the TED and net. Tows which had TED or net malfunctions were not sampled and therefore not included in the analyses. Net malfunctions included tows in which the net was severely damaged due to hitting a bottom obstruction, bogged nets, and fouled tickler chains. TED malfunctions were limited to cases where large obstructions, such as crab traps, occurred in the escape opening. Tow data included: tow location-beginning and end of tow, time at beginning and end of tow, water depth, and towing speed. When the trawls were hauled back the catch was shoveled into baskets to obtain a total catch weight for each net. A sub-sample of approximately 30 kilograms (approximately one basket) was collected from each net. If the total catch was less than one basket, the entire catch was sorted and sampled. For each tow, total weight for shrimp, sharks, and rays were recorded for the entire catch. Counts and weights for Atlantic croaker (*Micropogonias undulates*), trout (*Cynoscion* sp.), Spanish mackerel (*Scomberomorus maculatus*), and southern flounder (*Paralichthys lethostigma*) were collected from the subsample. The remainder of the subsample was separated into categories and weighed (e.g. other finfish, non-shrimp crustaceans, and non-crustacean invertebrates). All species were weighed on a Tri-coastal hanging scale (Model LP-C4) accurate to 0.01 kilograms. All sharks and rays were measured (to the nearest mm), weighed, and sexed. Twenty-five shrimp were measured once per day for both nets (carapace length).

Statistical Analysis

All catch rates are presented as kilograms/hour (CPUE) unless otherwise noted. Total catch, shrimp catch, and bycatch weights were compared using paired t-tests. Statistical significance was accepted at $P < 0.05$. The bycatch and shrimp reduction was computed by expressing the difference between the average CPUE (catch/hour) per tow of the control and experimental trawl (control minus experimental) as a percent of the average CPUE per tow of the control trawl. This is equivalent to subtracting the ratio of the two average CPUE values (experimental over control) from 1 and multiplying the difference by 100. The size distribution of shrimp and rays (where there were sufficient numbers) were compared using a two sample Kolmogov-Smirnov test.

RESULTS

Experiment 1: 2-Inch Flatbar TED vs. 4-Inch Flatbar TED

The evaluation of the 2-inch spacing flatbar TED was conducted in August, September, and October 2010 and March, April, and July 2011. A total of 65 comparative tows were completed in the inshore waters of Mississippi and Louisiana including the Mississippi Sound, Chandeleur Sound, and the marshes of Lake Borgne (Figure 3). Water depths ranged from 4.5-18.0 Ft. (1.4-5.5 m). The average tow time was 132.4 minutes and ranged from 58 minutes to 226 minutes.

The mean total catch for the control TED (CPUE) was 87.3 kg/h (Table 1). Finfish accounted for 87.1% of the catch and shrimp accounted for 12.3% by weight. Shark and ray bycatch represented less than one percent of the total catch. The most abundant bycatch species in the catch was Atlantic croaker which accounted for 46.9% of the total catch in the control TED. The experimental TED resulted in significant reductions in the finfish categories of total finfish (34.1%, $p<0.001$), Atlantic croaker (30.7%, $p<0.001$), southern flounder (53.7%, $P= 0.0048$), trout (31.6%, $p=0.0025$), and "other finfish" (38.9%, $p<0.001$).

A total of 80 sharks including Atlantic sharpnose (*Rhizoprionodon terraenovae)* (n=70), bonnethead (*Sphyrna tiburo)* (n=9) and finetooth shark (*Carcharhinus isodon*)(n=1) were captured during this study. Statistical analysis was not conducted on the finetooth shark due to small sample size. The experimental TED significantly reduced shark bycatch by 83.9% by weight and 77.9% by number which was significant ($p = 0.002$, $p<0.001$ respectively). The average size of the sharks caught in the control net was 45.7 cm total length (TL) (range 37.3-61.4 cm), as compared to 41.7 cm total length (TL) (range 37.9-44.4 cm) in the experimental net.

A total of 205 rays were caught during this evaluation. The following rays were caught: Atlantic stingray (*Dasyatis sabina)* (n=139), cownose ray (*Rhinoptera bonasus)* (n=46), and southern stingray (*Dasyatis americana)* (n= 20). By weight, ray bycatch was significantly reduced by 82.5% ($p<0.001$) with the experimental TED. By number, rays were significantly reduced by 56.5% ($p<0.001$). The mean individual ray weight for the control TED was 0.53 kg and was 0.25 kg for the experimental TED.

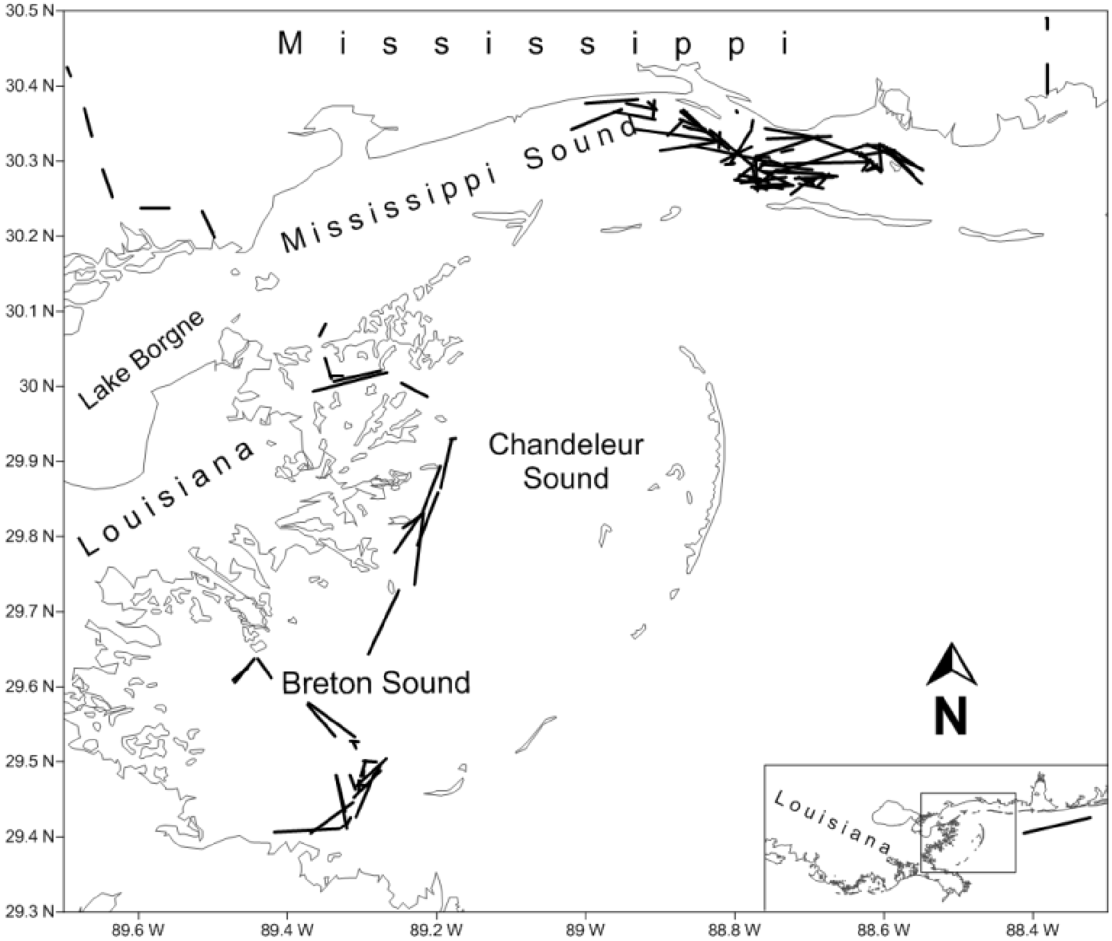

Figure 3. Location and Track Lines of RBS TED Tests 2010-2012.

During the evaluations, 1,310.0 kg of shrimp were caught with the control TED and 1,183.8 kg caught with the experimental TED. Catches were comprised of white, brown, and pink shrimp. White shrimp were the dominant shrimp species accounting for 62.2% (by weight) of the marketable shrimp catch in the control TED. Brown shrimp made up 36.6%, and pink shrimp were the least abundant making up 1.2% of the total marketable shrimp. Results of the study show that the experimental TED significantly reduced the total shrimp catch by 8.8%. A significant reduction by species was observed for white shrimp (8.6%) and pink shrimp (41.9%).

The size of shrimp (count per kilogram) caught with the control and experimental TEDs were 63.25/kg (28.75/lb) and 61.4/kg (27.9/lb) respectively for white shrimp and 110.4/kg (50.2/lb), 108.5/kg (49.3/lb) respectively for brown shrimp, and 54.8/kg (24.9/lb) and 51.4/kg (23.4/lb) for pink shrimp. Two sample Kolmogorov-Smirnoz tests failed to detect a significant difference in size distribution between control and experimental TEDs for any of the shrimp species ($p>0.677$).

Table 1. Catch comparisons for 4-inch bar spacing vs. 2-inch bar spacing for selected species (CPUE= kg/hour) conducted in MS and LA during 2010 and 2011. * Denotes significance p<0.05.

Common Name	Scientific Name	Control TED (4") CPUE kg/hour	Exp. TED (2") CPUE kg/hour	Reduction Rate	p-value
Total Catch		87.27	59.47	31.9%	<0.001*
Shrimp- (All species)	*Penaeus sp.*	9.26	8.44	8.9 %	0.0015*
• **White**	*Litopenaeus setiferus*	5.76	5.26	8.6%	0.0113*
• **Brown**	*Farfantapenaeus aztecus*	3.38	3.11	8.2%	0.0820
• **Pink**	*Farfantapenaeus duorarum*	0.12	0.07	41.9%	0.0173*
Total Finfish		76.05	50.15	34.1%	<0.001*
Croakers	*Micropogonias undulatus*	40.93	28.38	30.7%	<0.001*
Other Finfish	*Osteichththyes*	30.9	18.9	38.9%	<0.001*
Southern Flounder	*Paralichthys lethostigma*	0.09	0.04	53.7%	0.0048*
Trout	*Cynosion sp.*	4.0	2.74	31.6%	0.0025*
Spanish Mackerel	*Scomberomorus maculatus*	0.144	0.114	20.9%	0.1241
Sharks (All)		0.18	0.03	83.9%	<0.001*
• **Atlantic Sharpnose (n = 70)**	*Rhizoprinidon terraenovae*	0.15	0.03	80.5%	0.0013*
• **Bonnethead (n = 9)**	*Sphyra tiburo*	0.046	0.001	98.0%	0.0220*
Rays (All)		0.603	0.106	82.5%	<0.001*
• **Cownose Ray (n = 46)**	*Rhinoptera bonasus*	0.408	0.029	92.8%	<0.001*
• **Atlantic Stingray (n = 139)**	*Dasyatis sabina*	0.129	0.059	54.5%	0.0054*
• **Southern Stingray (n = 20)**	*Dasyatis americana*	0.014	0.011	26.4%	0.3747
Jellyfish	*Scyphozoa*	0.076	0.035	53.3%	0.0715
Other Invertebrates	*Lolliguncula, Squilla, Callinectes, Mellita,*	0.778	0.70	10.0%	0.2498

Experiment #2: 2-inch staggered bar TED vs. 4-inch TED
Evaluations of the 2-inch staggered bar TED were conducted in April, May, June, and October of 2012. A total of 60 comparative tows testing the 2-inch SB TED were completed. Tows were conducted in water depths from 6.0-16.1 feet (1.8-4.9 meters). The average tow time was 161 minutes (range = 45-268 min) Tows were conducted in the inshore waters of Mississippi and Louisiana including Mississippi Sound, Chandeleur Sound, and Breton Sound (Figure 3).

The mean catch weight (CPUE) with the control TED was 43.8 kg/h (Table 2). Finfish accounted for 73.8% of the total catch by weight and shrimp accounted for 23.2%. The most abundant bycatch taxa in the catch were "other finfish". The dominant species in this group included spot (*Leiostostomus xanthurus)*, gafftopsail catfish (*Bagre marinus),* hardhead catfish (*Arius felis)*, and cutlassfish (*Trichiurus lepturus). "*Other finfish" accounted for 56.6 % of the catch in the control TED. The analysis failed to detect a significant reduction for any taxa of teleost fishes.

The second most abundant bycatch species was Atlantic croaker which accounted for 15.5 % of the catch in the control net. There was a 4.0% reduction (p = 0.205) for croaker in the experimental TED, however, this was not significant. The mean length for Atlantic croakers was 142.1 mm in the control TED.

A total of 41 sharks were caught during the 2-inch SB TED testing, 29 in the control and 12 in the experimental TED. The shark species captured included: bonnethead (*Sphyrna tiburo)* (n=19)*,* Atlantic sharpnose (*Rhizoprionodon terraenovae)* (n= 20)*,* blacknose (*Carcharhinus acronotus)* (n=1, 40.3 cm TL) and the finetooth shark (*Carcharhinus isodon*) (n = 1, 66.3 cm TL). Statistical analysis was not conducted on blacknose shark and finetoothshark due to small sample size. The observed reduction in shark catch rate with the experimental TED was 59.8% by weight and 52.0% reduction by number which was marginally not significant (p=0.072, p=0.086 respectively). The average size of the sharks caught in the control net was 37.9 cm (TL), and the average size of the sharks caught in the experimental net was 38.7 cm (TL). Other mega-fauna captured in the control TED included a 99.5 cm (TL) redfish (*Sciaenops ocellatus)* and a 72.0 cm (TL) spotted gar (*Lepisosteus oculatus).* There were no additional mega-fauna captured in the experimental TED.

A total of 241 rays were caught in the control TED while 125 were caught in the experimental TED. The catch rate of rays with the experimental TED was significantly reduced 65% by weight, and 47.9% by number. The rays captured in the control TED included: Atlantic stingray (n=126), cownose ray (n=89), southern stingray (n=24), and smooth butterfly ray (*Gymnura micrura)* (n= 2). Statistical analysis was not conducted on smooth butterfly rays due to small sample size. The most common rays caught with the experimental TED were the Atlantic stingray (n=74), cownose ray (n=30), and southern stingray (n=21). Two-sample Komogorov-Smirinov tests of ray sizes was conducted for a sample of 341 rays that were measured. The tests detected a significant difference in the size distribution of the cownose rays between the two TED types, indicating smaller size distribution in the experimental TED (p<0.001). The analysis failed to detect a significant difference in size distribution for stingrays. However, the difference in size distribution of the Atlantic stingray was on the verge of significance (p = 0.053).

During this evaluation, 1520.6 kg of shrimp were caught in the control TED, while 1464.0 kg where caught in the experimental TED. The dominant shrimp species was brown shrimp which accounted for 57.1% of the total shrimp weight, white shrimp accounted for 42.9%, and pink shrimp accounted for less than .001% by weight. The experimental TED reduced the total shrimp weight by 4.5% and brown shrimp by 5.4%, with both point estimates being statistically significant. The size of shrimp (count per kg) for the control and experimental TED were 45.5/kg (20.7/lb) and 45.7/kg (20.8/lb) respectively for white shrimp and 118.6/kg (53.9/lb) and 115.3/kg (52.4/lb) for brown shrimp. Two-sample Kolmogrov-Smirnov tests failed to detect a significant difference in size distribution between control and experimental TEDs (p=0.147).

Table 2. Catch Comparisons for 4" Bar Spacing vs. 2" Staggered Bar Spacing for Selected Species. CPUE = kg/hour). * Denotes significance p<0.05.

Common Name	Scientific Name	Control TED (4") CPUE kg/hour	Exp. TED (2") CPUE kg/hour	Reduction Rate (by weight)	p- value
Total Catch		43.8	40.2	8.2%	0.0139
Shrimp- (All species)	*Penaeus sp.*	9.66	9.22	4.5%	0.0218*
• **White**	*Litopenaeus setiferus*	4.14	4.01	3.3%	0.2329
• **Brown**	*Farfantapenaeus aztecus*	5.51	5.21	5.4%	0.0063*
Total Finfish		32.4	30.1	7.0%	0.065
Croakers	*Micropogon undulatus*	6.8	6.53	4.0 %	0.2054
Other Fish	*Osteichththyes*	24.78	22.89	7.6%	0.0836
Southern Flounder	*Paralichthys lethostigma*	0.049	0.046	6.1 %	0.4193
Trout	*Cynosion sp.*	0.7319	0.6276	14.2 %	0.0636
Spanish Mackerel n = 37	*Scomberomorus maculatus*	0.0162	0.0269	- 66.1 %	0.4181
Sharks (All)		0.0529	0.0212	59.8%	0.0721
• **Atlantic Sharpnose n= 20**	*Rhizoprinidon terraenovae*	0.0180	0.0132	26.9%	0.4902
• **Bonnethead n= 19**	*Sphyra tiburo*	0.027	0.008	70.1%	0.0636
Rays (All sp.)		1.137	0.398	65.0 %	< 0.001*
• **Cownose Ray n = 119**	*Rhinoptera bonasus*	0.630	0.158	74.9 %	< 0.001*

• **Atlantic Stingray n = 200** • **Southern Stingray n = 45**	*Dasyatis sabina* *Dasyatis americana*	0.449 0.064	0.2008 0.032	55.2 % 49.6 %	0.0011* 0.1014
Other Invertebrates	*Callinectes, Loligungula, Squilla, Mellita, etc.*	0.2621	0.2506	0.4 %	0.3472

DISCUSSION

The purpose of this research was to determine if TEDs with reduced bar spacing increase bycatch exclusion of finfish and other mega-fauna such as sharks. To address this, a 2-inch TED, and a 2-inch staggered bar TED were tested in the inshore waters of MS and LA. While our study was limited to the inshore waters, the results are promising and warrant further examination in other areas.

Favorable bycatch exclusion rates observed in the first trial with the use of a 2-inch TED, and positive reports about shrimp retention from fishers in Australia prompted the evaluation of a 2-inch staggered bar TED in the second experiment. Shrimp retention rates appear to be higher with the use of the 2-inch staggered-bar TED, but bycatch exclusion rates were minimal when compared to the control, except for the exclusion rate of rays which was significant for three species encountered. Additionally, the exclusion rate for sharks was good for the staggered bar TED but was not statistically significant which may have been due to the low catch rates during the second experiment.

The bycatch reduction rates for the 2-inch TED were better than expected by researchers and by the vessel captain. The captain was very pleased with the results of the 2-inch bar spacing TED in that it showed a noticeable effect in the reduction of bycatch. Although the shrimp catch was reduced by 8.9% with the use of an experimental TED, the difference was minor according to the captain. Reduction of mega-fauna such as sharks and rays was expected but the reduction rates of small fish species such as croakers were surprising. The potential loss of large shrimp may be a primary concern with fishers. However, the results of our study indicated that there was no significant difference in the size of shrimp captured between the control and experimental TEDs.

While overall catch rates of sharks and rays were relatively low, research indicates that RBS TEDs are effective at excluding smaller sharks and thus have the potential to reduce the impact of shrimp trawling on shark populations. By number and weight, rays were reduced by approximately 83% and 57%, respectively with the use of the 2-inch TED. This indicates that the experimental TED was better at excluding larger rays. Likewise, standard TEDs with 4-inch bar spacing may exclude large sharks but smaller sharks have an increased possibility of passing through the bars and getting captured in the net.

The introduction of RBS TEDs can have an additional mitigation benefit for reducing sea turtle mortality in shrimp trawls. Recently, NMFS southeast shrimp fishery observers in the northern Gulf of Mexico have documented the capture of small turtles, primarily Kemp's ridleys (*Lepidochelys kempii*), that had passed between the TED deflector bars and into the tailbag of the net (NMFS, 2011). Additionally, small turtle captures have been documented by NMFS observers aboard skimmer trawl vessels operating in inshore waters of the northern Gulf of Mexico (Epperly and Stokes, 2012; Pulver, et al., 2014). While the skimmer trawl fishery is currently exempt from TED requirements, the estimated body depths of the turtles captured indicate that many of the turtles would have been capable of passing between the bars of a TED if 4-inch TED requirements had been in place. If TED requirements are implemented in the skimmer trawl fishery, consideration should be given to requiring a maximum bar spacing that is less than 4 inches (10.4 cm).

If TEDs with reduced bar spacing are mandated in shrimp fisheries, fishers will be concerned about the potential for shrimp loss. However, some shrimp loss may be acceptable to fishers depending on the quantities of bycatch in their operations. TEDs with reduced bar spacing (2-inch) are currently being used extensively in the shrimp fishery on the U.S. Atlantic coast for reduction of cannonball jellyfish. Presumably, vessel captains feel that the reduction in shrimp catch which may be associated with these TEDs is offset by the reduction of unwanted bycatch.

The BRDs that are currently used in the federal waters of the southeastern shrimp trawl fishery were developed as a joint effort between the fishing industry, universities, and state and federal agencies. Using a RBS TED in conjunction with another BRD will likely enhance bycatch reduction. BRDs certified for use in the southeast U.S. utilize fish behavior to achieve bycatch reduction and their effectiveness can be influenced by the level of illumination, i.e. daytime and nighttime fishing operations (Parsons et al. 2012). A mechanical sorting device such as a RBS TED may be equally effective at night as during the day. In order to optimize the bycatch reduction potential of TEDs, additional testing is needed to assess a range of bar spacing to find the most favorable bar spacing for various fishing conditions. It is likely that there is not a "one size fits all" solution, and the optimal bar spacing may vary depending on the catch composition, area, season, and TED configuration (i.e. style, size, flap type, and orientation).

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