NOAA Technical Memorandum NMFS-SEFSC-606

EVALUATION OF A TURTLE EXCLUDER DEVICE (TED) DESIGNED FOR USE IN THE U.S. MID-ATLANTIC ATLANTIC CROAKER FISHERY

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TABLE OF CONTENTS

TABLE OF CONTENTS iii
LIST OF TABLES iv
LIST OF FIGURES vi
ABSTRACT vii
INTRODUCTION 1
Background 1
Fishery Description 2
Preliminary TED Development 2
Objectives 3
METHODS 3
Experimental Design 3
Trouser Trawl Testing 5
Usability Testing 7
RESULTS 7
Trouser Trawl Testing 7
Atlantic croaker 8
Bluefish 8
Atlantic menhaden 8
Bycatch 9
Sea Turtle Bycatch 9
Usability Testing 10
DISCUSSION 11
ACKNOWLEDGEMENTS 13
LITERATURE CITED 14

LIST OF TABLES

Table 1. Date, location, target species, and haul code for flynet trouser trawl TED testing tows conducted during the 2008 fishing season along the North Carolina coast. Haul codes are: A = alternate gear used; C = calibration tow; F = net fouled; H = hang; M = mud tow; N = no catch; T = bag tripped; Z = good tow............................ 23

Table 2. Date, location, target species, and haul code for flynet trouser trawl TED testing tows conducted during the 2009 fishing season along the North Carolina coast. Haul codes are: A = alternate gear used; C = calibration tow; F = net fouled; H = hang; M = mud tow; N = no catch; T = bag tripped; Z = good tow............................ 24

Table 3. Total catch, target catch, bycatch CPUEs (kg/hr), and percent differences for flynet trouser trawl TED and control catches collected during tows targeting Atlantic croaker. Tows were conducted during the 2008 and 2009 fishing season along the North Carolina coast. TED position is the leg of the trawl where TED was installed (P = Port; S = Starboard). Negative sign indicates TED catch < control catch. 25

Table 4. Total catch, target catch, bycatch CPUEs (kg/hr), and percent differences for flynet trouser trawl TED and control catches collected during tows targeting bluefish. Tows were conducted during the 2009 fishing season along the North Carolina coast. TED position is the leg of the trawl where TED was installed (P = Port; S = Starboard). Negative sign indicates TED catch < control catch. 26

Table 5. Total catch, target catch, bycatch CPUEs (kg/hr), and percent differences for flynet trouser trawl TED and control catches collected during tows targeting Atlantic menhaden. Tows were conducted during the 2009 fishing season along the North Carolina coast. TED position is the leg of the trawl where TED was installed (P = Port; S = Starboard). Negative sign indicates TED catch < control catch.. 26

Table 6. Shark species bycatch CPUEs (kg/hr; #/hr), and percent differences for flynet trouser trawl TED and control catches collected during the 2008 and 2009 fishing season along the North Carolina coast. TED position is the leg of the trawl where TED was installed for a given tow (P = Port; S = Starboard). Negative sign indicates TED catch < control catch... 27

Table 7. Ray and skate species bycatch CPUEs (kg/hr; #/hr), and percent differences for flynet trouser trawl TED and control catches collected during the 2008 and 2009 fishing season along the North Carolina coast. TED position is the leg of the trawl where TED was installed for a given tow (P = Port; S = Starboard). Negative sign indicates TED catch < control catch... 28

Table 8. Capture information for sea turtles incidentally caught during flynet trouser trawl TED testing conducting during the 2008 and 2009 fishing seasons along the North Carolina coast. CCL = Curved Carapace Length. 29

Table 9. Results of catch comparisons for total, target, and bycatch categories by target species. All tows across target species containing primary bycatch species were analyzed separately. P values indicate the results of one-tailed paired t-tests; n = number of tows with species occurrences; negative sign for differences indicates TED catch < control catch. Power value indicates the results of analysis to determine power to detect the given difference at an alpha of 0.10. * = Power analysis was conducted to determine power to detect a 20% difference at an alpha of 0.10. 30

LIST OF FIGURES

Figure 1. Diagram of the "Staggered Bar Flynet TED".. 16

Figure 2. Diagram of the "Semi Rigid Cable TED". 17

Figure 3. Diagram of the "Semi Rigid Cable TED II". 18

Figure 4. Diagram of the "Flexible Flat bar Flynet TED"... 19

Figure 5. Diagram of the 85 ft (25.9 m) flynet with 32 in (81.3 cm) stretched mesh wings and trouser modification used throughout the study.. 20

Figure 6. Locations of flynet TED testing trouser trawl tows conducted during the 2008 and 2009 fishing seasons along the North Carolina coast. 21

Figure 7. Net reel configurations of the four vessels contracted to conduct TED usability testing.. 22

Figure 8. The FFF-TED stored on an 8 ft (3.6 m) wide reel (left) and narrower 4.5 ft (2 m) wide reel (right). 22

ABSTRACT

In 1994, the National Marine Fisheries Service (NMFS) Northeast Fisheries Observer Program (NEFOP) documented sea turtle bycatch in the Atlantic croaker (*Micropogonias undulatus*) and weakfish (*Cynoscion regalis*) trawl fishery off North Carolina. The fishery utilized a high opening bottom trawl locally known as a "flynet." In 1998, the NMFS Southeast Fisheries Science Center (SEFSC) initiated research to develop a Turtle Excluder Device (TED) for the flynet fishery. Over the next 10 years, numerous prototype designs were trialed in the fishery. In 2007, the Flexible Flatbar Flynet (FFF) TED was developed for the fishery and scheduled for catch retention trials. The specialized "trouser trawl" testing technique was utilized to conduct testing due to the highly variable catch rates of the fishery. The objectives of the study were to quantify the target and bycatch species catch loss associated with TED use in the Atlantic croaker targeted flynet fishery operating off North Carolina. In addition, usability testing was carried out to identify handling problems and specialized handling techniques required when using TEDs in this fishery. The study was carried out aboard contracted commercial vessels operating along the North Carolina coast and originating from Wanchese, NC. Results indicate that catch loss for the primary target species, Atlantic croaker, was not significant, averaging 3.9% (95%CI -15.5 to 7.8%; $p<0.2229$; power 0.996), while catch of other target species and primary bycatch species was significantly reduced. Usability testing proved invaluable during this study providing specialized handling techniques that prevented TED damage and facilitated deployment and retrieval processes.

INTRODUCTION

Background

All species of sea turtles that occur in coastal waters of the United States became listed as threatened or endangered under the Endangered Species Act (ESA) by 1978. Following this action, several studies determined that the primary cause of sea turtle mortality was incidental capture in the southeast U.S. shrimp fishery (Henwood and Stuntz 1987, National Research Council 1990). Listing sea turtles under the ESA made capture in shrimp trawls illegal, which had the potential for severe management actions including a complete closure of the fishery. To prevent closure of the fishery and to recover sea turtle populations, significant efforts were directed toward reducing sea turtle bycatch and mortality.

In 1978, the National Marine Fisheries Service (NMFS), Southeast Fisheries Science Center (SEFSC) initiated an intensive gear research program resulting in the development of the Turtle Excluder Device (TED). Cooperative research with the fishing industry continued through 1986 concentrating on advancing TED design to increase catch retention and improve usability. Despite significant design improvements and intensive technology transfer efforts, the industry opposed TED use, which prevented widespread voluntary adoption of the technology. This lack of voluntary TED use prompted environmental organizations to threaten to file suit against the NMFS challenging that sea turtles were not being adequately protected. Consequently, regulations were enacted requiring the use of TEDs in shrimp trawls operating in the southeastern U.S. shrimp fishery (Federal Register 1987).

Shortly after TED requirements were enacted for the shrimp trawl fishery, large numbers of sea turtles stranded along the North Carolina coast were linked to the summer flounder (*Paralichthys dentatus*) trawl fishery (Epperly et al. 1995). This prompted research to develop specialized TEDs for use in this fishery. Again, the NMFS SEFSC initiated intensive gear research in cooperation with the North Carolina Division of Marine Fisheries (NCDMF) and the fishing industry (Monaghan 1992, Watson 1992). As a result, two specialized TEDs were certified for use and TEDs were required in the southern portion of the summer flounder fishery (Federal Register 1992).

Following the implementation of TED regulations in the summer flounder fishery, NMFS continued to monitor the fishery along with other trawl fisheries operating in the same areas. In 1994, observers documented sea turtle bycatch in the Atlantic croaker (*Micropogonias undulatus*) and weakfish (*Cynoscion regalis*) trawl fishery off North Carolina. The fishery utilized a high opening bottom trawl locally known as a “flynet” and observers documented 20 sea turtle takes during two trips. Monitoring of the fishery continued over the next several years with more sea turtles observed. In 1998, the NMFS SEFSC initiated research to develop a TED for the flynet fishery. Several major challenges were encountered including high volume catches and stiff opposition by the industry.

Fishery Description

The flynet fishery is a multispecies fishery composed of offshore and nearshore components that operate along the East Coast of the U.S. The nearshore fishery operates from October through April inside of 30 ftm from North Carolina to New Jersey and targets Atlantic croaker, weakfish, butterfish (*Peprilus triacanthis*), harvestfish (*Peprilus lepidotus*), bluefish (*Pomatomus saltatrix*), menhaden (*Brevoortia tyrannus*), striped bass (*Morone saxatilis*), and kingfishes (*Menticirrhus spp*). The offshore fishery operates from November through April outside of 30 ftm from the Hudson Canyon off New York, south to Hatteras Canyon off North Carolina. Target species for the offshore fishery include bluefish, Atlantic mackerel (*Scomber scombrus*), squid (*Loligo pealeii*), black sea bass (*Centropristis striata*), and scup (*Stenotomus chrysops*). An additional squid (*Illex illecebrosus*) fishery also operates offshore (70-200 ftm) during summer months from May through September.

Vessels participating in the fishery typically range from 50 ft (15.2 m) to 100 ft (30.5 m) in length and are equipped to tow a single net in a stern rigged configuration. Nets are stored on net reels with drum sizes ranging from 4 ft (1.2 m) to 9 ft (2.7 m) wide. Vessels are equipped with either single or multiple reels to facilitate gear changes required for participation in multiple fisheries. Various types of steel doors are used along with various lengths of ground cables covered with 1 3/4 in (4.4 cm) rubber cookies. Trawls used in the offshore and nearshore fisheries are nearly identical with the exception of mesh sizes in the codend section of the net and ground gear configuration. Flynets typically used in these fisheries are two-seam fish trawls constructed of graduated mesh sizes beginning with large mesh 16-, 32-, or 64-inch (40.6-, 81.3-, or 162.6-cm) stretched mesh in the wings and mouth of the trawl following a slow 3:1 taper to smaller mesh sizes in the body, extension, and codend sections of the net. The trawls are bottom tending with net sizes ranging from 85 ft (25.9 m) to 110 ft (33.5 m) headrope lengths. Tow speeds are often between 3 kts (1.5 m/s) and 4 kts (2.1 m/s) with tow durations ranging from 10 minutes to several hours. High volume catches are not uncommon in this fishery with 30 minute tows yielding up to 100,000 lb (45,360 kg).

Preliminary TED Development

The first flynet evaluations were conducted in 1999 with initial testing conducted to determine the incidence of turtle entanglement in the large mesh sections in the wings and leading portion of the trawl (Mitchell 1999). Results of this study indicated that the slow taper of the trawl resulted in a low entanglement rate. In addition to the entanglement testing, two prototype TEDs were also constructed and evaluated using the small turtle TED certification protocol (Federal Register 1990). The grids were rigid folding designs constructed to facilitate storage on net reels, which are common features on vessels throughout the flynet fishery. The reels pose a significant bending problem for standard one piece TED grids. The TEDs were bi- and tri-fold designs and both were tested in top opening configurations and worked well, readily excluding turtles and easily folding and wrapping around the net reel. Field evaluations aboard commercial vessels confirmed that the TED worked well operationally but questions remained about catch loss. This prompted design modifications directed at minimizing fish escapement and a staggered-bar modification was incorporated into the bi-fold design (Figure 1). The prototype passed the small turtle test but was plagued with operational problems and fish loss during field evaluations (Mitchell 2000).

Following commercial trials of the rigid bi-fold TED prototypes, it was apparent that the design needed modification. The industry suggested a TED design constructed entirely of cables to provide the flexibility needed to successfully load the grid on net reels. In response to their request, the SEFSC Harvesting Systems Unit constructed and evaluated a TED composed entirely of 1/2 in (1.3 cm) plastic coated, galvanized cables. Diver observations indicated that the TED did not maintain shape when towed causing it to fail initial turtle trials. Consequently, changes were made to correct the problems and two rigid sections were added to the upper and lower portions of the grid with the center cable section acting as a hinge (Figure 2). The prototype had rectangular openings of 5 3/4 in (14.6 cm) by 11 in (27.9 cm) throughout to facilitate catch retention. The "Semi Rigid" TED performed well both operationally and functionally during commercial trials and was tested for turtle exclusion during 2004 small turtle testing. The prototype passed the turtle test in a top opening configuration but failed as a bottom opening TED (Mitchell 2004). Efforts to modify the TED to facilitate turtle escapement in a bottom opening configuration with offset horizontal bars were unsuccessful (Figure 3, Mitchell 2005 and 2006). Upon further examination aboard commercial vessels, structural concerns and problems with fish loss were also revealed.

To address both the structural and catch loss problems, the next prototype was much larger than previous designs and incorporated aluminum flat bar (Figure 4). The "Flexible Flat Bar Flynet" TED (FFF-TED) was approximately 7 1/2 ft (2.3 m) tall by 5 ft (1.5 m) wide and had 4 in (10.2 cm) bar spacing. The TED was trialed commercially with good results holding up structurally with very little target catch loss observed. The TED passed the small turtle test in a top opening configuration and released five out of five turtles during a cursory test as a bottom opening TED (Mitchell 2007 and 2008; Hataway and Gearhart 2009). On subsequent commercial trials, very little structural damage was observed and target catch loss was minimal. Based on its good performance, the FFF-TED was scheduled for catch retention testing.

Objectives

The objectives of this study are:

> To quantify the target species catch loss associated with TED use in the Atlantic croaker flynet fishery operating off North Carolina.
>
> To quantify the catch loss of key bycatch species associated with TED use in the Atlantic croaker flynet fishery operating off North Carolina.
>
> To identify handling problems or specialized handling techniques required when utilizing a TED in the Atlantic croaker flynet fishery operating off North Carolina.

METHODS

Experimental Design

Vessels participating in the Atlantic croaker flynet fishery are rigged to tow a single net. This feature combined with a fishing technique that targets individual schools of fish results in highly variable catch rates, which posed a problem when it came to designing a gear evaluation study to determine the amount of catch loss associated with TED use. Methods traditionally used when evaluating gear modifications on single rigged vessels are covered bag, alternate haul, two vessel paired comparisons, and trouser trawl (Pope et al. 1975). All of these methods have commonly been used and there are advantages and disadvantages associated with each.

For total catch TED comparisons in this fishery, a covered bag design was inappropriate because it required a bag affixed around the TED opening to capture escaping fish. This technique would likely result in a “masking effect” that would alter the rate of fish escapement. The alternate haul method requires one haul with an experimental net and a second tow with a control. The disadvantage of this method is that the population of fish sampled may vary significantly in both number and size between hauls, which requires a large number of hauls to remove enough between-tow variability to detect significant differences in total catch between experimental and control nets. The same problem can be expected for multiple vessel paired comparisons in which two boats fish in close proximity to each other with experimental and control nets.

It was suspected that the between-tow variability for the Atlantic croaker flynet fishery was too large to apply the alternate haul technique because of the cost prohibitive number of tows required to confidently detect differences in catch rates between TED equipped trawls and naked nets without TEDs. In 2007, the Atlantic Strategy Steering Committee (ASSC) determined that the minimum acceptable level of precision for all catch retention TED testing would be the ability to detect a 20% difference between treatments at an alpha of 0.1 and a beta of 0.2. To determine the number of alternate haul tows required to detect a difference, a power analysis was conducted with these parameters based on a two-sample design utilizing data from the Northeast Fisheries Observer Program (NEFOP). Because testing would likely be carried out on individual vessels to reduce between-vessel variability, calculations were performed by vessel for several individual vessels. Sample size calculations revealed that it would take between 360 and 1,092 tows per treatment or between 720 and 2,184 total tows to test a single TED. Based on an average of four successful tows per day and a vessel contract fee of approximately $3,000 per day, the total cost estimate for testing a single TED using this technique in the Atlantic croaker flynet fishery would be between $540K and $1.64M. Based on these projected costs, it was clear that another comparative towing technique needed to be investigated for this fishery.

The trouser trawl technique was selected as the preferred alternative for TED testing. The technique consists of a standard trawl modified with two codends and dividing panel that runs the entire length or a portion of the trawl body. The advantage of this technique is that it takes simultaneous samples in each codend resulting in lower variability between control and experimental catches resulting in fewer tows required to detect significant differences between treatments. Pope et al. (1975) outlined the procedures for making the trawl modification and stressed the importance of thoroughly examining the gear in a flume tank or under normal fishing conditions using video cameras or divers to ensure that the gear is configured properly before utilizing the trawl for comparative testing. The annual SEFSC Harvesting Systems Unit diver assisted trawl gear evaluations conducted in Panama City, Florida provided the opportunity to conduct these gear examinations.

Trouser Trawl Testing

The trouser trawl consisted of a standard flynet with an 85 ft (25.9 m) headrope length modified to accommodate two standard size extensions and codends (Figure 5). Prior to trawl modification, the standard flynet was towed and inspected by divers. Vertical and horizontal baseline measurements were taken along the body of trawl, extension and codend sections. These baseline measurements were used to determine the location of the extension split that would allow two full size extensions to be installed. In addition to the trawl split, a dividing panel was installed ahead of the split to minimize side bias of fish entering the extension area of the trawl. The dividing panel was wedge cut to minimize potential distortion effects of the top and bottom sheets of the trawl. After modifications were complete, divers inspected and measured modified sections of the trawl to determine if trawl distortion was occurring and to determine if the diameter of the modified sections matched the baseline measurements of the standard trawl. Divers determined that no trawl distortion was occurring and that all measurements matched, which allowed the trawl to be recommended for commercial trials.

Testing was conducted during the 2008 and 2009 fishing seasons aboard the contracted commercial vessel F/V Bridgot Denise, a steel trawler based in Wanchese, NC. The trawler measured 82 ft (25 m) in length with a volume of 142 gross tons and an engine rating of 680 horsepower (500 kilowatts). All testing was conducted along the northern North Carolina coast (Figure 6). The trouser trawl was loaded on the vessel prior to each trip and connected to the vessel's ground gear and doors, which consisted of 30 ftm of scissor gear made up of 10 ftm of 3/4 in (1.9 cm) stainless steel cable with the lower legs covered with 1 3/4 in (4.4 cm) rubber cookies with 1 lb (0.5 kg) lead weights added every foot (30.5 cm). The remaining portion of the lower legs of the scissor gear consisted of 20 ftm of 3/4 in (1.9 cm) stainless steel cable covered with 2 in (5.1 cm) rubber cookies. After the scissor gear, 30 ftm of bare 7/8 in (2.2 cm) stainless steel cable was added followed by 20 ftm of cookie sweep with 2 in (5.1 cm) rubber cookies installed along the entire length. Doors consisted of 92 in (233.7 cm) Thyboron type II doors that had an area of 40.2 ft^2 (3.7 m^2) and weighed 1,080 lb (490 kg). Settings for the doors remained unchanged throughout the study. Water depths were less than 20 ftm with trawl cable deployed at a 4:1 ratio. Tow speeds averaged 3.2 kts (1.6 m/s) and tow times were not restricted. The captain was instructed to fish normally targeting Atlantic croaker when available but to also target other species as fish availability and market conditions dictated.

The FFF-TED grid was 89.5 in (227.3 cm) tall by 57 in (144.8 cm) wide (Figure 4). The FFF-TED was constructed in three sections, two rigid upper and lower sections constructed of 6061 aluminum flat bar. The outer portion of the frames were constructed of 1/2 in (1.3 cm) by 2 in (5.1 cm) flat bar, while the deflector bars were constructed of 3/8 in (1 cm) by 2 in (5.1 cm) flat bar. The upper section had 15° bent bar section beginning 10 in (25.4 cm) from the upper edge of the frame. The upper section also had a brace bar constructed of 1/2 in (1.3 cm) by 2 in (5.1 cm) flat bar installed directly to the outer frame and behind the bent bar section of the deflector bars. Bar spacing in both the upper and lower sections was 4 in (10.2 cm). The upper and lower sections were joined by a flexible center section. The center section was constructed of two pieces of 304 stainless steel 1/4 in (0.6 cm) by 2 in (5.1 cm) flat bar with 1/2 in (1.3 cm) by 4 in (10.2 cm) schedule 40 stainless steel pipe nipples welded on 4 in (10.2 cm) center intervals. The two flat bar sections were connected with 1/2 in (1.3 cm) by 13 in (33 cm) stainless steel cable hydraulically swaged into each 1/2 in (1.3 cm) pipe nipple at 9,000 psi (620.5 bar). The center section was then bolted to the upper and lower sections with eight 9/16 in (1.4 cm) by 1 1/4 in (3.2 cm) stainless steel bolts installed at 16 in (40.6 cm) intervals. All welds were tungsten inert gas (TIG) welded and corner joints were fit corner to corner and full fillet welded.

The FFF-TED was installed into a webbing extension at a 48° angle in a top opening configuration with three #508, 8 in (20.3 cm) hard plastic floats installed on each side of the upper portion of the grid. The extension was constructed of 80mm x 3mm Euroline material and was 50 meshes long and 250 meshes in circumference with three mesh gores along each side. The TED opening was trapezoid shaped consisting of a 53 mesh cut along the top edge of the grid beginning at the first deflector bar on each side and continuing 27 bars forward along each side of the opening and terminating with a 32 mesh cut along the leading edge of the opening. After the opening was cut, ribline were installed to help the TED maintain angle under heavy loads. Two 3/8 in (1 cm) polypropylene riblines were installed beginning at the first deflector bar on either side of the opening and continuing along the bars of the meshes on the edges of the opening terminating at the top center of the extension. Two additional riblines were added to each side of the extension beginning at the same point at the first deflector bar on either side of the opening and continuing down the bars of the meshes terminating at the ends of the gores on each side of the extension. The TED flap was a single flap installed inside the TED opening and consisted of a piece of 1 5/8 in (4.1 cm), #30 (1.8 mm) polypropylene webbing 50 meshes long by 150 meshes wide. The flap was sewn 3:2 along the leading edge of the opening and down the sides of the opening to a row of meshes even with the posterior edge of the grid and extended unattached 20 in (50.8cm) beyond the posterior edge of the grid.

Prior to TED testing, an initial trip was conducted to perfect hauling techniques and to perform naked net comparisons without a TED installed to determine if catches from each side of the net were comparable and make gear changes as necessary. After this trip the FFF-TED was installed in the port leg of the trouser just behind the split extension section of the net (Figure 5). In addition, a funnel was installed immediately behind the TED to the leading edge of the first extension section of the port leg of the trawl. The funnel consisted of an 80 by 25 mesh straight section of net constructed of 80mm x 3mm Euroline material with two 4 in (101.6 mm) hard plastic floats attached to the lower trailing edge. The funnel was designed to close off the extension during haul back to prevent fish that passed through the grid from swimming forward and out the escape opening of the TED during haul back. A 50 mesh extension was added to the starboard control leg of the trawl in the same location. The TED was changed from side to side on a daily basis throughout the study to minimize side bias. Catches from the control and experimental TED codends were retrieved separately in a traditional manner through a stern ramp in multiple retrievals of approximately 6,000 lb (2,722 kg) each. Once onboard, each bag was weighed to the nearest 10 lbs (4.5 kg) with a Massload model ML700 tension link 10,000 lb (4,536 kg) loadcell and dumped on deck. Experimental and control catches were kept separate on deck for sampling. If catches in each bag were too large to divide on deck, then experimental and control catches were worked up separately to avoid mixing catches. After catches were weighed and dumped, the primary bycatch species were enumerated in each catch. These species were primarily spiny dogfish (*Squalus acanthias*) and clearnose rays (*Raja eglanteria*) with other select species such as Atlantic sturgeon (*Acipenser oxyrinchus*) also counted. Samples of each of these bycatch species were collected from each catch and weighed to the nearest 0.02 kg with TCI Model LPC-4 hanging scales. Sample counts were collected for each species sampled and total weights for each catch estimated using the following formula:

$$BycatchSpeciesEstimatedTotalWeight = (SampleNumber / SampleWeight) * TotalNumber$$

Target species total weight was then calculated as:

$$TargetSpeciesEstimatedTotalWeight = TotalWeight - \left(\sum BycatchSpeciesEstimatedTotalWeights\right)$$

Total catch, target catch, and bycatch weights were compared using a paired t-test. Sequential power analyses were conducted throughout the study to determine when enough samples were collected to detect a 20% difference in target catch (Atlantic croaker) with 80% power at an alpha of 0.1. Catch reduction rates by weight and number were calculated as:

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

Usability Testing

Because the trouser trawl required specialized hauling techniques, additional "Usability Testing" was recommended to test the structural integrity and functionality of the TED when installed in a standard trawl and used under normal fishing conditions. In many industries, end-user testing has proven to be an effective method of identifying design errors at early stages of development, when prototypes are still in basic form and not yet implemented. As errors are identified, appropriate solutions can be developed and changes are easier and cheaper to implement. For TEDs, this stage of development is crucial for industry acceptance and long term compliance with regulations requiring TED use.

Usability testing of the flexible TED prototype was conducted aboard four contracted commercial vessels. The TEDs were installed in each vessel's standard gear during fishing trips conducted between November and March during the 2008-2009 and 2009-2010 fishing seasons. Each trip was conducted with a SEFSC Harvesting Systems Unit Fishing Methods and Equipment Specialist (FMES) aboard to assist with gear deployment and retrieval and conduct video evaluations consisting of camera installation at various locations around the TED and TED opening to examine various factors including catch loss/retention, grid clogging, fish behavior, and TED/net configuration. In addition to video evaluations, total effort and catch information were collected from each tow along with video documentation of any specialized handling techniques. The captains were also asked to provide feedback regarding the TED including comments on design, construction, usability, handling, deployment, retrieval, and storage.

RESULTS

Trouser Trawl Testing

Three fishing trips were conducted during the 2008 fishing season, while four were conducted during the 2009 season (Tables 1 and 2). The first trip of 2008 consisted of four naked net tows with no TED installed to perfect hauling techniques and to determine if catches in each side of the trouser trawl were comparable prior to TED testing. During this trip, several hauling techniques and gear modifications designed to assist with retrieval of the trouser trawl were attempted and catches observed were comparable. All subsequent TED testing tows completed during this study were conducted along the North Carolina coast between the Virginia border and Cape Hatteras (Figure 6). A total of 59 tows were completed with data collected from 37 successful tows. Successful tows were defined as problem free tows with at least 1,000 lbs (453.6 kg) of total catch. For successful tows that did not contain target species, data were collected on primary bycatch species. Although Atlantic croaker were the primary target species during this study, Atlantic menhaden (*Brevoortia tyrannus*) and bluefish (*Pomatomus saltatrix*) were also targeted when croaker were unavailable. Data were collected from 23 tows targeting croaker, 12 tows targeting menhaden, and two tows targeting bluefish (Tables 1 and 2). Tow duration for all tows ranged from 15 to 275 min and averaging 114 ± 56 min with tow speed for all tows averaging 3.1 kts. For tows targeting croaker, tow duration ranged from 20 to 275 min and averaged 108 ± 55 min. Tows targeting menhaden ranged from 15 to 208 min and averaged 132 ± 62 while bluefish tows averaged 122 ± 2 min. All tows targeting menhaden were conducted north of Oregon Inlet and within three miles of shore, while tows targeting croaker and bluefish were primarily conducted south of Oregon Inlet and outside of three miles (Figure 6).

Atlantic croaker

Total catch for tows targeting croaker, consisting of the TED and control catch combined, ranged from 503.5 to 15,422.1 kg and averaged 4,119.5 kg. Target catches ranged from 0 to 12,700.6 kg and averaged 2,614.5 kg, while total bycatch ranged from 0 to 15,422.1 kg and averaged 1,495.6 kg. When catch rates (kg/hr) were examined, the average loss of target catch for TED equipped catches was 3.9%, while total bycatch was reduced by 36.4% (Table 3). These reduction rates were reflected in the total catch loss of 20.5% indicating that most of the loss was bycatch (Table 3). The reductions in total catch and bycatch were significant, while the target catch loss was not (Table 9). Power analyses were conducted for the observed differences in each category at an alpha of 0.1. However, if differences were less than 20% the analysis was adjusted to determine the power to detect a 20% loss. Using these methods, the power of the tests to detect these differences was good with 71.7% power for the total catch comparison, 99.6% for target catch and 67.7% for bycatch.

Bluefish

Total catch for the two tows targeting bluefish, consisting of the TED and control catch combined, were 453.6 and 644.1 kg with no bycatch observed during these tows. When comparing catch rates (kg/hr) between the TED and control, the average total and target catch loss observed for TED equipped catches was 72.5% (Table 4).

Atlantic menhaden

For tows targeting menhaden, the total catch, consisting of the TED and control catch combined, ranged from 2,286.1 to 21,500.3 kg and averaged 8,344.6 kg. Target catch ranged from 1,197.4 to 21,500.3 kg averaging 8,067.7 kg, while levels of bycatch observed were relatively low ranging from 0 to 1,088.7 kg and averaging 276.9 kg. Comparing TED and control catch rates (kg/hr), the total catch was reduced by 43.2% in TED equipped catches, while bycatch was reduced by 61.2% (Table 5). The reduction in total catch and relatively low levels of bycatch observed during these tows was reflected in the average target catch loss of 43% (Table 5).

Target and total catch reductions were marginally significant, while the bycatch reduction was highly significant (Table 9). Power analyses conducted for the observed differences for each of these categories indicated the need for more data with the power of the total catch comparison at 60.5% and 59.1% for target catch (Table 9). The large reduction rate and high level of significance for the bycatch comparison was confirmed by the 94.6% power to detect this difference with only six tows (Table 9).

Bycatch

The primary bycatch species encountered were spiny dogfish and clearnose rays. Other species of sharks, skates, and rays were encountered on an infrequent basis and were lumped with spiny dogfish and clearnose rays into general categories of shark species and ray species for analysis. Notably a basking shark (*Cetorhinus maximus*) approximately 5 m long was captured in the TED side of the trawl and was observed at the surface escaping out of the TED opening during haul back. In tows where sharks were caught, total catch, consisting of TED and control catches combined, ranged from 41.3 to 15,422.1 kg and averaged 1,317.7 kg, while numbers of sharks caught ranged from 6 to 6,390 and averaged 542 (Table 6). Comparing catch rates between TED and control catches, the total weight of sharks caught was reduced by 35.8% by the TED (Table 6). However, this reduction was negatively influenced by a large single tow conducted on March 4, 2009 (Table 6). Reduction rates for TED equipped catches were much greater during tows with smaller catches (Table 6). Shark numbers were reduced by 44.3% and the difference between biomass and number reductions indicates that the TED was size selective for sharks. Although no sharks were measured to confirm selectivity, the average individual weight of sharks averaged across tows was less in TED catches at 2.4 kg when compared to the control at 3.8 kg. The reduction in total shark catch was marginally significant with the power analysis confirming the need for more data to detect a difference at this level of catch loss (Table 9). In tows where rays were caught, total catch, consisting of TED and control catches combined, ranged from 6.8 to 466 kg averaging 165.1 kg. The number of rays caught per tow ranged from 1 to 290 and averaged 92 individuals. When ray catch rates (kg/hr) were compared between TED and control catches, the TED reduced the total catch of rays by 66.4% and reduced the number of individuals by 57.5% (Table 7). Again, the large volume tow conducted on March 4, 2009 negatively influenced the bycatch reduction rate with smaller tows yielding higher reductions rates. The TED also appeared to be size selective for rays with the average individual weight of rays averaged across tows for the TED at 1.8 kg and 4.8 kg for the control. The biomass reduction of rays caught was highly significant with the power analysis confirming this result with 98.7% power to detect the 66.4% difference with 17 tows (Table 9).

Atlantic sturgeon were encountered infrequently and primarily during menhaden targeted tows north of Oregon Inlet. A total of 16 individuals were encountered during TED testing with two occurring in TED catches and 14 in the control. During naked net trials with no TED installed 75 were captured in a single tow north of Oregon Inlet.

Sea Turtle Bycatch

A total of nine sea turtles were captured during the study and all were released alive with a tenth turtle observed escaping through the TED opening on video collected from the TED opening (Table 8). Five were captured during a single trip in late February 2008 and four were captured during a single trip in early January 2009. All of the captures occurred while targeting croaker and seven were observed in the control codend. Another was observed entangled in the large mesh 32 in (81.3 cm) wing section of the trawl and one was observed in the body of the net ahead of the trouser split. Four turtles were tagged prior to release and the size range of all turtles measured was 648 to 781 mm CCL (Table 8).

Usability Testing

A total of nine usability testing trips consisting of 22 fishing days were conducted during the 2008-2009 and 2009-2010 fishing seasons. Two trips were conducted during the 2008-2009 season consisting of five days, while seven trips consisting of 17 days were conducted during the 2009-2010 fishing season. The FFF-TED was tested over 14 days on six separate trips, while a new Cable TED prototype was tested over eight days on three separate trips. Fourteen additional days are scheduled for the 2010-2011 fishing season.

Video collected during this phase of testing revealed sharks, skates, rays and sturgeon readily escaping from the trawl through the TED opening without a significant amount of target catch loss observed. Catches of up to 40,000 lbs (18,144 kg) were documented. The FFF-TED also performed well functionally, easily wrapping around the net reel with no significant signs of structural damage.

Four vessels participated in usability testing, two with single net reel configurations and two with double net reels (Figure 7). These are the two most common configurations for vessels participating in the flynet fishery. The vessels utilized in this study with single reels mounted them on a gantry over a center stern ramp cut out, while the double reel vessels mount them on either side of the stern. One of the double reel vessels had stern ramps under the reels, while the other had no ramps. Reels on the single reel vessels were 6 ft (1.8 m) and 8 ft (2.4 m) wide with nets retrieved under the reels, while double reels were 4 1/2 ft (1.4 m) and 5 ft (1.5 m) wide with nets retrieved over the top of the reels. Storage and handling of the FFF-TED differed for each of these configurations. Wider single reels had a shorter bending radius than the double reels because the net was stored across a wider area (Figure 8). Storing the net across the wider area also allowed for uneven float and net storage prior to loading the TED and hauling the catch. When the TED was stored on an uneven surface, stress was placed on the rigid portions of the grid instead of the hinged portion causing slight bends in the deflector bars. These bends were usually caused by uneven float storage, which caused individual floats to protrude and be forced between the TED deflector bars by the weight of the catch and surging seas. This was not a problem on the narrow double reels because the net sufficiently covered all floats providing an even surface with a longer bending radius minimizing stress on the TED. For wider single reels another important aspect of net storage was TED orientation on the reel. To prevent damage to the TED, it needed to be stored as evenly as possible with the hinge running the length of the reel. The cable hinge provides room for error with respect to this but when stored at extreme angles on the reel stress is placed on rigid portions of the grid, which may cause the frame to bend. Narrower double reels did not have problems with this because there was little room on either side of the TED when stored to allow for uneven storage (Figure 8). One advantage to wider single net reels was the ability to store the TED on one side of the reel and haul the catch on the other side, which minimized pressure on the TED.

Methods for deploying and retrieving the TED also differed between single and double net reel vessels. When retrieving the TED in a top opening configuration, the TED almost always flipped upside down after it left the surface of the water resulting in a 180° twist ahead of the TED. This is normal for top opening TEDs because the area of the TED opening does not provide support for the TED frame. For both single and double reel vessels, this did not cause a significant problem when retrieving and loading the TED on the reel. The problem arose when deploying the TED and trying to remove the 180° twist. It was much easier for single net reel vessels to perform this task because the net was retrieved under the reel. Deck hands could handle and turn the TED easily from areas on either side of the ramp and lower the TED to the ramp. However, on double reel vessels it was more difficult because the net was retrieved over the top and there was little room to handle the TED on either side of the reel. In addition, there was a greater distance to the water for top loading reels and the TED tended to roll before it hit the water. To aid this problem, handles and tag lines were added to either side of the TED extension. This provided an easy means of turning the TED when loading or deploying it. In addition, the TED was trialed in a bottom opening configuration on one of the double net reel vessels, which alleviated the TED twisting problem. In a bottom opening configuration the TED did not roll upon retrieval therefore preventing the need to untwist the TED upon deployment. The result was virtually hands free operation.

In an effort to prevent possible TED damage, an alternative hauling technique was also employed by two of the captains. Instead of retrieving the catch up the stern ramp, these captains opted to haul catches over the rails on either side of the vessel. Hauling catches up the stern ramp is a common practice throughout the fleet. When this is done the portion of the trawl behind the TED is wrapped over the TED causing extreme pressure on the grid. The alternative side hauling technique consisted of bringing the TED to the stern ramp and then lifting the catch over the side rail. In this scenario, the TED hung freely while the catch was hauled aboard. The disadvantage to this technique is that it can not be done easily in rough seas.

Finally, a cable TED prototype was trialed during the 2009-20010 fishing season. The TED was designed to collapse on the net reel for easy storage and expand when fishing. The TED was entirely constructed of cable and was installed in a top opening configuration at a point ahead of the straight extensions in the final taper of the trawl. The TED loaded and deployed effortlessly and caught fish well with one tow yielding up to 100,000 lbs (45,360 kg). Vessels captains that trialed both devices liked the cable TED much better than the FFF-TED and requested its certification prior to a potential rule requiring TED use in the flynet fishery. The TED is slated for sea turtle certification trials in June 2010.

DISCUSSION

This study represents an initial effort to determine the effect of TED implementation on catch in the Atlantic croaker directed flynet fishery. Results indicate that target catch loss was minimal for croaker, while losses were greater for other target and bycatch species. The trouser trawl comparative testing technique was used throughout the study. This required significant gear modification and specialized handling techniques. However, the method appeared to work well for this fishery yielding robust results for many catch categories.

Overall, the catch loss for the primary target species, Atlantic croaker, was not significant, averaging 3.9% (95%CI -15.5 to 7.8%), while catch of primary bycatch species was significantly reduced (Table 9). These results can be attributed to the 4 in (10.2 cm) bar spacing of the grid and the size and shape of the species encountered. The primary bycatch species were spiny dogfish and clearnose skates. The body form of each of these species prevented them from easily passing through the grid. Video collected from the area just behind the escape opening and grid revealed individuals of both of these species falling back to the TED and being temporarily impinged on the grid prior to exclusion. Once impinged, both sharks and rays tended to move along the face of the grid until they passed through the grid or out the escape opening. Croaker behavior differed with individuals or groups swimming low in the trawl just ahead of the grid and eventually falling back and passing through the bars. Exclusion of spiny dogfish, skates and rays is desirable since these species are not marketed in this fishery. However, smooth dogfish (*Mustelus canis*), which were encountered less frequently and marketed on a limited basis, were also excluded. Although this species was not separated from the catch during testing, exclusion rates are expected to be similar to that of spiny dogfish. In addition to spiny and smooth dogfish, Atlantic sturgeon were also observed readily escaping through the TED opening. Throughout the study, only two sturgeon were observed in TED catches, while 14 were observed in control catches. Since retention of this species is prohibited exclusion of all sturgeon is desirable.

While croaker retention was good, loss of other target species was significant. Menhaden catches were reduced by 43%, while bluefish were reduced by 72.5%. Reasons for these catch losses differed by species with bluefish losses solely attributed to the 4 in (10.2 cm) bar spacing and the inability of most fish to pass through the grid. Menhaden catch loss can be attributed to the volume of the catches. When targeting this species, large dense schools of fish were often encountered, which overwhelmed the ability of the TED to sort the catch resulting in large amounts of catch lost through the escape opening. One factor that may have contributed to this loss was the installation of a funnel immediately behind the TED. The funnel was designed to stay open while fishing and collapse upon haul back preventing fish from traveling back through the grid and out the escape opening. However, during large volume tows the funnel may have inhibited the flow of fish causing a blockage just behind the TED. For this reason, the funnel was not installed during 2009 usability testing. Another factor that may have contributed to catch loss of this species is the behavior of menhaden in the trawl. Video collected from the area just ahead of the TED revealed menhaden swimming high in the trawl and searching the top of the net for areas to escape. The top opening configuration of the TED may have further facilitated escapement of this species.

No sea turtles were observed in TED catches, while seven were observed in control catches. Small turtle testing in 2009 established the ability of the FFF TED to readily exclude turtles, while underwater video collected from the TED opening revealed one turtle escaping from the trawl (Hataway and Gearhart 2009). All turtles were captured while targeting croaker in offshore areas south of Oregon Inlet. During 2009 testing, when turtles were captured, other vessels fishing in the vicinity also reported turtle bycatch and one turtle was observed floating on the surface. When targeting croaker, fishermen searched for schools of fish along warm water temperature breaks that changed from approximately 45°F (7.2°C) to 65°F (18.3°C). The cooccurrence of sea turtles and croaker along these temperature breaks may explain sea turtle bycatch in this fishery.

Usability testing proved to be invaluable during this study providing insight into handling problems and affording the ability to formulate solutions prior to TED implementation. Since the trouser trawl required its own specialized handling techniques, usability testing in standard flynets aboard commercial vessels of various configurations was required. It was determined that specialized handling techniques will be needed to prevent TED damage and facilitate the deployment and retrieval processes. Prior to TED storage, nets should be loaded on to the net reel as evenly as possible to provide a good foundation for the TED with special attention paid to the storage of trawl floats. Uneven trawl float storage often results in a build up of material on one side of the net reel causing lopsided TED storage, which results in pressure on rigid portions of the grid instead of the hinge during the fish handling process. This is especially true for wider net reels on vessels with single net reel configurations. Tag lines approximately six ft (1.8 m) long were added to each side of the TED to assist with deployment and retrieval. When installed in a top opening configuration the TED flips 180° upon retrieval. The TED should be left in this orientation prior to storage and flipped back over prior to deployment. The tag lines are especially helpful when attempting to right the TED. However, if the TED is installed in a bottom opening configuration, the TED does not flip and when stored on net reels that retrieve the net over the top of the reel the operation is virtually hands free.

Finally, the cable TED shows great promise as an alternative to the semi-rigid design. Easy storage and improved catch retention when compared to the FFF TED make this design worth pursuing. Recently, the TED passed the 2010 small turtle test and is slated for more inspection dives and usability testing. Industry has endorsed the cable TED as the preferred design if it can be constructed affordably. It is hoped that design improvements that reduce the amount of labor needed to construct the TED are developed so an affordable version of the cable TED can be made available to the industry sometime during the 2010-2011 fishing season.

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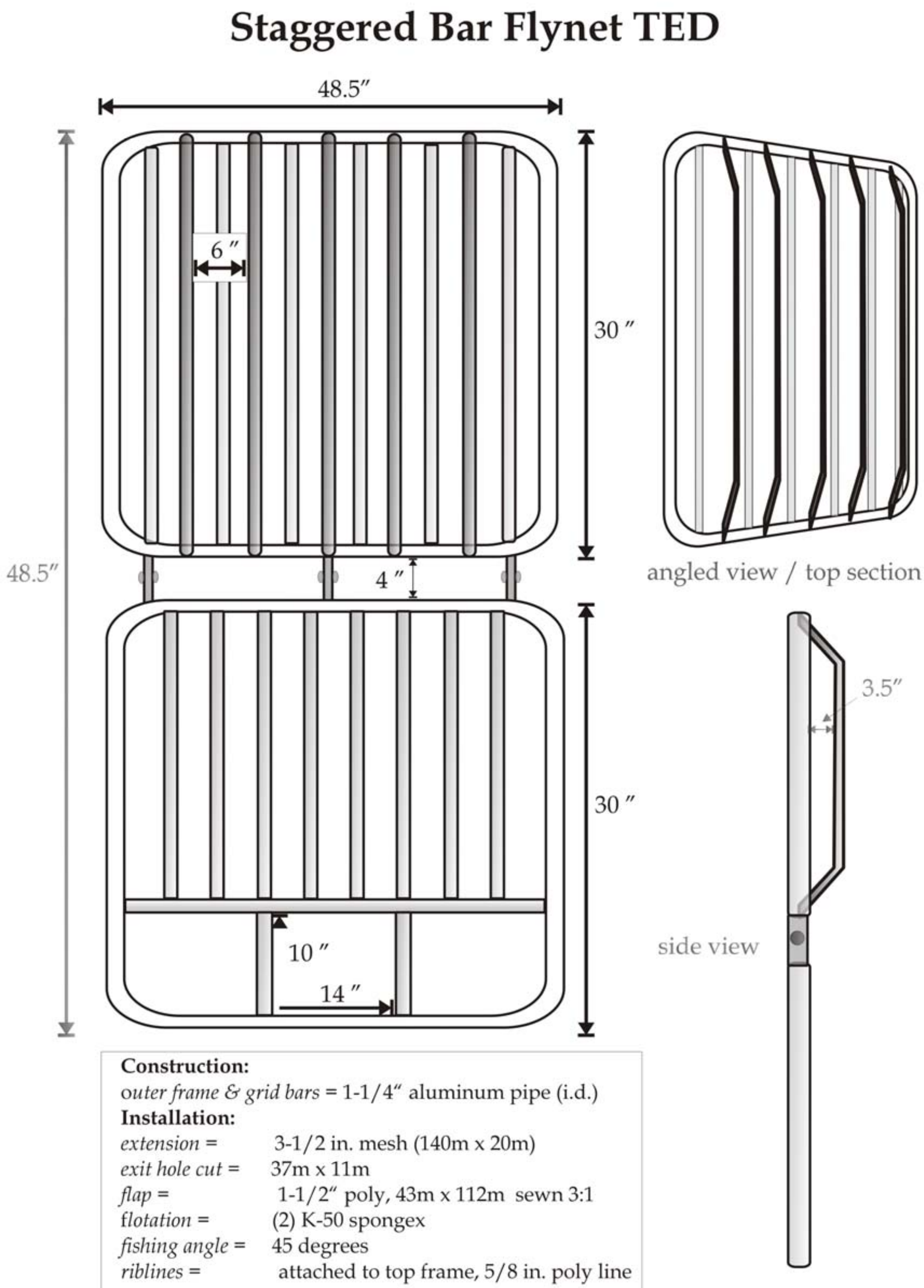
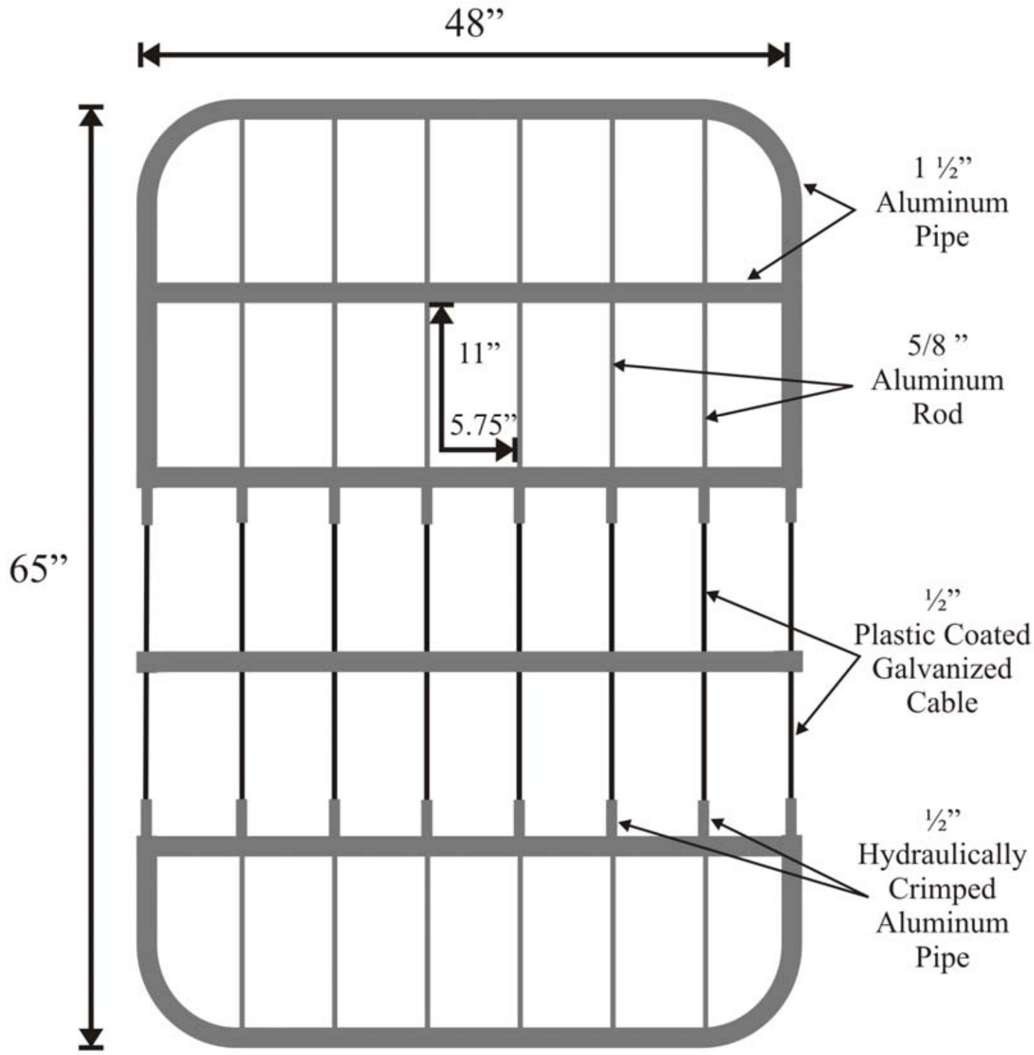


Figure 1. Diagram of the "Staggered Bar Flynet TED".

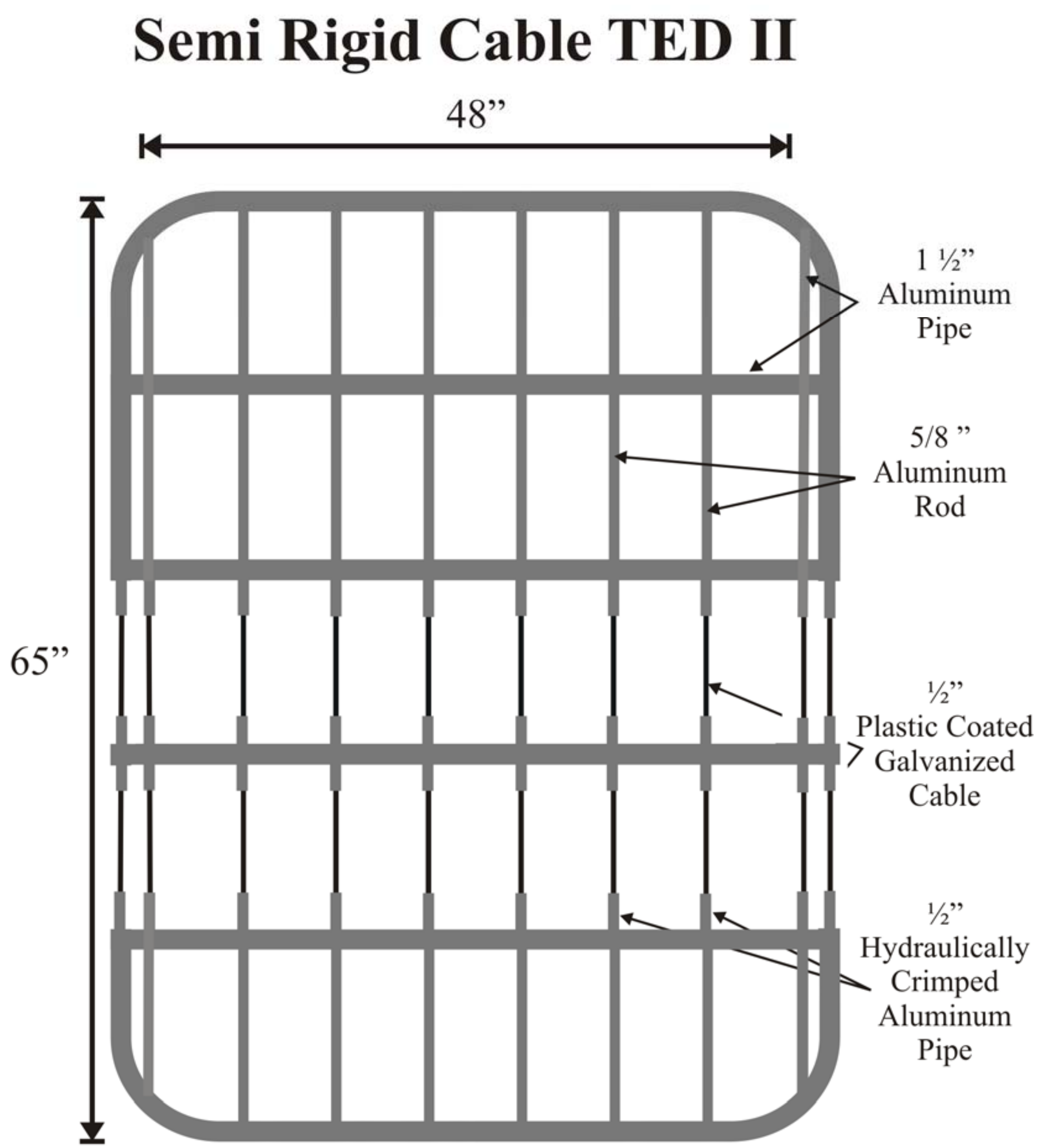
Semi Rigid Cable TED



Installation:

extension = 2 3/4”, braided #60 nylon (150m x 60m)
exit hole cut = 33m x 12m (91” x 33”)
flap = 1 ½” poly, 36m x 100m, sewn 3:1
flotation = (2) K-50 spongex
fishing angle = 48 degrees
riblines = attached to top and along midpoint of frame, ½” braided, spectra

Figure 2. Diagram of the “Semi Rigid Cable TED”.

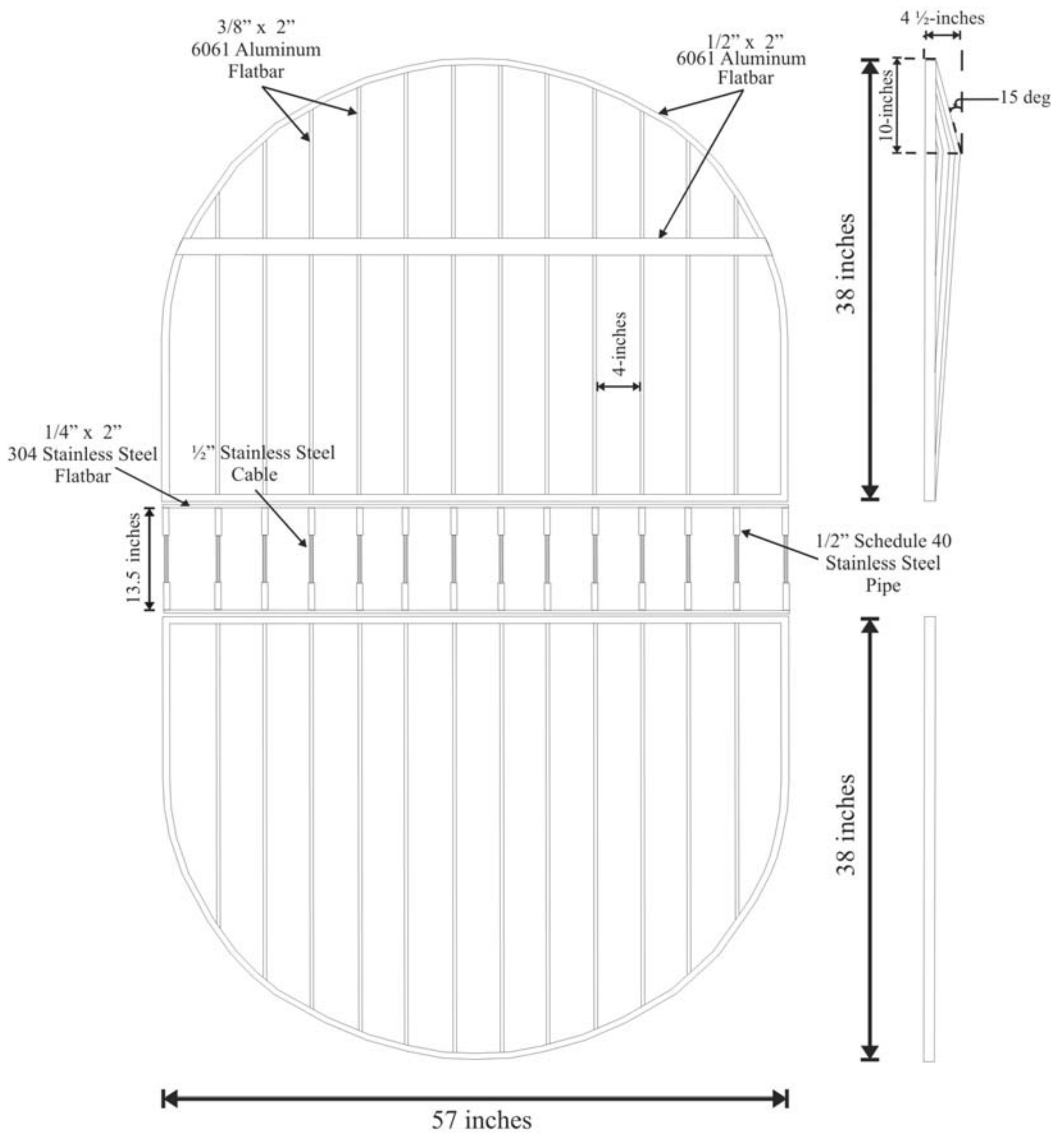


Installation:

extension =	2 3/4”, braided #60 nylon (150m x 60m)
exit hole cut =	33m x 12m (91” x 33”)
flap =	1 ½” poly, 36m x 100m, sewn 3:1
flotation =	(2) K-50 spongex
fishing angle =	48 degrees
riblines =	attached to top and along midpoint of frame, ½” braided, spectra

Figure 3. Diagram of the “Semi Rigid Cable TED II”.

Flexible Flat Bar Flynet Cable TED



Installation:

extension =	80mm x 3mm Euroline (250m x 50m)
exit hole cut =	53M x 27B x 32M Trapezoid Cut
flap =	1 5/8” #30 poly, 150m x 50m, sewn 3:2 along the leading edge inside opening to posterior edge of grid Extending 20” beyond posterior edge of grid
flotation =	(6) #508 8-inch Hard Plastic
fishing angle =	17M diff top and bottom = ~48 degrees
riblines =	3/8” poly prop gore, 3/8” poly prop ribline from bars at corner of opening down bars to gores

Figure 4. Diagram of the “Flexible Flat bar Flynet TED”.

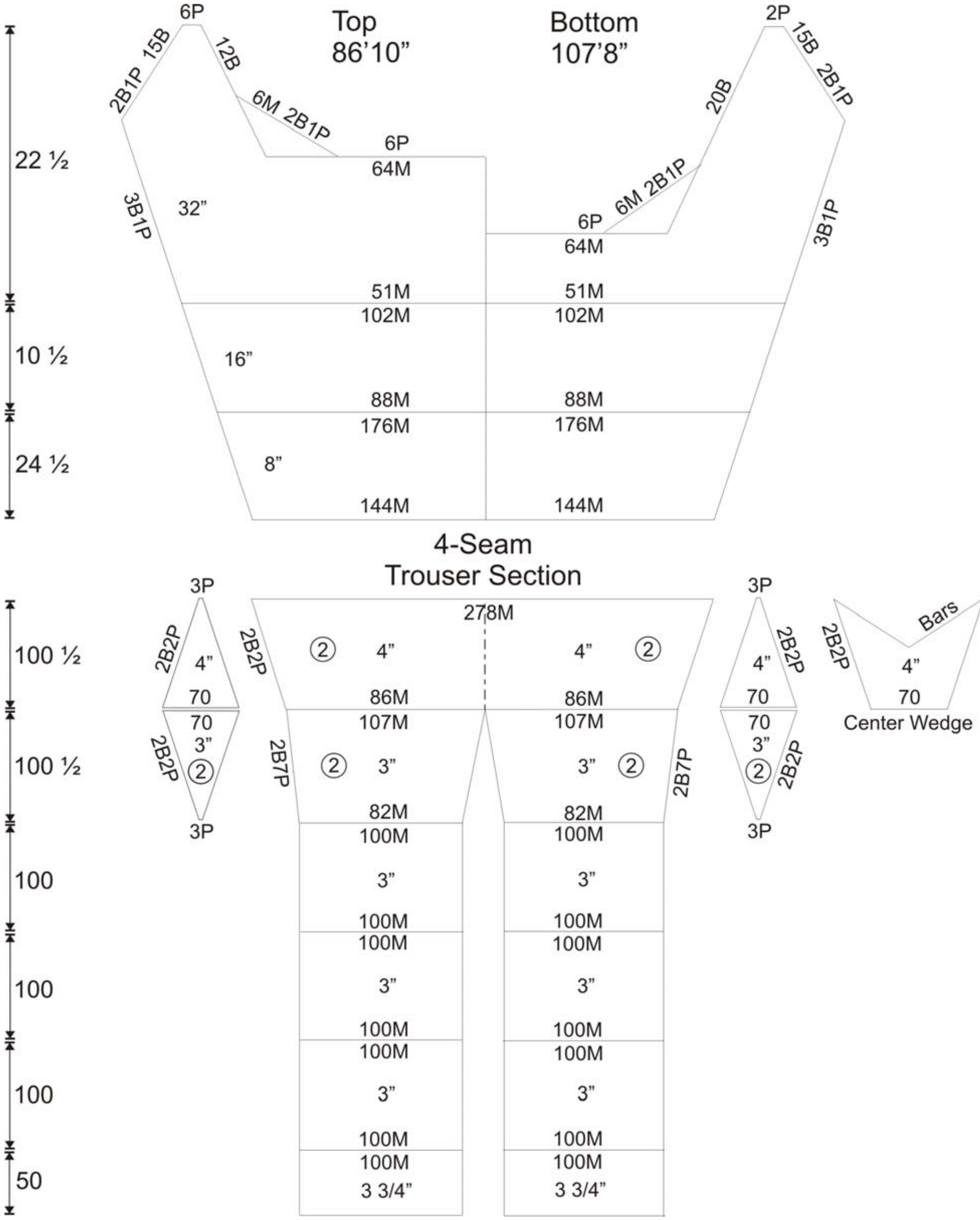


Figure 5. Diagram of the 85 ft (25.9 m) flynet with 32 in (81.3 cm) stretched mesh wings and trouser modification used throughout the study.

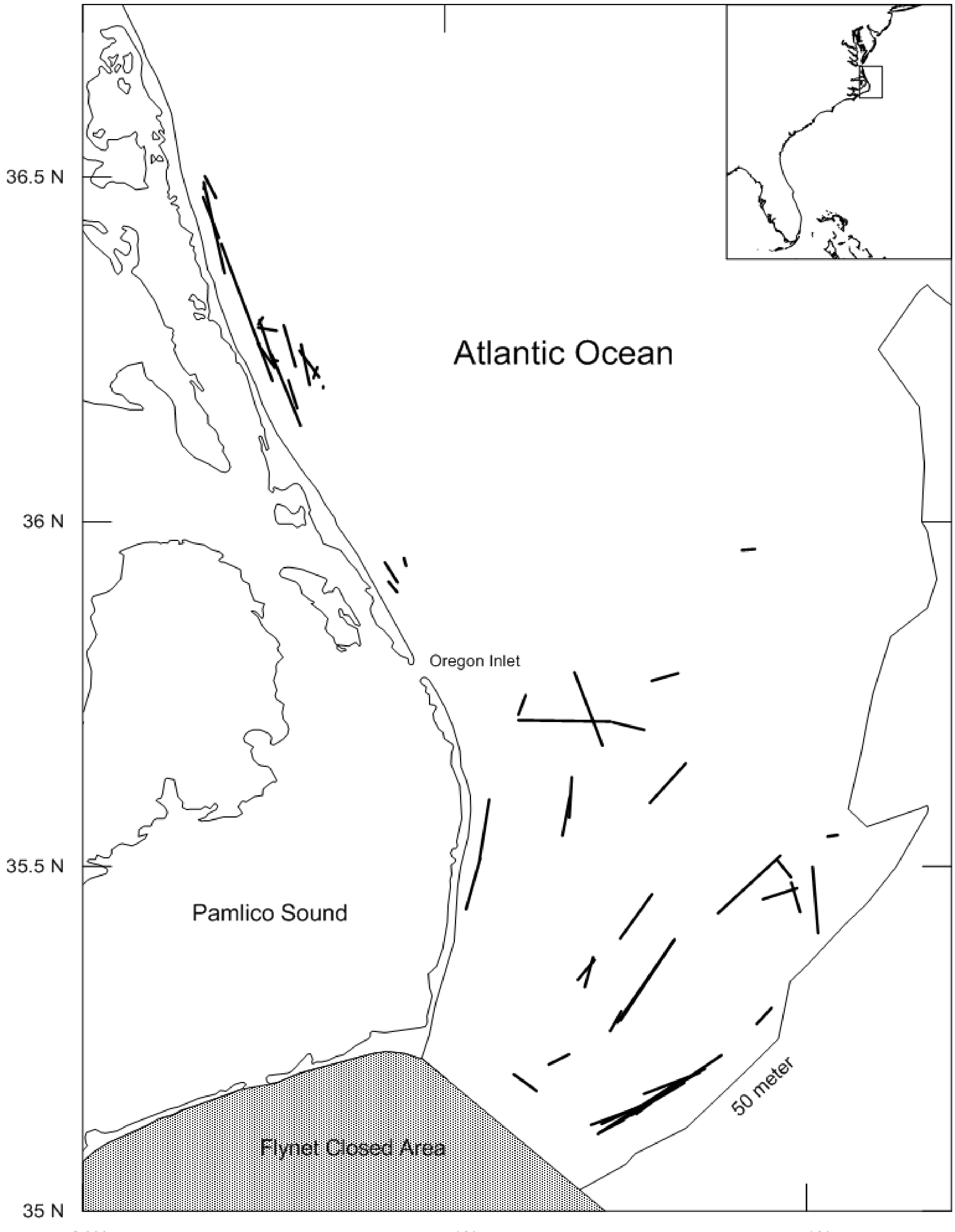


Figure 6. Locations of flynet TED testing trouser trawl tows conducted during the 2008 and 2009 fishing seasons along the North Carolina coast.

Figure 7. Net reel configurations of the four vessels contracted to conduct TED usability testing.

Figure 8. The FFF-TED stored on an 8 ft (3.6 m) wide reel (left) and narrower 4.5 ft (2 m) wide reel (right).

Table 1. Date, location, target species, and haul code for flynet trouser trawl TED testing tows conducted during the 2008 fishing season along the North Carolina coast. Haul codes are: A = alternate gear used; C = calibration tow; F = net fouled; H = hang; M = mud tow; N = no catch; T = bag tripped; Z = good tow.

TripID	Tow #	Date	Latitude	Longitude	Target	Haul Code
200801	1	1/15/2008	35 20.140	75 18.960	Croaker	C
	2	1/15/2008	35 22.090	75 17.690	Croaker	C
	3	1/16/2008	36 08.370	75 41.940	Croaker	C
	4	1/16/2008	36 14.070	75 44.150	Croaker	C
200802	1	2/28/2008	32 07.411	75 16.605	Croaker	H
	2	2/28/2008	35 09.431	75 12.911	Croaker	Z
	3	2/28/2008	35 08.346	75 14.529	Croaker	Z
	4	2/29/2008	35 08.060	75 15.116	Croaker	Z
	5	2/29/2008	35 12.046	75 08.868	Croaker	N
	6	2/29/2008	35 10.456	75 22.370	Croaker	T
	7	2/29/2008	35 12.765	75 21.375	Croaker	T
	8	2/29/2008	35 16.606	75 15.411	Croaker	Z
	9	2/29/2008	35 23.634	75 10.948	Croaker	Z
	10	2/29/2008	35 15.674	75 16.276	Croaker	M
	11	2/29/2008	35 23.734	75 15.444	Croaker	A
200803	1	3/22/2008	36 28.197	75 48.957	Croaker	Z
	2	3/23/2008	35 26.289	75 28.220	Croaker	Z
	3	3/23/2008	35 30.553	75 27.107	Croaker	Z
	4	3/23/2008	35 56.463	75 34.951	Croaker	Z
	5	3/24/2008	36 12.329	75 42.952	Croaker	T
	6	3/24/2008	36 17.114	75 43.332	Croaker	Z

Table 2. Date, location, target species, and haul code for flynet trouser trawl TED testing tows conducted during the 2009 fishing season along the North Carolina coast. Haul codes are: A = alternate gear used; C = calibration tow; F = net fouled; H = hang; M = mud tow; N = no catch; T = bag tripped; Z = good tow.

TripID	Tow #	Date	Latitude	Longitude	Target	Haul Code
200901	1	1/9/2009	35 46.891	75 19.236	Croaker	Z
	2	1/9/2009	35 32.704	75 20.231	Croaker	Z
	3	1/9/2009	35 44.901	75 23.288	Croaker	Z
	4	1/9/2009	35 42.737	75 23.887	Croaker	Z
	5	1/10/2009	35 42.556	75 16.064	Croaker	T
	6	1/10/2009	35 57.532	75 05.353	Croaker	Z
	7	1/10/2009	35 46.811	75 10.639	Croaker	Z
	8	1/11/2009	35 34.250	75 19.674	Croaker	Z
	9	1/11/2009	35 38.965	75 10.011	Croaker	Z
200902	1	2/7/2009	35 07.504	75 17.860	Croaker	Z
	2	2/7/2009	35 09.919	75 12.498	Croaker	F
	3	2/7/2009	35 13.573	75 07.053	Croaker	N
	4	2/7/2009	35 07.927	75 15.149	Croaker	F
	5	2/7/2009	35 06.732	75 17.290	Croaker	Z
	6	2/8/2009	35 07.598	75 16.980	Croaker	N
	7	2/8/2009	35 25.937	75 07.333	Croaker	Z
200903	1	2/10/2009	35 29.075	75 01.297	Croaker	N
	2	2/10/2009	35 26.025	75 00.532	Croaker	N
	3	2/10/2009	35 27.149	75 03.617	Croaker	Z
	4	2/10/2009	35 32.605	74 58.251	Bluefish	Z
	5	2/10/2009	35 29.950	74 59.500	Bluefish	Z
	6	2/11/2009	35 53.877	75 33.939	Menhaden	Z
	7	2/11/2009	35 56.150	75 33.190	Menhaden	Z
200904	1	3/4/2009	35 17.686	75 02.901	Croaker	Z
	2	3/5/2009	36 03.720	75 38.552	Croaker	N
	3	3/6/2009	36 13.441	75 40.555	Menhaden	Z
	4	3/6/2009	36 12.592	75 40.414	Menhaden	Z
	5	3/6/2009	36 15.421	75 41.893	Menhaden	Z
	6	3/6/2009	36 11.642	75 40.063	Menhaden	N
	7	3/7/2009	36 16.630	75 43.920	Menhaden	Z
	8	3/7/2009	36 17.784	75 45.082	Menhaden	Z
	9	3/7/2009	36 17.549	75 45.348	Menhaden	Z
	10	3/7/2009	36 13.418	75 44.079	Menhaden	Z
	11	3/7/2009	36 15.531	75 45.498	Menhaden	N
	12	3/8/2009	36 12.270	75 44.271	Menhaden	Z
	13	3/8/2009	36 24.716	75 48.706	Menhaden	Z
	14	3/8/2009	36 29.414	75 49.896	Menhaden	Z
	15	3/8/2009	36 29.560	75 49.963	Menhaden	F

Table 3. Total catch, target catch, bycatch CPUEs (kg/hr), and percent differences for flynet trouser trawl TED and control catches collected during tows targeting Atlantic croaker. Tows were conducted during the 2008 and 2009 fishing season along the North Carolina coast. TED position is the leg of the trawl where TED was installed (P = Port; S = Starboard). Negative sign indicates TED catch < control catch.

			TED	Total Catch (kg/hr)			Target Catch (kg/hr)			Bycatch (kg/hr)		
TripID	**Tow #**	**Date**	**Pos**	**TED**	**Control**	**%Diff**	**TED**	**Control**	**%Diff**	**TED**	**Control**	**%Diff**
200802	2	28-Feb-08	S	160.1	224.1	-28.6%	154.3	187.2	-17.6%	5.8	36.9	-84.3%
	3	28-Feb-08	S	169.9	97.5	74.2%	94.9	81.4	16.6%	0.0	16.1	-100.0%
	4	29-Feb-08	S	1,280.7	1,171.9	9.3%	1,269.4	1,149.2	10.5%	11.3	22.7	-50.2%
	8	29-Feb-08	S	490.7	400.0	22.7%	412.4	320.5	28.7%	78.3	79.5	-1.5%
	9	29-Feb-08	S	1,176.4	1,659.3	-29.1%	1,132.5	1,615.4	-29.9%	43.9	43.9	0.0%
200803	1	22-Mar-08	P	234.4	604.8	-61.3%	0.0	0.0	-	234.4	604.8	-61.2%
	2	23-Mar-08	P	284.3	614.8	-53.8%	0.0	0.0	-	284.3	614.8	-53.8%
	3	23-Mar-08	P	493.4	977.0	-49.5%	0.0	0.0	-	493.4	977.0	-49.5%
	4	23-Mar-08	P	467.8	786.7	-40.5%	0.0	0.0	-	467.8	786.7	-40.5%
	6	24-Mar-08	P	366.3	829.2	-55.8%	0.0	0.0	-	366.3	829.2	-55.8%
200901	1	9-Jan-09	S	312.9	214.3	46.0%	289.9	151.4	91.5%	22.9	62.9	-63.6%
	2	9-Jan-09	S	5,487.0	5,706.5	-3.8%	5,487.0	5,706.5	-3.8%	0.0	0.0	-
	3	9-Jan-09	S	705.9	620.9	13.7%	569.8	486.2	17.2%	136.1	134.6	1.1%
	4	9-Jan-09	S	243.6	146.4	66.4%	152.0	78.9	92.7%	91.7	67.6	35.7%
	6	10-Jan-09	S	87.6	248.5	-64.7%	0.0	0.0		87.6	248.5	-64.7%
	7	10-Jan-09	S	659.8	670.8	-1.6%	659.8	670.8	-1.6%	0.0	0.0	-
	8	11-Jan-09	S	4,846.6	5,592.2	-13.3%	4,846.6	5,592.2	-13.3%	0.0	0.0	-
	9	11-Jan-09	S	1,205.8	1,205.8	0.0%	1,205.8	1,205.8	0.0%	0.0	0.0	-
200902	1	7-Feb-09	P	1,127.5	855.3	31.8%	1,127.5	855.3	31.8%	0.0	0.0	-
	5	7-Feb-09	P	725.7	850.5	-14.7%	725.7	716.7	1.3%	0.0	133.8	-100.0%
	7	8-Feb-09	P	1,298.5	1,903.3	-31.8%	858.3	951.4	-9.8%	440.2	951.9	-53.8%
200903	3	10-Feb-09	P	898.6	1,412.2	-36.4%	462.2	462.2	0.0%	436.5	950.0	-54.1%
200904	1	4-Mar-09	P	10,583.8	15,119.7	-30.0%	0.0	0.0	-	10,583.8	15,119.7	-30.0%
		Average CPUE		1,448.1	1,822.2	-20.5%	845.6	879.6	-3.9%	765.8	1,204.5	-36.4%

Table 4. Total catch, target catch, bycatch CPUEs (kg/hr), and percent differences for flynet trouser trawl TED and control catches collected during tows targeting bluefish. Tows were conducted during the 2009 fishing season along the North Carolina coast. TED position is the leg of the trawl where TED was installed (P = Port; S = Starboard). Negative sign indicates TED catch < control catch.

			TED	Total Catch (kg/hr)			Target Catch (kg/hr)			Bycatch (kg/hr)		
Tow #	Tow #	Date	Pos	TED	Control	%Diff	TED	Control	%Diff	TED	Control	%Diff
200903	4	10-Feb-09	P	48.7	265.5	-81.7%	48.7	265.5	-81.7%	0.0	0.0	-
	5	10-Feb-09	P	68.0	158.8	-57.1%	68.0	158.8	-57.1%	0.0	0.0	-
		Average CPUE		58.4	212.1	-72.5%	58.4	212.1	-72.5%	0.0	0.0	-

Table 5. Total catch, target catch, bycatch CPUEs (kg/hr), and percent differences for flynet trouser trawl TED and control catches collected during tows targeting Atlantic menhaden. Tows were conducted during the 2009 fishing season along the North Carolina coast. TED position is the leg of the trawl where TED was installed (P = Port; S = Starboard). Negative sign indicates TED catch < control catch.

			TED	Total Catch (kg/hr)			Target Catch (kg/hr)			Bycatch (kg/hr)		
Tow #	Tow #	Date	Pos	TED	Control	%Diff	TED	Control	%Diff	TED	Control	%Diff
200903	6	11-Feb-09	P	19,958.0	41,471.3	-51.9%	19,958.0	41,471.3	-51.9%	0.0	0.0	-
	7	11-Feb-09	P	14,260.9	22,969.9	-37.9%	14,260.9	22,969.9	-37.9%	0.0	0.0	-
200904	3	6-Mar-09	P	445.3	513.9	-13.3%	356.8	145.7	144.9%	88.6	368.2	-75.9%
	4	6-Mar-09	P	657.7	714.4	-7.9%	626.6	613.9	2.1%	31.1	100.5	-69.1%
	5	6-Mar-09	P	738.3	825.2	-10.5%	695.2	706.6	-1.6%	43.1	118.6	-63.7%
	7	7-Mar-09	P	3,164.6	4,708.9	-32.8%	3,133.0	4,625.0	-32.3%	31.5	83.9	-62.4%
	8	7-Mar-09	P	805.1	1,219.0	-34.0%	699.5	1,022.6	-31.6%	105.6	196.4	-46.2%
	9	7-Mar-09	P	903.6	1,248.3	-27.6%	786.1	1,041.2	-24.5%	117.5	207.1	-43.3%
	10	7-Mar-09	P	1,602.7	2,373.8	-32.5%	1,602.7	2,373.8	-32.5%	0.0	0.0	-
	12	8-Mar-09	P	556.1	1,386.9	-59.9%	556.1	1,386.9	-59.9%	0.0	0.0	-
	13	8-Mar-09	P	2,044.6	2,507.2	-18.5%	2,044.6	2,507.2	-18.5%	0.0	0.0	-
	14	8-Mar-09	P	1,072.1	1,484.5	-27.8%	1,072.1	1,484.5	-27.8%	0.0	0.0	-
		Average CPUE		3,850.8	6,785.3	-43.2%	3,816.0	6,695.7	-43.0%	69.6	179.1	-61.2%

Table 6. Shark species bycatch CPUEs (kg/hr; #/hr), and percent differences for flynet trouser trawl TED and control catches collected during the 2008 and 2009 fishing season along the North Carolina coast. TED position is the leg of the trawl where TED was installed for a given tow (P = Port; S = Starboard). Negative sign indicates TED catch < control catch.

			TED	Shark Catch (kg/hr)			Shark Catch (#/hr)		
TripID	Tow #	Date	Pos	TED	Control	%Diff	TED	Control	%Diff
200802	2	28-Feb-08	S	5.8	36.9	-84.3%	1	4	-66.7%
	3	28-Feb-08	S	0.0	16.1	-100.0%	0	2	-100.0%
	4	29-Feb-08	S	11.3	17.9	-36.9%	4	3	50.0%
	8	29-Feb-08	S	78.3	79.5	-1.5%	39	37	6.2%
	9	29-Feb-08	S	43.9	43.9	0.0%	18	18	0.0%
200803	1	22-Mar-08	P	157.5	413.5	-61.9%	58	140	-58.3%
	2	23-Mar-08	P	220.6	483.1	-54.3%	83	156	-47.3%
	3	23-Mar-08	P	328.3	696.2	-52.8%	110	232	-52.8%
	4	23-Mar-08	P	140.6	405.5	-65.3%	54	120	-54.5%
	6	24-Mar-08	P	184.7	404.0	-54.3%	84	166	-49.3%
200901	1	9-Jan-09	S	11.8	51.0	-76.9%	17	64	-73.5%
	3	9-Jan-09	S	105.6	81.9	29.0%	64	43	47.8%
	4	9-Jan-09	S	66.4	42.1	57.7%	93	41	124.1%
	6	10-Jan-09	S	39.2	57.9	-32.4%	16	27	-38.5%
200902	5	7-Feb-09	P	0.0	73.7	-100.0%	0	4	-100.0%
	7	8-Feb-09	P	440.2	951.9	-53.8%	179	397	-54.9%
200903	3	10-Feb-09	P	436.5	950.0	-54.1%	190	380	-50.1%
200904	1	4-Mar-09	P	10,583.8	15,119.7	-30.0%	4602	6048	-23.9%
	3	6-Mar-09	P	83.8	125.8	-33.4%	35	52	-31.7%
	4	6-Mar-09	P	22.4	65.0	-65.5%	8	28	-69.7%
	5	6-Mar-09	P	39.0	85.4	-54.3%	16	33	-50.5%
	7	7-Mar-09	P	16.7	45.3	-63.1%	7	17	-60.0%
	8	7-Mar-09	P	97.2	156.4	-37.8%	37	57	-36.3%
	9	7-Mar-09	P	98.7	179.8	-45.1%	40	74	-46.2%
		Average CPUE		550.5	857.6	-35.8%	45	81	-44.3%

Table 7. Ray and skate species bycatch CPUEs (kg/hr; #/hr), and percent differences for flynet trouser trawl TED and control catches collected during the 2008 and 2009 fishing season along the North Carolina coast. TED position is the leg of the trawl where TED was installed for a given tow (P = Port; S = Starboard). Negative sign indicates TED catch < control catch.

TripID	Tow #	Date	TED Pos	Ray Catch (kg/hr) TED	Ray Catch (kg/hr) Control	%Diff	Ray Catch (#/hr) TED	Ray Catch (#/hr) Control	%Diff
200802	4	29-Feb-08	S	0.0	4.8	-100.0%	0	1	-100.0%
200803	1	22-Mar-08	P	29.8	37.2	-19.7%	22	22	0.0%
	2	23-Mar-08	P	59.2	125.7	-52.9%	38	73	-48.5%
	3	23-Mar-08	P	26.9	118.6	-77.3%	17	68	-75.2%
	4	23-Mar-08	P	34.5	72.3	-52.3%	17	44	-60.6%
	6	24-Mar-08	P	39.2	112.2	-65.1%	26	78	-66.9%
200901	1	9-Jan-09	S	11.1	11.9	-7.1%	9	9	11.1%
	3	9-Jan-09	S	30.5	52.8	-42.2%	21	13	57.1%
	4	9-Jan-09	S	25.2	25.4	-0.7%	19	18	4.8%
	6	10-Jan-09	S	48.4	190.5	-74.6%	46	103	-55.0%
200902	5	7-Feb-09	P	0.0	45.4	-100.0%	0	1	-100.0%
200904	3	6-Mar-09	P	4.8	157.5	-97.0%	2	75	-97.2%
	4	6-Mar-09	P	8.7	29.3	-70.4%	5	14	-66.7%
	5	6-Mar-09	P	4.1	26.8	-84.8%	2	12	-84.2%
	7	7-Mar-09	P	14.8	38.6	-61.6%	7	17	-60.0%
	8	7-Mar-09	P	6.8	13.8	-50.7%	2	6	-66.7%
	9	7-Mar-09	P	18.8	16.4	14.6%	6	8	-20.0%
		Average CPUE		21.3	63.5	-66.4%	14	33	-57.5%

Table 8. Capture information for sea turtles incidentally caught during flynet trouser trawl TED testing conducting during the 2008 and 2009 fishing seasons along the North Carolina coast. CCL = Curved Carapace Length.

TripID	Tow #	Date	Species	CCL(mm)	Latitude	Longitude	Cond	Comments
200802	2	2/28/08	Loggerhead	781	35 08.459	75 14.108	Alive	In control codend
200802	8	2/29/08	Loggerhead	730	35 23.599	75 10.972	Alive	In control codend
200802	8	2/29/08	Loggerhead	NA	35 23.599	75 10.972	Alive	Entangled wing of net
200802	10	2/29/08	Loggerhead	781	35 17.400	75 15.356	Alive	In body of net
200802	11	3/1/08	Loggerhead	648	35 27.584	75 12.810	Alive	In control codend
200901	1	1/9/09	Loggerhead	700	35 40.513	75 16.913	Alive	In control codend
200901	4	1/9/09	Loggerhead	760	35 42.620	75 16.251	Alive	In control codend
200901	5	1/10/09	Loggerhead	NA	35 41.879	75 13.457	Alive	In control codend
200901	8	1/11/09	Loggerhead	NA	35 37.757	75 19.470	Alive	Video escaping from TED
200901	9	1/11/09	Loggerhead	NA	35 35.549	75 12.974	Alive	In control codend

Table 9. Results of catch comparisons for total, target, and bycatch categories by target species. All tows across target species containing primary bycatch species were analyzed separately. P values indicate the results of one-tailed paired t-tests; n = number of tows with species occurrences; negative sign for differences indicates TED catch < control catch. Power value indicates the results of analysis to determine power to detect the given difference at an alpha of 0.10. * = Power analysis was conducted to determine power to detect a 20% difference at an alpha of 0.10.

Category	Species	n	Mean Diff (kg/hr)	SD	% Change	P value	Power
Targeting Atlantic croaker							
	Total Catch	23	374.1	948.4	-20.5%	0.0359	0.717
	Target Catch	16	48.9	250.0	- 3.9%	0.2229	0.996*
	Bycatch	18	438.7	1,042.6	-36.4%	0.0460	0.677
Targeting Atlatnic menhaden							
	Total Catch	12	2,934.5	6,322.3	-43.2%	0.0681	0.605
	Target Catch	12	2,879.7	6,347.9	-43.0%	0.0722	0.591
	Bycatch	6	109.5	84.5	-61.2%	0.0123	0.946
Primary Bycatch Species							
	Shark spp	24	2,499.3	2,994.8	-35.8%	0.0568	0.631
	Ray spp	17	42.1	48.2	-66.4%	0.0012	0.987