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EVALUATIONS OF TURTLE EXCLUDER DEVICE (TED) PERFORMANCE IN U.S. SOUTHEAST ATLANTIC AND GULF OF MEXICO SKIMMER TRAWL FISHERIES

BY
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U. S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southeast Fisheries Science Center

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ABSTRACT

Skimmer trawls are utilized throughout the southeastern United States to target penaeid shrimp (Penaeidae). Skimmer trawls consist of nets attached to rigid frames on each side of the vessel that are pushed through the water column. Once the frames and nets are lowered into the water, only the cod ends are retrieved to remove the catch, while the mouths of the skimmer trawls continually fish. Because the cod ends can be readily retrieved, skimmer trawls are allowed to utilize restricted tow times (55 and 75 minute, seasonally) in lieu of TED requirements as a sea turtle bycatch mitigation measure. However, observations aboard commercial vessels indicate that tow times are often exceeded (Scott-Denton et al. 2006). Recently, a mass stranding event occurring in the late spring 2010 along the Mississippi Gulf Coast was attributed to skimmer trawl activity. To address this potential problem, the NMFS SEFSC Harvesting Systems Unit investigated the feasibility of TED use in these fisheries. Utilizing multiple commercial vessels, paired comparisons designed to examine target shrimp catch retention, bycatch reduction and gear usability associated with TED use were conducted. During testing, a TED was installed in one net, while the other was left naked (no TED installed) with the TED switched between nets daily to remove potential vessel side bias. Various TED configurations were tested in Mississippi, Alabama (2008 and 2009) and North Carolina (2010). Results from these studies indicate that TEDs can function effectively in commercial skimmer trawl operations with a relatively minimal reduction in target shrimp catch, which ranged from an increase of 1.3% to a reduction of 11%. In addition, unwanted bycatch (e.g., skates, teleost fish) was significantly reduced on most operations. Fishermen were surveyed and results indicate that fishermen highly favored the levels of bycatch reduction observed. In addition, there were no sea turtle interactions observed in skimmer trawls equipped with TEDs and three sea turtle captures were observed in control nets without TEDs. However, due to the small sample size these results were not statistically significant. Results of these studies and post interviews with the contracted fishermen indicate that TEDs are a viable management option for the reduction of sea turtle bycatch in skimmer trawls. While shrimp loss was observed, reductions associated with TED use were minimal. The SEFSC Harvesting Systems staff will continue to work with the industry to develop the most efficient TEDs for these trawl fisheries with the goal of reducing bycatch and minimizing shrimp losses to the greatest extent possible. Testing of several different TED configurations is slated for North Carolina and Louisiana during the 2011 shrimp season.

INTRODUCTION

Background

Skimmer trawls are used to target penaeid shrimp (Penaeidae) throughout the southeastern U.S. as an alternative to traditional bottom-otter trawls. Due to the size, construction, and method of fishing, skimmer trawls have the benefit of operating in relatively shallow water (Hein and Meier 1995). Nets are attached to frames on each side of the vessel, which are lowered and pushed through the water column (Figure 1). The trawls are fished continuously with tail bags retrieved periodically to dump the catch.

Unlike standard bottom-otter trawls used to target shrimp, skimmer trawls have remained exempt from turtle excluder device (TED) requirements since the implementation of TED regulations in the early 1990s. In lieu of the use of TEDs, skimmer trawl operations have been required to adhere to tow time limits (55 and 75 minute, seasonal; FR 2005). Because skimmer trawl operations allow tail bags to be easily retrieved, tow time limits are a seemingly workable solution that can significantly decrease sea turtle bycatch and potential mortality. However, observations aboard commercial operations indicate that tow times are often exceeded and thus an increased risk of sea turtle mortality continues to exist in this fishery (Scott-Denton et al. 2006).

In late spring 2010, a mass sea turtle stranding event occurred along the Mississippi coastline. Prior to the stranding event, the inshore commercial shrimp fishery in Mississippi sound was opened, which is prosecuted primarily with the use of skimmer trawls. This prompted a draft emergency rule to require TEDs in skimmer trawls for the southeast Atlantic and Gulf of Mexico. However, due to the Deepwater Horizon oil spill in the Gulf of Mexico in 2010 and the subsequent immediate closure of commercial fishing activities in the area, the rule was not enacted. Nevertheless, regulations requiring the use of TEDs in skimmer trawl operations throughout the southeastern U.S. are likely to be enacted.

Fishery Description

Commercial skimmer trawl operations occur in the inshore waters of Louisiana, Mississippi, Alabama, Florida and North Carolina. Vessels are rigged and operate in essentially the same manner in all of these areas and are exclusively used to target penaeid shrimp (Penaeidae). Hein and Meier (1995) provide a detailed description of vessel rigging and operation in Louisiana, which is similar to methods used in other areas. In general, skimmer trawl operations consist of two rigid “L” shaped frames attached to each side of the vessel forward of the midline with nets attached along the two sides of the frame. The frames are lowered into the water perpendicular to the gunwale of the vessel with the outer portion of the frame, which is affixed with a skid, resting on the sea floor. The lead line of the trawl is attached to the skid on the outer portion of the frame and a bullet weight along the inner portion, which spreads the net horizontally and vertically. A tickler chain shorter than the lead line is attached at the same locations as the lead line. The nets are pushed along and “lazylines” or “easy lines” are attached just ahead of the tail bags and are used to retrieve the catches, which are dumped on deck for culling while the mouth of the net continues to fish. Frames, bullet weights, and lazylines are all typically retrieved with winches.

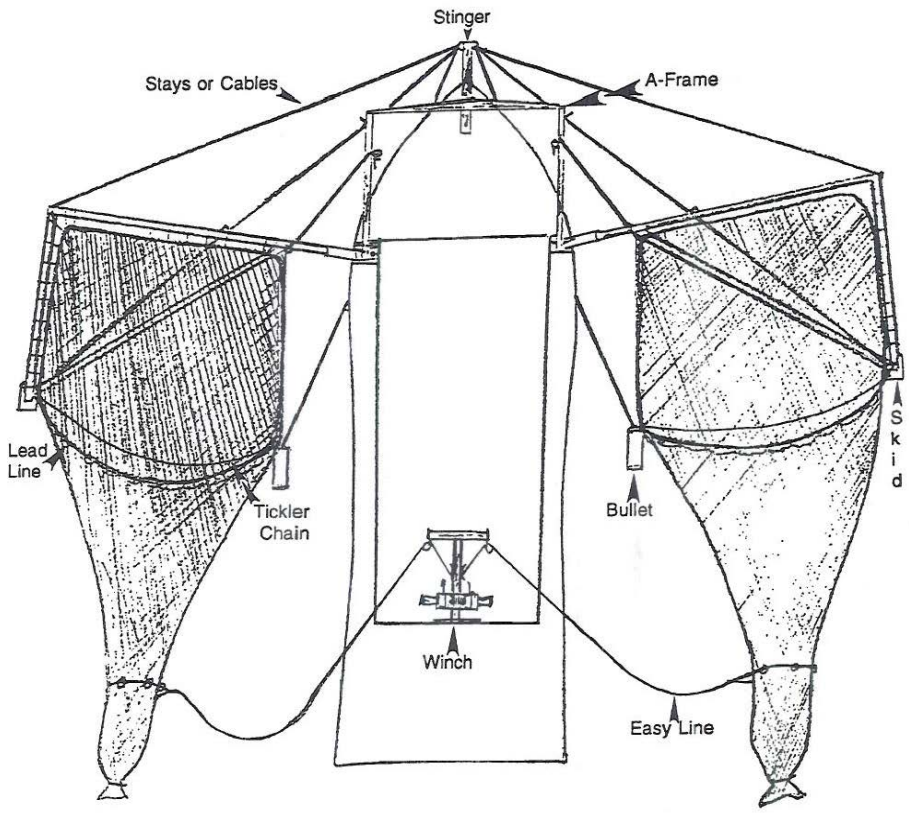

Figure 1. Diagram of typical skimmer trawl operation. Source: Hein and Meier 1995.

Vessel sizes vary by location, but are generally smaller than standard otter trawl vessels (25-45 ft) as skimmer trawls operate in shallower waters. However, vessels larger than 50 ft are not uncommon and are often rigged to fish in deeper water.

Skimmer trawls were initially developed in Louisiana in 1983 following experimentation by the commercial shrimp industry. This gear was developed in response to the industry noting that larger white shrimp were lost to the catch as they jumped over the cork line of standard otter trawls being operated in shallow water (Bourgeois 2003). Commercial skimmer trawls are used extensively throughout Louisiana state waters with more than 6,500 resident (per net) and 60 non-resident (per net) licenses sold in 2010 (Louisiana Department of Wildlife and Fisheries, http://www.wlf.louisiana.gov/licenses/statistics). Unlike other states (e.g., North Carolina), skimmer trawl fishermen also target brown shrimp in the shallow waters in Louisiana accounting for approximately 60% of all brown shrimp landings from 2000 – 2002 (Bourgeois 2003). Skimmer trawls may operate year around, barring closed areas (e.g., nursery areas) in Louisiana, but peak months for brown shrimp landings are May – August, while landings for white shrimp peak from August – December (LDWF 2000).

In North Carolina, skimmer trawls became prevalent in the early 1990s as technology was transferred from Louisiana fishermen (Hines et al., 1999). Skimmer vessels in North Carolina are typically 30' long and operate with crews of one or two fishermen. Skimmer trawls exclusively operate in shallow, inshore, estuarine waters of North Carolina. The majority of the fishing effort occurs during the summer/fall (June – October) when white shrimp (*Litopenaeus setiferus*) are most prevalent. Some fishermen also target brown shrimp (*Penaeus aztecus*) in the early summer months, but this is a relatively small fleet (< 50) of fishermen. During the 2009 fishing season, approximately 800 skimmer trawl trips were reported to the North Carolina Division of Marine Fisheries (NCDMF) trip ticket database. These trips landed more than 181,000 lbs of shrimp representing about 3% of the total commercial shrimp landings throughout the state in 2009.

In Mississippi, trawl licensing does not differentiate between trawl types (e.g., otter trawl, skimmer trawl). Therefore a precise indicator of skimmer trawl effort cannot be obtained. However, under the Hurricane Katrina Emergency Disaster Recovery Program (EDRP – NOAA funded), 53 resident commercial shrimp trawl license holders identified themselves as skimmer trawl fishermen as recently as 2008.

Similar to Mississippi, licensing in Alabama and Florida state waters do not differentiate between trawl types. As a result, there is no accurate information currently available on the size of the skimmer trawl fleet, extent of operations or landings for these states. However, Florida state regulations currently require the use of TEDs in skimmer trawls operating in state waters, which exclusively occurs in the panhandle region.

Objectives

The objectives of this study are:

To quantify the difference in shrimp catch associated with TED use in skimmer trawls.

To quantify reductions in bycatch associated with TED use in skimmer trawls.

To identify handling problems or specialized handling techniques required when utilizing TEDs in skimmer trawls.

METHODS

The Harvesting Systems Unit conducted TED testing in skimmer trawls during the 2008, 2009 and 2010 fishing seasons. Commercial skimmer trawl vessels in Alabama, Mississippi (2008 and 2009), and North Carolina (2010) were contracted to conduct comparative TED and usability testing on traditional fishing grounds in these areas. All vessels were twin rigged, which facilitated paired testing with a TED installed in one trawl while the other net was left naked (no TED installed). To minimize potential sea turtle mortality, tows were limited to a 55 minute maximum for all testing. Prior to TED testing, several tows were conducted to assess potential side bias and to conduct any necessary gear tuning. To reduce side bias, TEDs were switched between trawls on a daily basis. Four TED configurations were tested (Table 1).

Ten vessels were contracted for TED testing with five different TED configurations tested from 2008 through 2010 (Table 1). All TEDs were "Super Shooter" style grids constructed of 5/8 inch aluminum rod. Two different sizes were tested, nine mid-size (41" x 31") grids and one large (51" x 41") grid. All TEDs were installed at 55° in 1 ½ inch stretched mesh polypropylene extensions 60 meshes long in either a top or bottom-opening configuration. Mid-sized grids were installed in extensions that were 140 meshes in circumference, while large grids were installed in 160 mesh extensions. Openings were either double cover, offshore, leatherback openings or single cover, inshore, 44 inch openings. Opening cuts for both the double cover and 44 inch openings measured 56 inches by 20 inches and began within 4 inches of the outer edge of the grid. All TED flaps were constructed of 1 5/8 inch, #30 polypropylene, heat-set, depth-stretched, webbing. Double cover flaps consisted of two flaps 30 meshes long by 60 meshes wide sewn 2:1 along the leading edge of the opening cut plus three additional meshes on each side of the opening. Double cover flaps overlapped by 10 meshes in the center of the opening, which measured 15 inches stretched. The flaps were sewn to the extension along their entire length, which terminated 16 inches beyond the posterior edge of the grid. The single flap installed for the 44 inch opening was sewn across the leading edge of the opening cut plus three meshes on either side of the opening. The flap was sewn to the extension along each side to a point that was 6 inches beyond the posterior edge of the grid. Beyond this point, an additional ten inches of flap was left unattached. A length of ½ inch polypropylene rope was woven around the entire frame to prevent chaffing. A single "Spongex" float measuring 8 inches by 6 inches was attached to the top center of each bottom opening TED.

NMFS Harvesting Systems staff and/or Southeast Fishery Science Center trawl observers (NMFS-SEFSC, Galveston) manned and recorded data on all trips recording start and finish locations, depth and speed of each successful tow. Successful tows were all tows where the gear worked properly and the trawl was hauled in perfect condition. For each tow, observers recorded the total catch and total shrimp weight for both the port and starboard nets. Sample baskets were selected from each trawl and were examined for species composition and weights. Weights and counts of all marketable shrimp from the sample basket were recorded. The remainder of the sub-sample was separated and weighed by species group: finfish, non-shrimp crustaceans, invertebrates other than crustaceans, and debris. Other select species (e.g., skates, rays, sharks) were also separated, counted and weighed. Total catch and samples were weighed to the nearest 0.02 kg with TCI Model LPC-4 hanging scales. Total weights for each species group for each tow were estimated using the following formula:

$$SpeciesGroupEstimatedTotalWeight = (GroupSampleWeight/SampleWeight)*TotalWeight$$

Total catch, shrimp catch, and bycatch weights were compared using paired t tests. Significant differences were accepted at an alpha of 0.05. Power analyses were also conducted for each test, which measures the probability that a statistical test will reject the null hypothesis when the null hypothesis is false (i.e. that it will not make a Type II error or a false negative decision). As power increases, the chances of a Type II error occurring for a given test decreases. The probability of a Type II error occurring is referred to as the false negative rate (β). Therefore power is equal to $1 - \beta$, which is also known as the sensitivity of a given test.

In addition, reduction rates and ratio based 95% confidence intervals were calculated for each catch category and species group. Catch reduction rates by weight and were calculated as:

$$\%CatchDifference = ((Control - Experimental/Control)*100)* - 1$$

Table 1. TED configurations tested during the 2008, 2009, and 2010 fishing seasons in the commercial skimmer trawl fishery. All grids were "Super Shooter" style and inshore single flap openings stretched to 44 inches.

Year	Area	TED size	# of Vessels	TED Orientation	TED Opening
2008	**AL, MS**	Large (50" grid)	1	Top Opening	Double Cover
		Mid-size (40"grid)	1	Top Opening	Double Cover
2009	**AL, MS**	Mid-size (40"grid)	2	Top Opening	Double Cover
2010	**NC**	Mid-size (40"grid)	2	Top Opening	Double Cover
			2	Bottom Opening	Double Cover
			1	Top Opening	Inshore Single Flap
			1	Bottom Opening	Inshore Single Flap

RESULTS

2008

A total of 52 successful comparative tows were conducted aboard two separate vessels (Figure 2) in Mississippi and Alabama waters. One vessel, the *F/V Vanna Lavie*, was equipped with a large 50 inch grid TED, while the other, *F/V My Joy* was equipped with a mid-sized 40 inch grid TED. Both TED configurations were top-opening with double cover escape openings. Tow speed averaged 3.2 kts for the *Vanna Lavie*, while the *My Joy* averaged 2.0 kts. Total catch was significantly reduced with means ranging from a 14% to 51% reduction on both the *Vanna Lavie* and *My Joy* (Table 2). Bycatch (all species groups combined) was reduced significantly by more than 55% on the *My Joy*, and by nearly 16% on the *Vanna Lavie*. Shrimp reductions were significant on the *Vanna Lavie* and also significant on the *My Joy* with mean shrimp losses ranging from 4% to 8%, respectively (Table 2).

Species groups analyzed for skimmer TED testing in 2008, 2009, and 2010 included crustaceans, invertebrates, teleost fish, and rays. In the 2008 study, significant reductions were observed on both vessels for the categories of teleost fish, and rays (Table 3). Crustaceans and invertebrate reductions were not found to be significantly reduced on either vessel (Table 3).

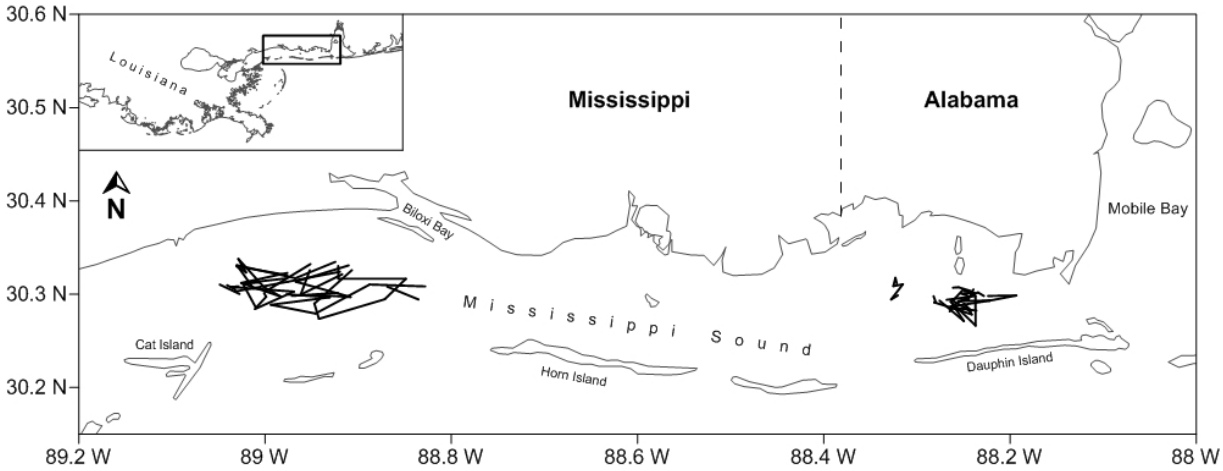

Figure 2. Locations of skimmer trawl TED testing tows conducted during the 2008 fishing season along the Mississippi and Alabama coast.

Table 2. Summary statistics, results of paired t tests, power analyses, percent differences and corresponding 95% confidence intervals for total catch (bycatch + shrimp catch), bycatch, and shrimp catch (kgs) by vessel for 2008 skimmer trawl TED testing conducted in MS and AL.

	TED	Species	Control Net			Exp Net (TED)			Reduction (wt.)				
Vessel	Type	Group	N	Mean	SD	N	Mean	SD	L 95% CI	% Diff	U 95% CI	p-value	Power
Vanna Lavie	Top Opening Double Cover	Total Catch	31	194.02	59.93	31	166.04	57.22	8.22	14.42	20.63	< 0.0001	0.998
		Bycatch	31	174.94	57.89	31	147.82	55.81	8.65	15.50	22.36	< 0.0001	0.997
		Shrimp	32	19.14	8.34	32	18.33	7.49	- 0.11	4.24	8.59	0.0200	0.652
My Joy	Top Opening Double Cover	Total Catch	28	87.20	41.42	28	42.76	17.15	35.30	50.96	66.61	< 0.0001	> 0.999
		Bycatch	28	79.56	41.92	28	35.76	17.49	37.49	55.05	72.61	< 0.0001	> 0.999
		Shrimp	30	7.81	2.13	30	7.15	2.07	4.29	8.37	12.45	0.0001	0.992

Table 3. Summary statistics, results of paired t tests, power analyses, percent differences and corresponding 95% confidence intervals for groups (crustaceans, invertebrates, teleost fish, and rays) (kgs) by vessel for 2008 skimmer trawl TED testing conducted in MS and AL.

	TED	Species	Control Net			Exp. Net (TED)			Reduction (Wt.)				
Vessel	Type	Group	N	Mean	SD	N	Mean	SD	L 95% CI	% Diff.	U 95% CI	p-value	Power
Vanna Lavie	Top Opening Double Cover	Crustac	4	0.08	0.12	4	0.14	0.17	-919.26	- 80.65	757.97	0.339	0.100
		Inverte	31	1.09	1.25	31	1.26	1.27	- 64.90	- 15.70	33.50	0.241	0.171
		Teleost fish	31	130.83	43.35	31	118.26	52.82	1.46	9.61	17.76	0.017	0.697
		Rays		27.68	35.31		5.34	3.97	17.25	80.70	144.15	0.008	0.819
My Joy	Top Opening Double Cover	Crustac	28	0.56	1.64	28	0.19	0.17	- 49.35	65.26	179.88	0.129	0.301
		Inverte	28	0.36	0.54	28	0.23	0.20	- 21.10	36.30	93.69	0.109	0.339
		Teleost fish	28	49.80	23.35	28	26.33	13.06	32.18	47.13	62.07	< 0.0001	> 0.999
		Rays	27	22.45	27.02	27	3.56	7.90	38.02	84.13	130.25	< 0.0001	0.996

2009

Two vessels conducted 72 successful comparative tows during 2009 skimmer trawl TED testing in Mississippi and Alabama waters (Figure 3). Both TED configurations were top-opening, mid-sized, 40 inch grid TEDs with double cover escape openings. Tow speed averaged 2.1 kts for the *F/V Easy Money*, while the *F/V Sky Baby* averaged 2.3 kts. Total catch was significantly reduced by nearly 19% on the *Easy Money*, while reductions of approximately 3% observed on the *Sky Baby* were not statistically significant (Table 4). Bycatch (all species groups combined) was reduced significantly by over 25% on the *Easy Money*, while only reduced non-significantly by 3% on the *Sky Baby* (Table 4). Shrimp reductions were non-significant with means ranging from less than 1% to 3% on both vessels (Table 4).

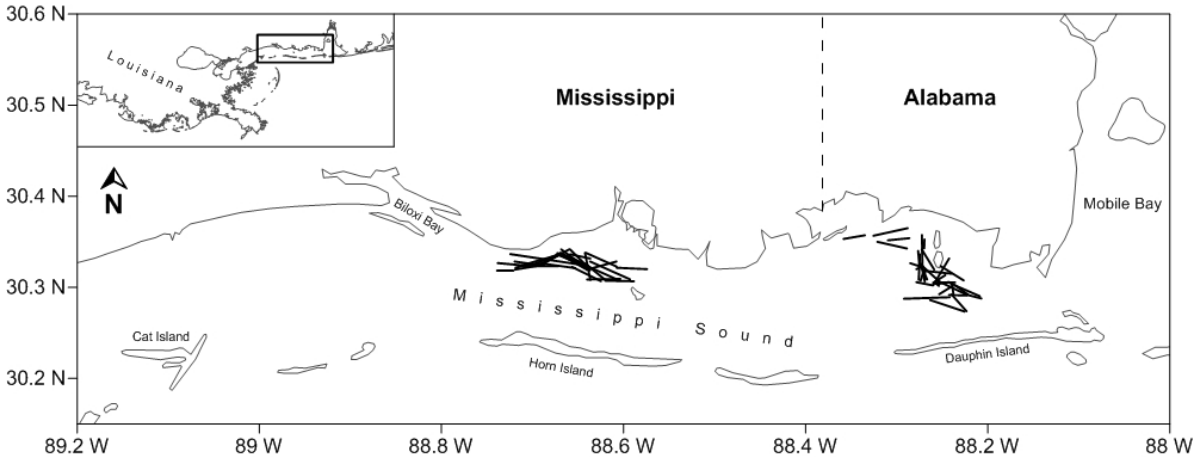

Figure 3. Locations of skimmer trawl TED testing tows conducted during the 2009 fishing season along the Mississippi and Alabama coast.

Table 4. Summary statistics, results of paired t tests, power analyses, percent differences and corresponding 95% confidence intervals for total catch (bycatch + shrimp catch), bycatch, and shrimp catch (kgs) by vessel for 2009 skimmer trawl TED testing conducted in MS and AL.

	TED	Species	Control Net			Exp. Net (TED)			Reduction (wt.)				
Vessel	Type	Group	N	Mean	SD	N	Mean	SD	L 95% CI	% Diff	U 95% CI	p-value	Power
Easy Money	Top Opening Double Cover	Total Catch	36	17.88	11.15	36	14.52	9.17	8.94	18.78	28.62	< 0.001	0.997
		Bycatch	36	12.91	9.64	36	9.60	7.27	11.97	25.68	39.39	< 0.001	0.998
		Shrimp	36	4.97	3.38	36	4.93	3.61	- 6.48	0.87	8.22	0.407	0.079
Sky Baby	Top Opening Double Cover	Total Catch	39	26.22	10.91	39	25.47	10.58	- 2.26	2.85	7.96	0.134	0.294
		Bycatch	39	20.93	10.93	39	20.35	10.37	- 3.38	2.80	8.97	0.183	0.228
		Shrimp	39	5.29	3.61	39	5.12	3.54	- 2.85	3.08	9.02	0.150	0.270

Species group reductions were not found to be significant barring the teleost fish group on the *Easy Money* (Table 5). Teleost fish were significantly reduced by a mean of 32% on the *Easy Money*. Crustaceans were reduced on the *Easy Money* by nearly 21%, but this reduction was not significant. Invertebrates were reduced by 1% on the *Easy Money*, but this was also not

significant. No significant reductions in species groups were observed on the *Sky Baby* during 2009 skimmer TED testing (Table 5). However, invertebrate catch increased slightly in the trawl equipped with the TED, but the difference (1%) was not significant (Table 5).

Table 5. Summary statistics, results of paired t tests, power analyses, percent differences and corresponding 95% confidence intervals for groups (crustaceans, invertebrates, teleost fish, and rays) (kgs) by vessel for 2009 skimmer trawl TED testing conducted in MS and AL.

	TED	Species	Control Net			Exp. Net (TED)			Reduction (Wt.)				
Vessel	TYPE	Group	N	Mean	SD	N	Mean	SD	L 95% CI	% Diff.	U 95% CI	p-value	Power
Easy Money	Top Opening Double Cover	Crustac	35	0.07	0.08	35	0.06	0.07	- 15.97	20.84	57.64	0.143	0.279
		Inverte	35	2.72	2.58	35	2.69	2.98	- 15.76	1.25	18.25	0.442	0.067
		Teleost fish	35	10.00	8.35	35	6.78	5.32	14.49	32.18	49.87	< 0.001	0.999
		Rays	.	.	.	.	.	.	.	.	.	.	.
Sky Baby	Top Opening Double Cover	Crustac	38	0.07	0.06	38	0.06	0.06	- 8.96	18.70	46.36	0.108	0.304
		Inverte	38	1.96	3.18	38	1.99	3.18	- 19.74	- 1.13	17.49	0.064	0.451
		Teleost fish	39	18.26	9.52	39	17.72	8.81	- 3.11	2.92	8.94	0.166	0.249
		Rays	25	0.75	0.95	25	0.95	2.11	-194.92	- 26.59	141.74	0.348	0.124

2010

Six contracted skimmer trawl vessels from three separate areas of North Carolina estuaries were contracted to conduct comparative TED testing. Four different TED configurations were tested during this portion of the study; top-opening double cover, bottom-opening double cover, top-opening inshore single flap and bottom-opening inshore single flap (Table 1). All inshore single flap openings stretched to 44 inches and all grids were "Super Shooter" style TEDs. A total of 56 trips and 341 successful tows were completed with four vessels conducting 10 trips each, while two vessels conducted eight trips each (Table 6 and Figure 4). Tow speed averaged 2.2 kts for all six vessels ranging from 0.8 kts to 2.8 kts throughout all tows.

Table 6. The total number of trips and tows by vessel for 2010 NC skimmer trawl TED testing.

Vessel	Trips (n)	Tows (n)
Miss April	10	64
Emerald Lady	8	42
Capt. Jack	10	52
Knotsamuch	10	60
Mad Lady II	8	59
Unnamed	10	64
Totals	56	341

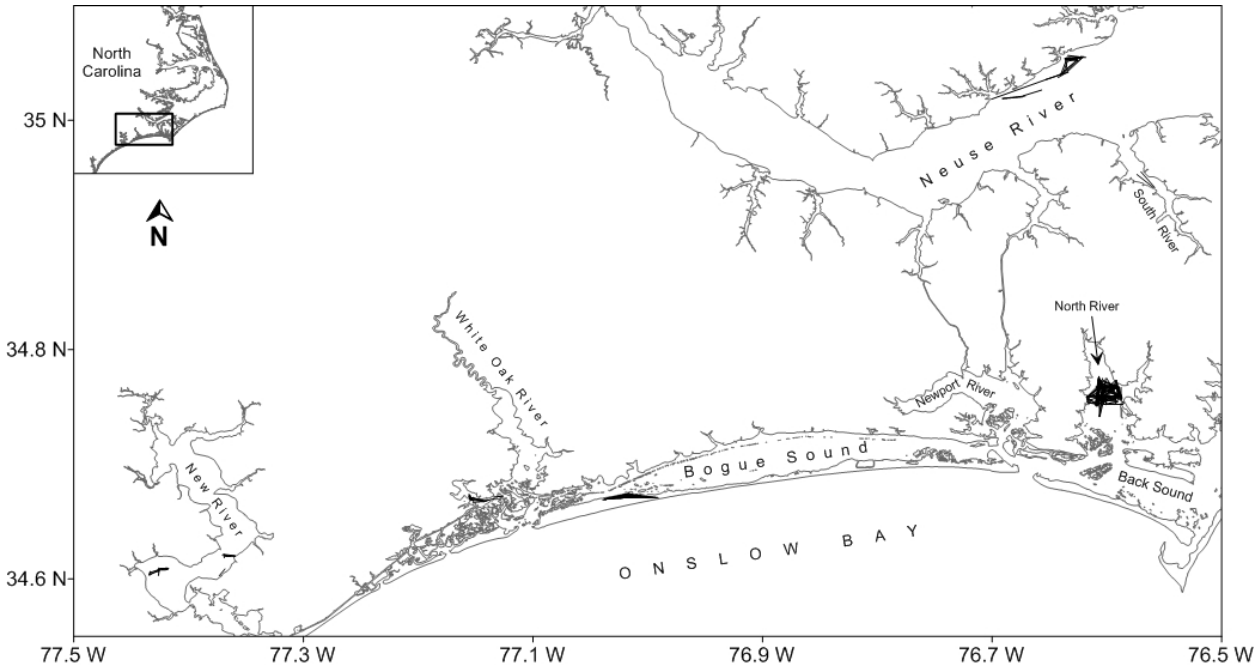

Figure 4. Locations of skimmer trawl TED testing tows conducted during the 2010 fishing season along the North Carolina coast.

All six vessels in the 2010 skimmer TED testing in NC showed significant reductions in the total catch, and bycatch groups (Table 7). Reductions in total catch for TED equipped nets ranged from a mean of 18% on the *F/V Miss April* to more than 32% on the unnamed vessel (Table 7). Bycatch reductions ranged from 23% on the *F/V Knotsamuch* to 43% on the *F/V Emerald Lady* (Table 7). Statistically significant shrimp reductions were observed for TED equipped trawls on the unnamed vessel and the *F/V Captain Jack*. Shrimp reductions ranged from a mean of 9% to 11% on these two vessels. Shrimp loss was less on the other four vessels ranging from an increase of 1% on the *Miss April* to a 7% shrimp loss on the *F/V Mad Lady II*, but these reductions were not significant (Table 7).

Significant reductions in teleost fish and rays were generally observed on all six vessels in the 2010 NC skimmer TED testing (Table 8). Teleost fish reductions with the use of TEDs ranged from a mean of 10% on the *Mad Lady II* to more than 27% on the unnamed vessel (Table 8). Significant reduction in rays by weight ranged from a mean of 55% on the *Captain Jack* to 98% on the *Emerald Lady* (Table 8). Reductions in rays approached significance on both the unnamed vessel ($p = 0.056$), and the *Knotsamuch* ($p = 0.069$). Crustacean and invertebrate reductions were more variable on the six vessels in the 2010 study relative to teleost fish and ray groups, but either one or both were found to be significantly reduced on the unnamed vessel, the *Captain Jack*, and the *Miss April* (Table 8).

Table 7. Summary statistics, results of paired t tests, power analyses, percent differences and corresponding 95% confidence intervals for total catch (bycatch + shrimp catch), bycatch, and shrimp catch (kgs) by vessel for 2010 skimmer trawl TED testing conducted in NC.

	TED	Species	Control Net			Exp. Net (TED)			Reduction (wt.)				
Vessel	Type	Group	N	Mean	SD	N	Mean	SD	L 95% CI	% Diff	U 95% CI	p-value	Power
Unnamed	Top Opening Dble Cover	Total Catch	64	32.43	24.25	64	21.99	10.81	14.28	32.19	50.10	<0.001	0.968
		Bycatch	64	25.36	23.25	64	15.68	9.60	15.92	38.16	60.40	<0.001	0.955
		Shrimp	64	7.07	4.07	64	6.31	4.33	4.81	10.75	16.68	<0.001	0.958
Capt. Jack	Btm Opening Dble Cover	Total Catch	52	13.55	7.14	52	10.93	5.27	9.21	19.34	29.46	<0.001	0.987
		Bycatch	52	6.95	3.81	52	4.91	2.94	15.53	29.39	43.25	<0.001	0.990
		Shrimp	52	6.60	5.53	52	6.03	4.35	- 0.51	8.76	18.04	0.021	0.658
Mad Lady II	Top Opening Single Flap	Total Catch	60	21.44	14.95	60	17.09	9.51	6.38	20.25	34.13	0.002	0.903
		Bycatch	60	13.25	14.02	60	9.44	7.35	6.58	28.74	50.90	0.004	0.852
		Shrimp	60	8.33	5.01	60	7.78	4.85	- 2.34	6.52	15.39	0.418	0.077
Knotsamuch	Btm Opening Dble Cover	Total Catch	61	17.40	11.27	61	14.12	10.31	9.79	18.82	27.85	<0.001	0.994
		Bycatch	60	12.92	10.58	60	9.89	9.32	11.44	23.48	35.51	<0.001	0.991
		Shrimp	60	4.57	3.77	60	4.42	3.96	- 3.90	3.19	10.28	0.192	0.218
Miss April	Btm Opening Single Flap	Total Catch	64	20.75	11.42	64	17.01	9.06	7.56	18.00	28.45	<0.001	0.956
		Bycatch	64	12.81	10.82	64	8.98	7.01	13.00	29.96	46.91	<0.001	0.973
		Shrimp	64	7.93	6.02	64	8.04	6.29	- 6.10	- 1.30	3.49	0.291	0.136
Emerald Lady	Top Opening Dble Cover	Total Catch	45	13.04	7.69	45	8.86	4.42	17.90	32.05	46.21	<0.001	>0.999
		Bycatch	45	9.63	5.95	45	5.46	2.54	25.86	43.33	60.79	<0.001	>0.999
		Shrimp	42	3.66	3.32	42	3.65	3.20	- 5.49	0.22	5.94	0.469	0.058

Table 8. Summary statistics, results of paired t tests, power analyses, percent differences and corresponding 95% confidence intervals for groups (crustaceans, invertebrates, teleost fish, and rays) (kgs) by vessel for 2010 skimmer trawl TED testing conducted in NC.

	TED	Species	Control Net			Exp. Net (TED)			Reduction (Wt.)				
Vessel	Type	Group	N	Mean	SD	N	Mean	SD	L 95% CI	% Diff.	U 95% CI	p-value	Power
Unnamed	Top Opening Dble Cover	Crustac	64	0.99	0.58	64	0.84	0.70	- 0.32	15.64	31.61	0.041	0.543
		Inverte	36	0.88	1.38	36	0.67	1.17	- 0.67	23.44	47.56	0.009	0.791
		Teleost fish	64	19.49	11.66	64	14.13	9.37	15.01	27.50	40.00	<0.001	0.994
		Rays	33	8.03	27.09	33	0.31	0.75	- 23.49	96.11	215.71	0.056	0.481
Capt. Jack	Btm Opening Dble Cover	Crustac	51	0.52	0.42	51	0.37	0.25	4.73	28.60	52.48	0.014	0.727
		Inverte	43	0.74	1.63	43	0.54	1.13	- 23.46	27.49	78.44	0.135	0.293
		Teleost fish	52	4.69	2.69	52	3.52	2.01	12.19	25.02	37.85	< 0.001	0.984
		Rays	36	1.18	1.74	36	0.53	0.97	2.10	55.00	107.91	0.036	0.570
Mad Lady II	Top Opening Single Flap	Crustac	60	0.78	0.56	60	0.73	0.49	- 12.74	6.06	24.85	0.265	0.155
		Inverte	37	0.11	0.18	37	0.10	0.18	- 67.17	8.81	84.79	0.412	0.078
		Teleost fish	60	8.77	8.21	60	7.88	6.92	- 1.90	10.10	22.10	0.044	0.500
		Rays	43	4.03	10.71	43	0.84	1.06	- 2.64	79.17	160.98	0.030	0.600
Knotsamuch	Btm Opening Dble Cover	Crustac	59	0.61	0.53	59	0.65	0.68	- 35.82	- 5.75	24.31	0.346	0.106
		Inverte		0.39	0.51		0.30	0.32	- 24.53	23.71	71.94	0.177	0.235
		Teleost fish	61	9.90	8.73	61	8.12	7.95	7.38	17.98	28.58	<0.001	0.971
		Rays	41	1.64	2.26	41	0.99	1.45	- 7.73	39.75	87.24	0.069	0.439
Miss April	Btm Opening Single Flap	Crustac	62	0.66	0.64	62	0.50	0.46	5.39	24.64	43.89	0.007	0.809
		Inverte	22	0.08	0.24	22	0.09	0.23	-110.66	- 23.21	64.24	0.262	0.154
		Teleost fish	64	9.22	7.75	64	7.63	5.93	5.37	17.28	29.18	0.001	0.923
		Rays	41	2.82	6.30	41	0.90	1.46	- 3.29	68.27	139.84	0.037	0.565
Emerald Lady	Top Opening Dble Cover	Crustac	28	0.04	0.05	28	0.02	0.06	- 45.11	33.66	112.44	0.241	0.171
		Inverte	.	.	.	.	.	.	.	.	.	.	.
		Teleost fish	45	6.04	3.23	45	5.36	2.48	- 0.74	11.17	23.07	0.034	0.580
		Rays	29	5.50	5.15	29	0.11	0.41	62.38	98.04	133.70	< 0.001	> 0.999

Sea Turtle Bycatch

There were no observed sea turtle interactions in the 2008 or 2009 TED testing conducted in MS or AL. However, three sea turtle captures were observed during the 2010 testing in NC (Table 9). All turtles were Kemp's ridley sea turtles observed in control (No TED) nets (Table 9). All three turtles were measured tagged and released alive.

Table 9. Date, location, species, condition, final disposition and straight carapace length (SCL cm) for sea turtle interactions observed during the 2010 NC skimmer trawl TED testing.

Date	Capture Location	Species	Capture Condition	Final Disposition	SCL (cm)
21-Sep-10	34° 45' 49" 76° 35' 23"	Kemp's	Alive	Alive, released	31
15-Sep-10	34° 45' 40" 76° 35' 29"	Kemp's	Unresponsive	Alive, released	28.5
14-Sep-10	34° 45' 18" 76° 36' 57"	Kemp's	Alive	Alive, released	24

Combined Reductions

Combining data from the 2008, 2009 and 2010 skimmer trawl TED testing, a mean of 5% shrimp loss was calculated (Table 10). Total catch (bycatch + shrimp) was reduced by 23%, and bycatch was reduced by greater than 27% (Table 10). Shrimp loss associated with TED use ranged from 3% to 7%, total catch reductions ranged from 18% to 29%, while bycatch reductions ranged from 20% to 34% (Table 10).

Table 10. Combined total catch, bycatch and shrimp catch from the 2008, 2009 and 2010 skimmer trawl TED testing showing mean reductions for each total catch (bycatch + shrimp catch), bycatch and shrimp catch.

Species Group	Control Net			Exp. Net (TED)			Reduction (wt.)		
	N	Mean	SD	N	Mean	SD	L 95% CI	% Diff	U 95% CI
Total Catch	496	38.47	54.48	496	29.53	46.21	17.58	23.24	28.91
Bycatch	515	30.67	50.08	515	22.31	41.75	20.27	27.24	34.21
Shrimp	494	7.54	6.40	494	7.17	6.20	2.89	4.97	7.05

DISCUSSION

Skimmer trawl TED testing in 2008, 2009 and 2010 was successful in assessing the feasibility of TED use in skimmer operations, estimating shrimp and bycatch reductions, and identifying baseline TED configurations that could be functionally efficient depending on location. Follow up interviews were conducted with the skimmer trawl captains and crews that were contracted to conduct the research. These interviews were used to incorporate industry expertise on TED design, function, performance, and to offer insights into practical use and application in the commercial skimmer trawl fishery. In the 2010 NC study, contracted fishermen rated the overall performance of the TED from 5 to 9 (on a scale of 1 to 10 with 10 being excellent). Generally, fishermen approved of the TED stating that bycatch was reduced and there was minimal observed shrimp loss. One fisherman also pointed out that an additional benefit of the TED was the potential elimination of sea turtle captures.

A few of fishermen in the NC study operating the *Mad Lady II*, and *Emerald Lady* experienced initial complications with top-opening TEDs rolling during deployment and retrieval and also during the frequent turns that the skimmer operations made. Harvesting staff have documented the tendency of top-opening TEDs to twist a half turn when the TED breaks the surface of the water during deployment and retrieval. However, bottom-opening TEDs do not exhibit this twisting behavior. During sharp turns, skimmer trawl operations require that one frame (on one side of vessel, Figure 1) be lifted, which causes the TED to come to the surface. One fisherman overcame this by attaching an extra line from the back side of the frame towards the head of the net. This line did not put tension on the TED during operation, but allowed the fisherman to pull it tight quickly if the TED was beginning to roll and allow the floats and the water pressure to right the TED. The other fisherman was able to slow down the operation to give the TED a chance to right itself. However, this fisherman reported in the post interview that the top-opening TED was not preferable to him. On the *Miss April*, the crew reported that lowering the skimmer frames prior to the deployment of the TED greatly reduced TED twisting.

In 2010, on the *Miss April* and unnamed vessel, crew and captains initially reported chaffing on the bottom of the TED and were concerned about the destruction of the gear. These vessels were operating in very shallow water (< 5 ft) at the time. Chaffing material was sewn on the bottom of both the top and bottom-opening TEDs on these vessels and no further problems were observed or reported.

Fishermen in the 2010 NC study were asked to provide input and thoughts for potential modifications to make TEDs function optimally in their operations. Common input from these fishermen included the desire to: 1) attach floats on each side of the bottom-opening TEDs instead of using one float on the top; 2) reduce bar spacing in the TED frames to 3" to reduce bycatch even further; 3) test TEDs on both sides of the operation to eliminate drag on one side of the vessel; and 4) ensure that mesh counts between tailbag, extension, and tail of the net were all uniform. For the latter, TED extensions constructed for this research were 140 meshes in circumference and were sewn into tailbags that ranged from 120 meshes to 160 meshes in circumference.

Mean shrimp reductions by percentage with the use of a TED in skimmer operations ranged from -1.3% (an increase) on the *Miss April* (2010) to a mean of 10.75% loss on the unnamed (2010), (Tables 2, 4, 7). Shrimp losses were statistically significant (alpha = 0.05) on the *Vanna Lavie* (2008), *My Joy* (2008), unnamed (2010), and *Captain Jack* (2010), while losses on the other vessels were not statically significant. Power analyses revealed that detecting small differences in shrimp catch with acceptable power requires many tows. For example, a reduction of 0.22% may take 100's of tows to detect statistically. Resources and time prevent this, but overall the relatively small reductions in target catch were encouraging to the industry.

Bycatch reductions ranged from a mean of 3% on the *Sky Baby* to nearly 61% on the *Emerald Lady* throughout the 2008, 2009 and 2010 skimmer TED testing (Tables 2, 4, 7). Bycatch reductions were significant with excellent statistical power on all vessels barring the *Sky Baby*, where a mean reduction of 3% was observed. As pointed out earlier, the reduction in bycatch associated with TED use was appreciated by the contracted fishermen for this research,

especially with regard to stingrays. Large catches of rays extended culling times, presented safety issues, and cause damage to the target shrimp catch.

Rays, primarily cownose rays, were reduced by a mean of 40% on the *Knotsamuch* (2010) to a mean of more than 98% on the *Emerald Lady* (Tables 3, 5, 8). On the unnamed, and the *Knotsamuch*, ray reductions were not significant, but were closely approaching with $p = 0.056$ and $p = 0.069$, respectively. On the *Sky Baby*, ray bycatch increased by a mean of 27% for the TED equipped trawl. This anomaly could have been the result of an erroneous tow or due to an increased ray capture during a net retrieval. Overall, the reduction in the number of rays with the use of a TED was acceptable to the industry.

Reductions with the use of a TED were more variable with regard to Crustaceans and invertebrates when compared to rays and other species groups in all three years of the skimmer TED testing. Reductions of Crustaceans ranged from an increased mean of 81% on the *Vanna Lavie* to a decreased mean of 36% on the *My Joy*. Crustacean reductions were statistically significant on the unnamed vessel, *Captain Jack*, and *Miss April*. All other reductions of Crustaceans throughout the 2008, 2009, and 2010 skimmer TED studies were not significant, and had relatively low statistical power. Similar variability existed with invertebrate catches, which ranged from an increase of 16% on the *Vanna Lavie* to a decrease of 36% on the *My Joy*. Invertebrate reductions were only significant on the unnamed vessel. The variability associated with Crustacean and invertebrate reductions associated with the use of a TED may be explained by the relatively small capture weights of these species groups.

Teleost fish reductions associated with the use of TEDs in skimmer trawl operations ranged from a mean of 10% on the *Vanna Lavie* to 47% on the *My Joy*. Reductions of this species group were statistically significant in all years and for all vessels barring testing aboard the *Sky Baby* (2009) where a 3% reduction was observed. Teleost fish reductions may have also been statistically significant on the *Sky Baby* with an increased number of tows.

The reductions of unwanted or unmarketable bycatch such as the species groups identified were valued highly by the contracted fishermen in these studies. Large amounts of bycatch can lower the quality of the target catch through increased cull time and damaged catch. Results of this study indicate that the TED designs trialed were effective at maintaining shrimp catches, while decreasing the amount of unwanted bycatch.

Overall, the four TED configurations tested showed promise for effective use in the skimmer trawl fishery (Table 1). TEDs do not seem to be a significant burden for skimmer trawls with minor handling problems and target catch loss averaging 4.97% (95%CI 2.89% to 7.05%) across all testing (Table 10). This reduction in target catch represents the trade off required to significantly reduce sea turtle bycatch, while maintaining fishing operations in the region. Some configurations seem to work better than others regarding handling. However, like TED use in the bottom otter trawl fishery personal preference, vessel configuration, and local conditions will play a large role when it comes to selecting a specific configuration.

In the 2010 study, both the top-opening double and single cover TEDs were initially reported as having twisting and rolling problems during the deployment and retrieval processes and also

during turns. This problem was mostly remedied by crews aboard the *Emerald Lady* and *Mad Lady II* by either attaching a line from the back side of the TED that could be quickly jerked for the TED to right itself, or changing gear deployment (e.g., lowering frames before deploying the TED) and slowing down during turns. However, of these two vessels, one stated that the top-opening TED is preferable, while the other stated a preference for a bottom-opening TED. While both TED configurations functioned well and both fishermen operated under similar conditions, this exemplifies personal preference.

The 2008, 2009, and 2010 skimmer TED tests all had the commonality of testing a "twin trawl" operation with a TED on one side of the vessel, while the net on the other side fished without a TED. There may be some side bias associated with the potential extra drag on the side with a TED. To discern this and determine an optimum TED configuration in inshore waters, further testing has been scheduled in NC during the fall 2011. Different TED configurations will be tested against each other on the same vessel with multiple vessels conducting testing. Funding has been secured for this project and work is scheduled to begin in June 2011.

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