Reducing Sea Turtle Bycatch in Trawl Nets: A History of NMFS Turtle Excluder Device (TED) Research

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Introduction

Sea turtle, Chelonioidea, bycatch became a Federal management issue for the U.S. southeast shrimp trawl fishery in the 1970's after the listing of all seven sea turtle species under the Endangered Species Act (ESA). Although five species of sea turtle may encounter shrimp trawls in U.S. waters, those of most concern are the loggerhead, *Caretta caretta,* and Kemp's ridley, *Lepidochelys kempii*.

The loggerhead is the sea turtle most often captured by U.S. shrimp trawls. At the beginning of the National Marine Fisheries Service (NMFS), NOAA, research program, the Kemp's ridley was considered the most endangered sea turtle, because it nests on only one beach, Rancho Nuevo, Mexico, and at one time had a nesting female population of only 300 individuals (National Research Council, 1990; Lutz and Musick, 1997; Lutz et al., 2003). NMFS and the U.S Fish and Wildlife Service (FWS) share responsibility for protecting sea turtles, with NMFS being responsible for protection at sea and the FWS being responsible for protection on land, such as protecting nesting females, eggs, and hatchlings.

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ABSTRACT—Thirty-six years ago, NOAA's National Marine Fisheries Service began research on how to reduce mortality of sea turtles, Chelonioidea, *in shrimp trawls. As a result of efforts of NMFS and many stakeholders, including domestic and foreign fishermen, environmentalists, Sea Grant agents, and government agencies, many trawl fisheries around the world use a version of the turtle excluder device (TED). This article chronicles the contributions of NMFS to this effort, much of which occurred at the NMFS Mississippi Laboratories in Pascagoula. Specifically, it summarizes the impetus for and results of major developments and little known events in the TED research and discusses how these influenced the course of subsequent research.*

To conserve sea turtles, people have taken measures to protect them, particularly as hatchlings and adults. Beach monitors relocate and place protective barriers around nests. Municipalities have encouraged or mandated that residents regulate light use and beach traffic. With limited success, some conservation and management groups have attempted captive breeding, artificial imprinting of hatchlings on new nesting beaches, and headstarting (the captive rearing and release of turtles once they are beyond the size of most natural predation) (National Research Council, 1990; Lutz and Musick, 1997; Lutz et al., 2003).

However, studies on the reproductive value of different life stages of loggerhead sea turtles reveal that recovery of these populations cannot occur with protection of eggs and hatchlings alone. The most reproductively valuable lifestages are subadults and adults, which are the lifestages most impacted as bycatch (Crouse et al., 1987). Thus is it critical to reduce sea turtle mortality in shrimp trawls.

Shrimp and sea turtles often share the same aquatic habitat—including coastal waters along the southeastern United States—so shrimpers have likely encountered sea turtles since the beginning of the U.S. shrimp trawl fishery in 1913. This fishery involves pulling a net behind a boat. With advances in fishing technology, such as more powerful engines and winches to haul the net, shrimpers began using larger nets and pulling them for longer periods of time. Presently, shrimpers typically tow their nets underwater for 2–3 h at a time. Sea turtles encountering a net might attempt to swim away from it and are often entrained. If unable to surface to breathe, turtles can drown during the long tow time (National Research Council, 1990).

To address the problem of sea turtle bycatch in trawls, it is essential to understand the fishing process and the fishing gear used. During the shrimp fishing process the outriggers, which are stored upright, are lowered over the water (Fig. 1). Attached to each outrigger are one or two nets typically 30–50 ft in headrope length (Fig. 2). Each net is equipped with a pair of large rectangular wooden doors that are 3–10 ft long. When lowered into the water, they slide on their edge along the seabed. The doors are rigged with chains to pull at an angle so that the force of the water pushes them apart and spreads the net open between them.

For each door, attached between the door and ahead of the net is a tickler chain. This looped length of chain drags along the seabed, startling shrimp off the bottom so that they can be captured by the net. A leadline, also known as a footrope, is the weighted line that extends between the doors along the bottom of the net and helps to keep the net close to the seabed. The corkline, floatline, or headrope is attached to the top of the net and is fixed with varying numbers of floats. The floats and weights help determine the shape of the net in the water.

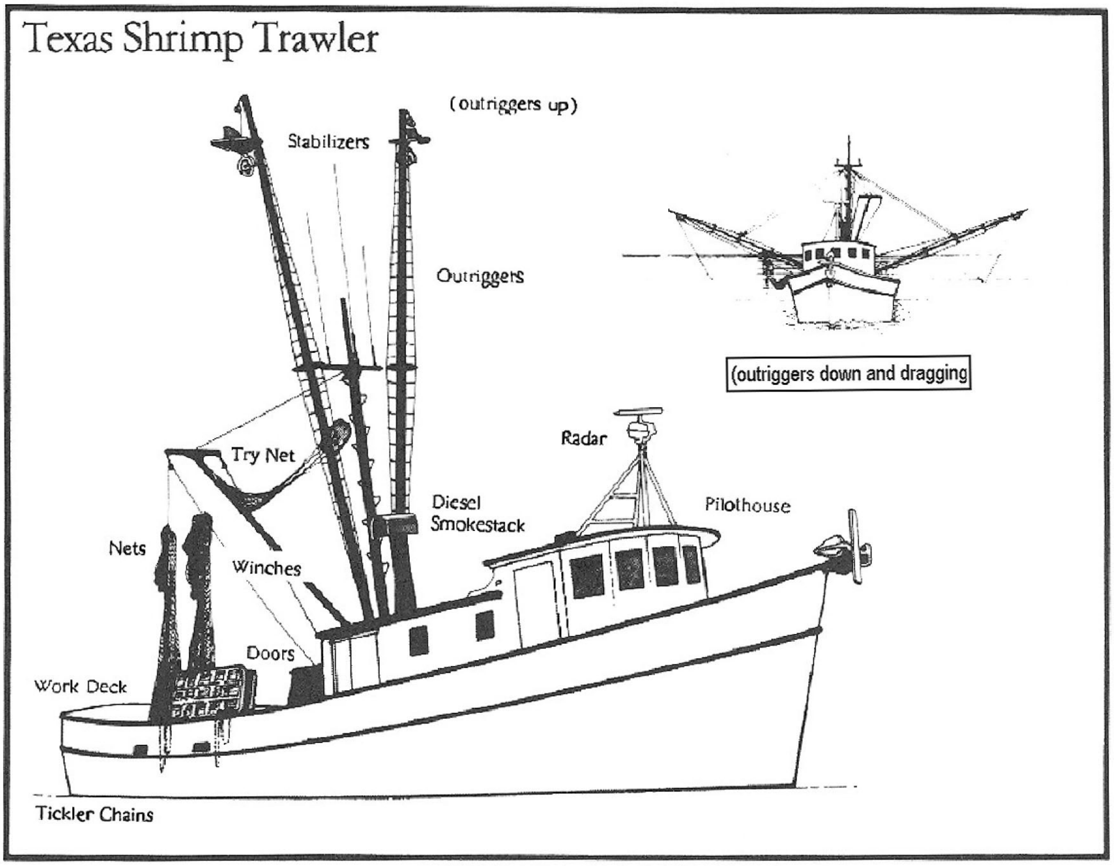

Figure 1.—Shrimp trawl boat (Source: Maril, 1983).

The shape of the net is also affected by how it is sewn together, and about six different types of net designs are used in the U.S. shrimp trawl fishery. The seams of the net, where the top net is sewn to the bottom net, are called the wings. The entrance of the net is called the mouth. The net tapers back from the mouth to form a funnel, and the narrow part of the funnel is referred to as the throat. At the back of the net is the net bag or codend, where the captured shrimp are collected. Attached to the codend is the lazy line that allows the back of the net to be swung onboard for emptying (Maril, 1983; 1995; Maiolo, 2004).

This paper chronicles the research that the NMFS began 36 years ago on reducing mortality of sea turtles in shrimp trawls. As a result of the combined efforts of NMFS and many stakeholders—including domestic and foreign fishermen, environmentalists, Sea Grant agents, and government agencies—this extended community invented and continues to improve the turtle excluder device (TED). The notable contributions of members of this community, including shrimpers and Sea Grant agents, far exceeds the capacity of one paper, so this article focuses on the contributions of NMFS to this effort, much of which occurred at the NMFS Mississippi Laboratories in Pascagoula (Fig. 3). Specifically, it summarizes the impetus for and results of major NMFS developments and little known events in the TED research and discusses how these influenced the course of subsequent NMFS research.

History

Barrier Devices

The effort to invent a device to reduce sea turtle bycatch in trawls began in 1976, but it was linked to events that took place in 1973 and 1974. During those years, while observing the operation of various experimental trawl nets, NMFS serendipitously recorded three sea turtles encountering the trawl net. One of these trawls was a separator trawl, a type of net that has a large mesh panel that directed large objects out of a hole in the net while allowing small objects like shrimp to proceed into the net bag (Fig. 4). The turtle became entangled by its scutes and flippers and became trapped in the exclusion chute (Ogren et al., 1977). The video of these encounters laid the foundation for the initial course of research NMFS pursued in 1976, when NMFS began researching gear modifications that would reduce sea turtle mortality in shrimp trawls. At the beginning of its research program, NMFS consulted with sea turtle specialists Archie Carr and Larry Ogren. Based

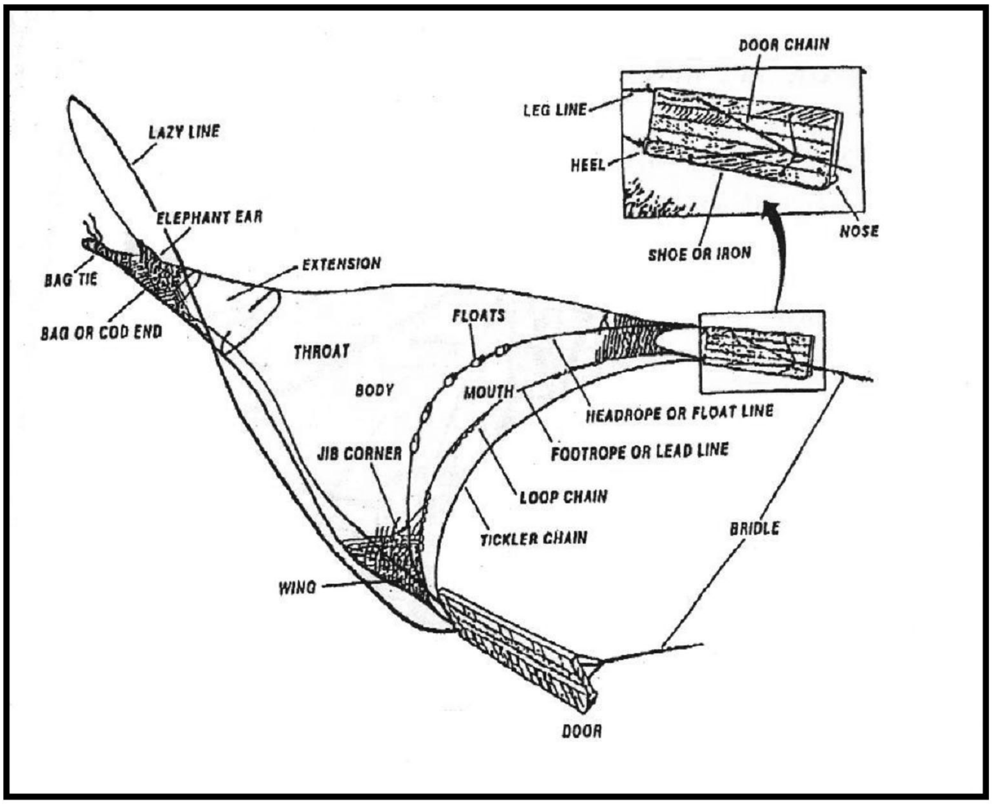

Figure 2. —Shrimp trawl net (Source: Maiolo, 2004).

on the video, the turtle specialists were concerned that if a sea turtle entered the trawl net, its marginal scutes might become entangled in the mesh. For this reason, NMFS initially pursued a barrier panel to prevent the capture of sea turtles by barring their entrance to the net.

Fieldwork on the gear began in 1978, with limited collaboration with the Southeastern Fisheries Association and the Texas Shrimp Association to facilitate the use of commercial fishing vessels to conduct sea turtle population studies and to test gear. NMFS developed two panel designs. One design was called the "forward barrier," which consisted of a panel of webbing attached to and sloping forward from the headrope down to a bottom-line that ran between the trawl doors. This design can be likened in appearance and function to the cowcatchers placed on locomotives. Unfortunately, turtles were able to go under the bottom-line and into the trawl. Also, some fishing conditions altered the trawl configurations, causing the bottom-line of the barrier to touch the seafloor, stimulating shrimp ahead of the trawl and allowing their escape. In 1978, NMFS abandoned the forward barrier, because it only reduced turtle capture by 30% and had a large (38–53%) shrimp loss.

In 1979, gear specialists modified the forward barrier design, resulting in the "reverse barrier" (Fig. 5). In this design, the webbing panel attached to the headrope and sloped backwards from it to the footrope. The best reverse barrier design reduced turtle capture by 79% and shrimp capture by 15–30%. Unfortunately, the reverse barrier increased the drag on the trawl, causing it to lift up like the wing of a plane and resulted in the loss of shrimp. NMFS attempted to correct this problem by adding weight to the footrope, but the shrimpers on the cooperative vessels testing the gear objected to this as it made the trawl more difficult to use. NMFS tried various other rigging techniques to correct the problems with the reverse barrier with limited success.

In 1981, NMFS abandoned the reverse barrier device because of its high rate of shrimp loss and complex design. The device also became easily clogged with debris that caused the trawl to become deformed, resulting in the capture of turtles and the loss of shrimp. In addition, the device required custom fitting to the net, thus greatly restricting subsequent alterations to the trawl dimensions. For example, in order to fish effectively for different species of shrimp, shrimpers commonly alter the height of the trawl mouth with floats, but the custom fitted reverse barrier would inhibit such alterations.

The NMFS TED

In 1980, the University of Georgia, Marine Extension Service (UGA MAREX) sent NMFS photos of a "jellyball shooter" and suggested a similar approach could work for ex-

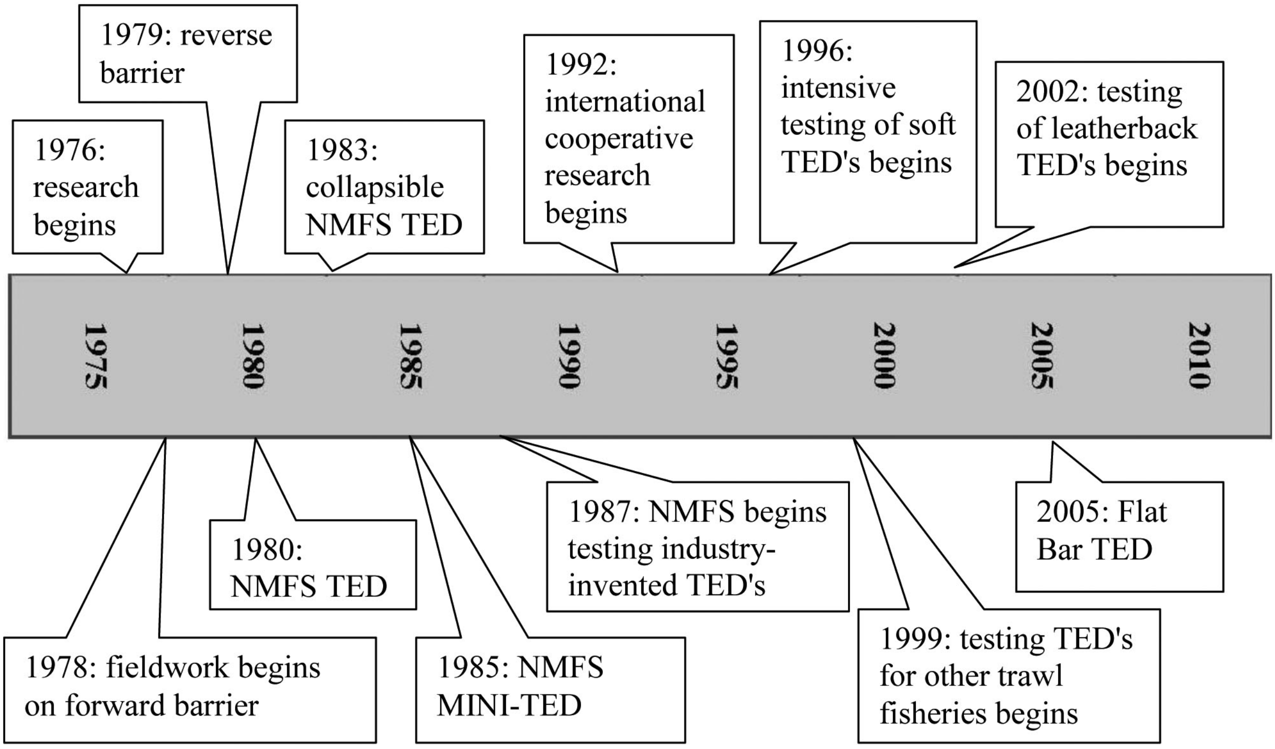

Figure 3.—Timeline of major events in NMFS sea turtle bycatch reduction research.

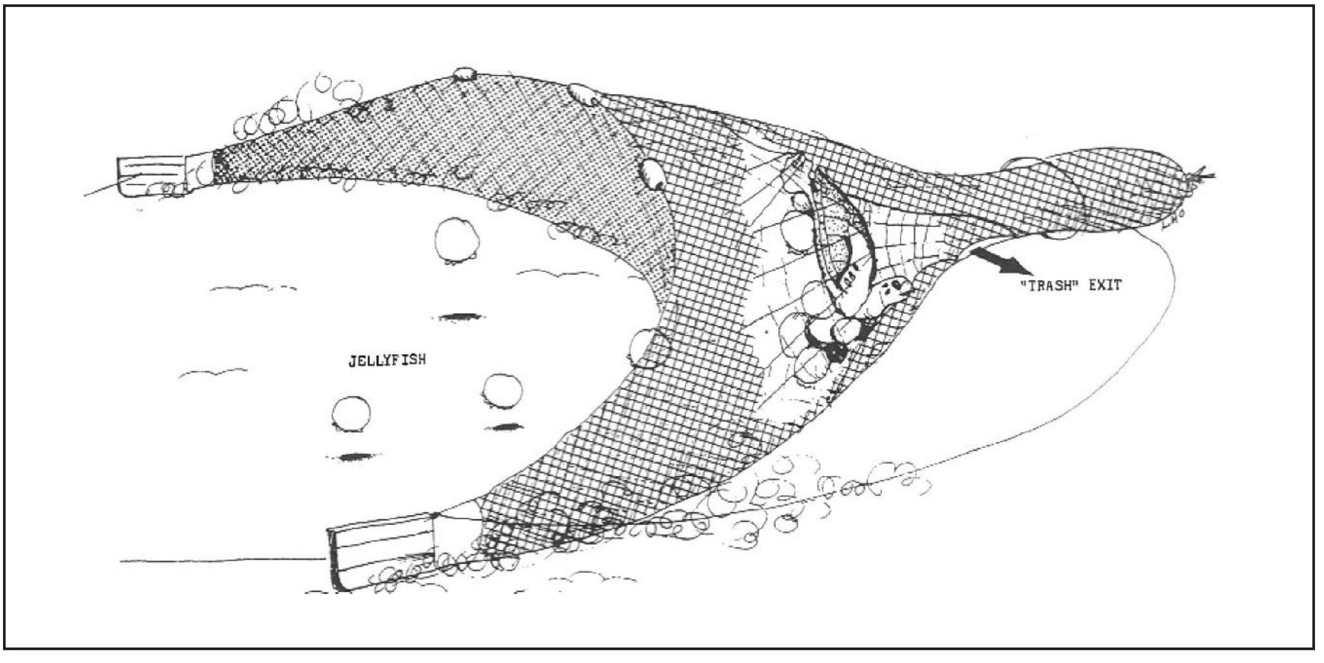

Figure 4.—Separator trawl with entrained sea turtle (Source: Ogren et al., 1977).

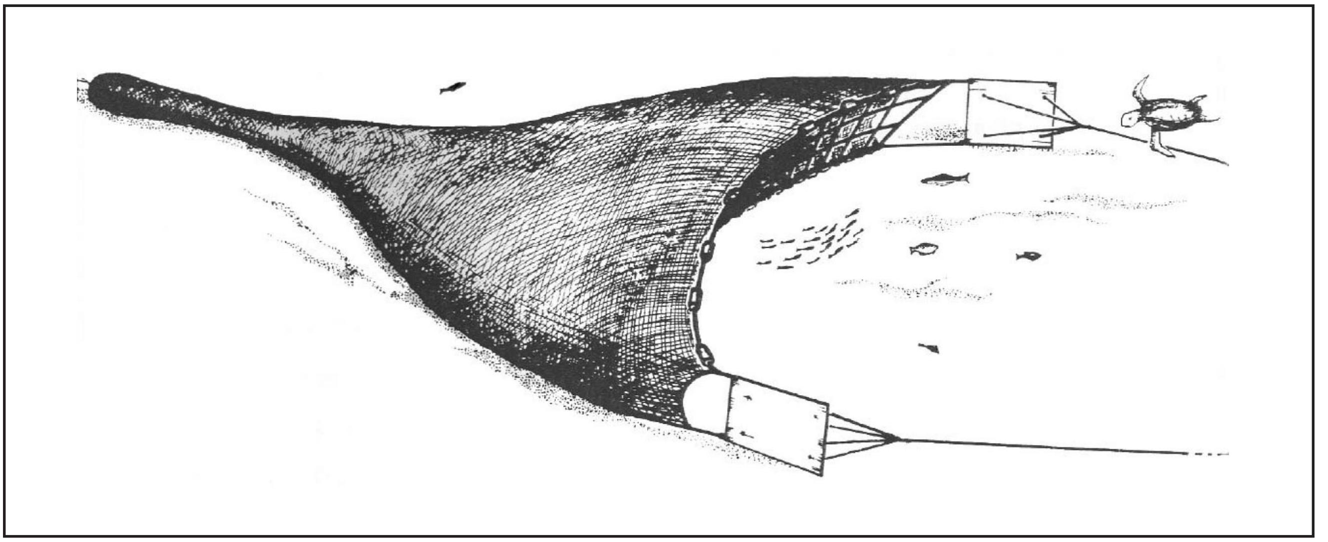

Figure 5.—Reverse barrier (Source: J. Watson. 1980. Milestone report: sea turtle excluder trawl project. NMFS, SEFC, Pascagoula Laboratory, Miss. [Available from Jenkins.]).

cluding turtles. The jellyball shooter had been used for decades, especially by shrimpers in South Carolina and Georgia, when cannonball jellyfish, *Stomolophus meleagris*, are so dense that shrimping could not otherwise occur. The jellyball shooter consists of a grid that is placed in the neck of the trawl to block large objects from entering the net bag and directs them out of a hole cut in the net.

Based on these photographs, John Watson, then head of the NMFS Sea Turtle Excluder Trawl Project, and Eddie Toomer, a contract vessel captain from Winter Haven, Fla., independently and simultaneously conceived of placing the grid within a frame. Watson constructed his version from fragile PVC and Toomer constructed his from heavy steel. Though Toomer's original model was too heavy and Watson's too fragile to be practical, NMFS drew ideas from both to apply to a new design. NMFS called the resulting prototype the turtle excluder device (TED) (Fig. 6).

The original prototype resulting from these conceptual models was designed to exclude large loggerhead turtles. The frame was slightly more than 1 cu yd and weighed about 97 lb. A grid was slanted 45° between a front and back oval hoop. The grid bars were spaced six inches apart and the device had a 3-ft square door on the bottom. The NMFS TED excluded 89% of the turtles that entered the net and had no statistically significant loss of shrimp. NMFS developed a top-opening TED as a result of divers' observations that turtles had difficulty escaping out of the bottom-opening door and attempted to escape upwards. This top-opening TED increased the turtle exclusion rate to 97%.

To reduce shrimp loss, NMFS developed a device called an accelerator funnel. This tube of webbing functioned by accelerating the water through the TED, thus carrying more shrimp into the codend. The result was a 7% increase in shrimp catch in comparison to a trawl without a TED.

One of the research objectives for 1981 was to determine if there was a difference in shrimp catch with TED's on major shrimping grounds. After testing the NMFS TED against a standard trawl net in South Carolina, Georgia, Florida, Mississippi, Alabama, Louisiana, and Texas, NMFS determined there was either no statistical difference or an increase in shrimp retention when using TED's.

In 1982, hoping to increase TED adoption, NMFS reduced the size of the NMFS TED to exactly 1 cu yd. Observer data on size of the most commonly caught turtle species suggested that the TED could be smaller with no reduction in turtle release efficiency. NMFS reduced the size of the TED, so it would fit the smaller twin trawls common in the Gulf of Mexico fishery. Also, the size reduction allowed for easier handling and storage. During testing, this TED had a statistically insignificant increase in shrimp catch.

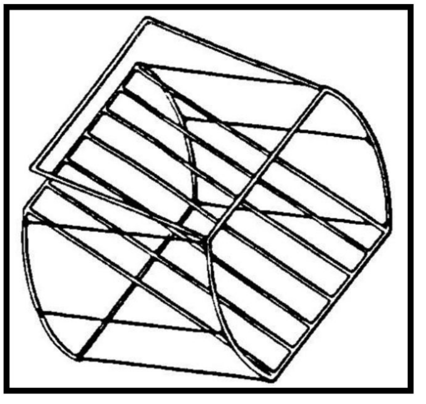

Figure 6.—The NMFS TED (Source: NMFS, SEFC, Pascagoula Laboratory, Miss. [Available from Jenkins.]).

In 1983, to make the TED even more appealing to shrimpers, NMFS modified not only the device but also its name. NMFS officially renamed the "turtle excluder device" the "trawling efficiency device" in an attempt to market its ability to exclude trash that could damage the net and to reduce finfish bycatch with a hummer wire that vibrated, encouraging fish to exit the net.

NMFS also explored the use of alternative lighter materials for TED construction. With the help of the Naval Surface Weapons Center's Plastics Laboratory, NMFS created two new prototypes: a plastic NMFS TED and a fiberglass NMFS TED. The plastic NMFS TED was too flexible and could not withstand minimum loads. The fiberglass NMFS TED was stable but not durable, so NMFS modified it to increase durability. NMFS also created a collapsible fiberglass TED. Testing showed that these prototypes were not strong enough for commercial use.

NMFS also explored the use of aluminum TED's but determined that they would be more costly than those made from galvanized steel. The aluminum TED was also too light and was unstable when towed on the surface, causing the TED to roll, twisting the codend. In 1983, NMFS also began work on the collapsible NMFS TED. Both ends of the deflector bars had hinges that allowed this TED to fold for easy space-saving storage. During fishing, the water tension forced the TED into an open configuration.

In 1984, NMFS further modified the NMFS TED to improve the its handling. NMFS decided to make the TED even smaller by reducing the door width from 36 to 30 inches and the frame width from 52 to 42 inches. This reduction would still allow 95% of turtles to escape. The remaining 5% represented mostly large adult loggerheads.

In 1985, NMFS developed a smaller TED for use in inshore waters. A prototype half-scale TED became easily fouled and was not large enough to reduce bycatch. A two-thirds scale TED, however, reduced bycatch by 50% without any statistically significant shrimp loss. This TED became known as the Mini-TED.

During the next 2 yr, NMFS conducted field tests of the NMFS TED on board cooperative vessels in every southeast U.S. state with a commercial fleet. These states were North Carolina, South Carolina, Georgia, Florida, Louisiana, Alabama, and Texas. Mississippi had been the site of previous field tests, as it is the home of NMFS laboratory that developed the NMFS TED. As a result of the field tests, NMFS further modified the NMFS TED, most notably by removing a shock cord that was used to hold the accelerator funnel in place. The shock cord could become lodged between the front carapace and neck of sea turtles as they passed through the accelerator funnel, inhibiting their ability to exit through the TED.

The late 1980's marked the end of in-depth research to modify and improve the NMFS TED. Around 1990 NMFS focused anew on TED invention, and these efforts produced the Taylor Soft TED and the Super Shooter TED, which will be discussed later. What immediately followed the NMFS TED era was a period of increased NMFS cooperation with the fishing industry to test and improve shrimper-invented TED's. During this time the protocols for testing TED's also evolved.

TED Testing Protocols

Part of the foundation of the effort to invent a device to reduce sea turtle bycatch was the development of a process by which to test these devices. The process by which TED's were evaluated changed significantly over the first 15 years of research. Initially, NMFS evaluated TED's using a comparative trawl test design in which one net had a TED and the other net on the same vessel did not. NMFS consistently used this test design through 1985. While this allowed NMFS to evaluate the shrimp retention of TED's under various fishing conditions in numerous states, it was not well suited to evaluate sea turtle exclusion. Because researchers did not know the density of sea turtles in an area, they could not determine whether a TED had effectively excluded sea turtles or whether the trawl did not encounter any turtles.

In 1986 the UGA MAREX conducted a demonstration test at Cape Canaveral, Fla., that led to the development of a testing protocol that compared the number of wild turtles caught in a net that had a TED with the number of wild turtles caught in a control net that did not have a TED. The Cape Canaveral ship channel was known to have a very high density of sea turtles, so testing in this area almost insured that both the control net and the net with the TED would encounter sea turtles.

From 1986 to 1989, NMFS used tests in the Cape Canaveral ship channel to evaluate industry-developed TED's and certify them for commercial use. For a TED to become certified for commercial use it must exclude at least 97% of the turtles that enter the trawl (NOAA, 1990a). This figure is based on the exclusion rate obtainable with the NMFS TED. There were several problems with this protocol including the unexplained death of a couple of turtles, the inability to document the number of turtles entering each net, and the vague definition of a "captured turtle." With the latter problem, it was often difficult to determine if a turtle discovered in the net at the end of a test had entered the net just before the test ended and would have exited through the TED if given more time or if that turtle was truly ensnared in the net.

NMFS abandoned this testing protocol in 1989, because there was no longer a high concentration of turtles in the Cape Canaveral channel. UGA MAREX continued to survey the turtle populations in this and other potential testing sites with dense turtle populations. By the time the Cape Canaveral turtle populations had recovered, however, NMFS was committed to a different testing protocol, so testing in Cape Canaveral has only occurred a few times since then. In 1988, NMFS used a new testing protocol to evaluate several TED's, and this alternative protocol evolved into the small-turtle TED testing protocol.

NMFS developed a small-turtle TED testing protocol for conducting tests using small sea turtles in the clear waters off Panama City, Fla., that it has used consistently since 1990. The protocol consisted of seven components[1]:

1) Each day, the researchers randomly selected two TED's and tested each 10 times. This was repeated on a second day, so that they tested each TED a total of 20 times.
2) Turtles were kept in holding pens until transferred to the test vessel, where they were held in a fiberglass tank of seawater.
3) Each turtle was delivered to divers by placing it in a Herculite bag and clipping it to a steel messenger wire that was attached to the trawl.
4) Three divers monitored the test. Diver number one received the turtle and released it under and behind the trawl headrope.
5) Diver number two recorded a) the time elapsed from the turtle's release into the trawl to the turtle's encounter with the TED, b) time elapsed from the turtle's encounter with the TED to the turtle's escape or removal from the TED, c) turtle activity code, and d) water clarity code.
6) Diver number three recorded each test using an underwater video camera.
7) Once the turtle encountered the TED, the divers initiated a 2-min time limit. If after this time the turtle had not escaped, a diver removed it. This limit allowed sufficient time to evaluate TED performance, limited diver time, and insured minimal stress to the turtle.

Based on an idea originally proposed by UGA MAREX, the protocol involved the release of captive-reared juvenile green turtles into the net and the filming of their progress through the net. The turtles had to escape within a certain time or it was considered captured. After the first year of testing, NMFS increased the testing time limit from 2 to 5 min. If the turtle remained in the net after the time limit, NMFS declared it a capture. An even longer time limit was proposed but blood chemistry tests revealed that this would increase the turtle's stress level.

Over the years, NMFS has improved the small-turtle testing protocol. To evaluate the small-turtle TED testing protocol, in 1989 NMFS convened a review panel that determined the protocol was limited in that: 1) captive turtles behaved differently than wild caught turtles, 2) captive turtles were not as physically fit as wild turtles, and 3) test turtles could not be introduced to the net in the same way a wild turtle would be. In response, NMFS conditioned the turtles in ponds to make them more physically fit.

During the first few years of the small-turtle testing, many of the turtles were positively buoyant. NMFS addressed the buoyancy problem by improving the turtle's conditioning, minimizing their stress, and noting for consideration during analysis when turtles displayed buoyancy problems during the test. Eventually, NMFS partially addressed the effect of release position on the test by randomizing the release location of the turtle into the net. Although this testing protocol remains controversial, NMFS believes that the test is precautionary, because a TED should exclude a sea turtle no matter its condition, making any behavioral abnormalities, such as lack of an escape response, inconsequential.

After the first use of the small-turtle testing protocol, in 1988, NMFS began to use Kemp's ridley sea turtles, *Lepidochelys kempii*, because they were easier to acquire from captive-rearing facilities and were the species of greatest concern. When environmental groups protested the use of highly endangered Kemp's ridley sea turtles, in 1994 NMFS began to use the threatened loggerhead sea turtle, *Caretta caretta*.

Even though the small-turtle TED testing protocol has improved, the option remained available to certify a TED using the Cape Canaveral protocol and was used occasionally for a number of years. In 1990, NMFS developed the Modified Cape Canaveral Testing Protocol (NOAA, 1990b). Instead of a paired trawl test design in which one trawl had an experimental TED and the other did not have a TED, under the modified protocol both nets had an experimental TED. Each of the trawls were also mounted with an underwater camera that allowed NMFS technicians to monitor the wild turtles that entered the net. With the modified protocol, the turtle is given 10 minutes to escape. If the turtle does not escape within 10 minutes, the turtle is considered captured, the trawl is retrieved, and the turtle is released. It is important to note that only one type of test protocol could be given to a TED, so failure of either test meant failure of the TED. No further testing was allowed unless the TED was modified.

To pass the certification test with any of the protocols, the candidate TED had to exclude 97% of turtles with a 90% confidence interval, according to the standard set by the control TED during that round of testing. Initially, NMFS used the NMFS TED as a control, because it was the most extensively tested TED and was 97% effective in excluding turtles. Using the NMFS TED as a control addressed the variations between the Cape Canaveral and small-turtle testing protocols, because the NMFS TED had a known exclusion rate. Any variation in this rate could be viewed as an artifact of the small-turtle testing protocol and was adjusted for in the statistical analysis.

In 1996, NMFS began using the Super Shooter TED as the control TED. NMFS calculated the probability of Type I and Type II errors in order to insure that the sample size of the test was large enough that a statistical analysis would be powerful enough to correctly reject or accept a TED. Based on this calculation, NMFS eventually increased the number of turtles released into the candidate TED from 20 to 25.

NMFS invited TED inventors and manufacturers to participate in the testing. NMFS allowed the inventor to install the TED, view preliminary video of the TED's underwater performance, and make adjustments if necessary. If the TED was failing or had failed the test, NMFS or the inventors could modify

[1]Mitchell, J. F. 1988. Project report: TED evaluation and video documentation. NMFS, SEFC, Pascagoula Laboratory, Miss. Available from Jenkins.

the TED and retest during the same test session if time allowed.

NMFS gave copies of the testing videos to the TED inventors and manufacturers and invited them to attend the TED Testing Review Committee meeting. This committee was comprised of Sea Grant agents, shrimp fishing industry representatives, fishing gear specialists, and sea turtle experts. The committee reviewed the video of each test and could score the test as a capture or escape or they could choose to discard the test. In 1995, however, NMFS abandoned use of the review panel and the process of scoring the tests, because the criteria for making classifications were too vague.

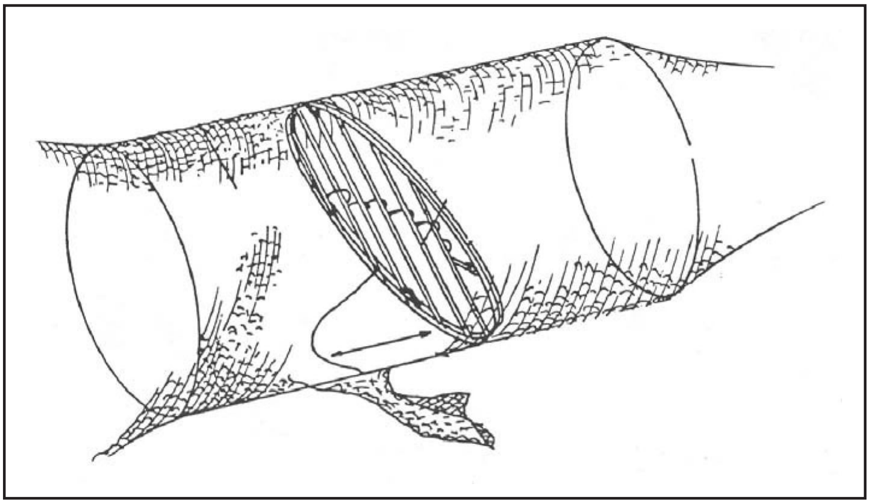

Figure 7.—Georgia Jumper TED (Source: S. Boone. Patent application. [Available from Jenkins.]).

Testing of Industry-developed TED's

While NMFS was developing the NMFS TED, members of the shrimp fishing industry had begun to develop different types of TED's, and several of these inventors worked closely with Sea Grant to evaluate the devices. Following the successful demonstration in Cape Canaveral in 1986, in 1987 NMFS joined this effort and began field tests of some of these devices. That year marked a turning point in the NMFS TED program, as most of the effort in the following years focused on evaluating, testing, and modifying TED's that members of the shrimp fishing industry designed. Three designs in particular made substantial early advances in TED design. These were the Georgia Jumper, invented by Sinkey Boone of Darien, Ga.; the Morrison Soft TED, invented by Sonny Morrison of McClellanville, S.C.; and the Anthony Weedless TED, invented by Ernest Anthony of Lacombe, La.

The Georgia Jumper was the first frameless TED; the oval shaped metal frame was sewn directly into the net at a 45° angle (Fig. 7). Beginning in 1987, NMFS frequently evaluated modifications of the Georgia Jumper. Much of this work focused on how the device was configured in the net; the grid itself has remained largely unchanged. NMFS certified the Georgia Jumper for commercial use in 1987.

The Morrison Soft TED was the first TED to use flexible mesh webbing (as opposed to a rigid grid) as the separator panel in the TED (Fig. 8). Unlike a grid that is placed in the throat of the trawl net, the soft TED panel begins in the mouth of the trawl and tapers back, forming a mesh ramp to the escape opening. NMFS evaluations and modifications of this TED centered on refining it so that it would perform consistently across styles of nets and fishing environments. NMFS certified it for commercial use in 1987. The Parker Soft TED, which is a variation of the Morrison Soft TED, is currently the only soft TED that remains certified (Fig. 9).

The Anthony Weedless TED was the first TED design to solve the problem of TED's becoming clogged with vegetation and similar debris (Fig. 10). It consisted of a frameless grid, the bars of which did not attach to the bottom of the grid, allowing debris to enter the codend rather than clog the TED. In comparison to other TED's, NMFS certified this TED by proxy to its similarity to the Georgia Jumper with limited evaluations, focusing on shrimp retention. Subsequent to its certification, NMFS analyzed the impact of an improperly installed Anthony Weedless TED on sea turtle escapement.

In addition to the innovative Georgia Jumper, Morrison Soft, and Anthony Weedless TED's, NMFS evaluated, tested, or modified over 30 different fishing industry-invented TED designs. This number does not include the many modifications and version of each design nor the over 15 designs that were proposed but never tested.

The fishing industry and other stakeholders attacked the sea turtle bycatch problem from all angles. Most of the ideas were variations on barrier devices, hard TED's, and soft TED's. Others were more novel, such as the Sonic Excluder. This device, invented by Daniel Leveque of Lake Charles, La., Michael Tritico of Longville, La., and Martin Lenhardt of the Virginia Institute of Marine Science, used sound waves to ward turtles away from an approaching trawl. Another novel device, the Turtle Detection Device, invented by Ricky Bourg of Dulac, La., consisted of a mechanical trigger located at the codend attachment point that released a tethered float from the trawl when a sea turtle or large object was encountered (Fig. 11).

The shrimp fishing industry also proposed a number of TED accessories. One such device was the Pierce Shrimp Broom invented by Webster Pierce and Mitch Serigne of Louisiana (Fig. 12). This broom of plastic fibers was attached to a TED frame so as to prevent shrimp from exiting through the escape opening. During testing in 1995,

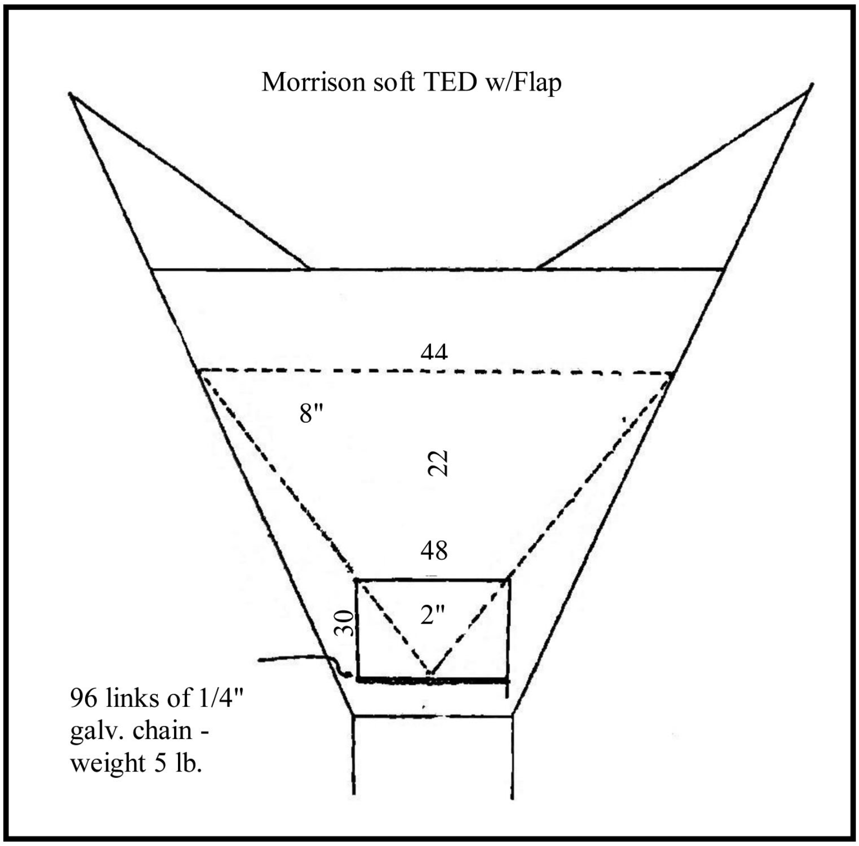

Figure 8.—Morrison Soft TED (Source: J. F. Mitchell. 1989. Project report: soft TED evaluations, video documentation and small turtle tests. NMFS, SEFC, Pascagoula Laboratory, Miss. [Available from Jenkins.]).

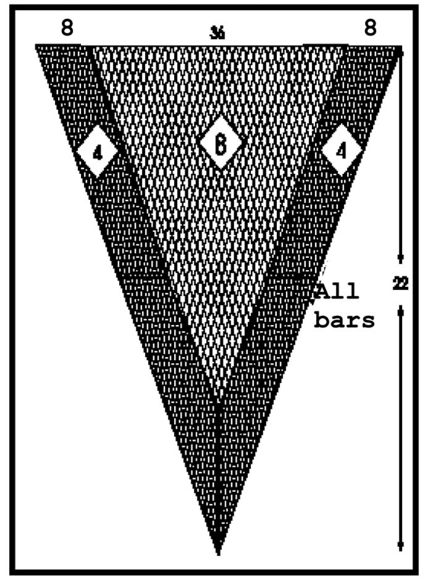

Figure 9.—Parker Soft TED (Source: Mitchell, J. F. and W. Taylor. 1997. Report on small turtle TED test: phase 2 soft TED testing. NMFS, SEFC, Pascagoula Laboratory, Miss. [Available from Jenkins.]).

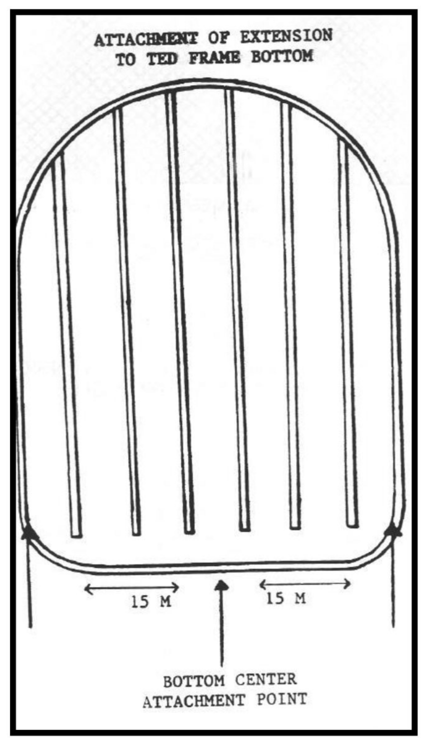

Figure 10.—Anthony Weedless TED (Source: NMFS, SEFC, Pascagoula Laboratory, Miss. [Available from Jenkins.]).

this device excluded all turtles. Other notable accessories were the Darien Roller and Georgetown Roller (Fig. 13). These similar devices consisted of a PVC pipe attached to the bottom of the TED frame. NMFS certified these devices for use to prevent chaffing and tearing of the net.

The years of cooperation between NMFS and the fishing industry resulted in TED's that were increasingly efficient in releasing turtles and more effective in retaining shrimp. The designs reflected the collective scientific, engineering, and fishing knowledge of NMFS personnel, Sea grant agents, and industry collaborators. However, there are two major points of difference between NMFS and industry in the approach to TED design: whether turtles were released more effectively from top or bottom-opening TED's and whether soft TED's could effectively and consistently exclude turtles.

Bottom-opening vs. Top-opening TED's

To determine if TED's performed better as top opening or bottom opening, NMFS evaluated four different TED designs (the NMFS TED, the Georgia Jumper, the Anthony Weedless TED, and the Super Shooter TED) in 1995 and 1996 in a total of 14 different fishing configurations using captive-reared sea turtles. All the top-opening TED designs had equal or better turtle exclusion rates than their bottom opening counterpart. With the exception of one configuration of bottom-opening Super Shooter TED, all the top-opening TED's had shorter escape times than their bottom opening counterparts. In fact, the escape times of top-opening TED's (55–85 sec) were

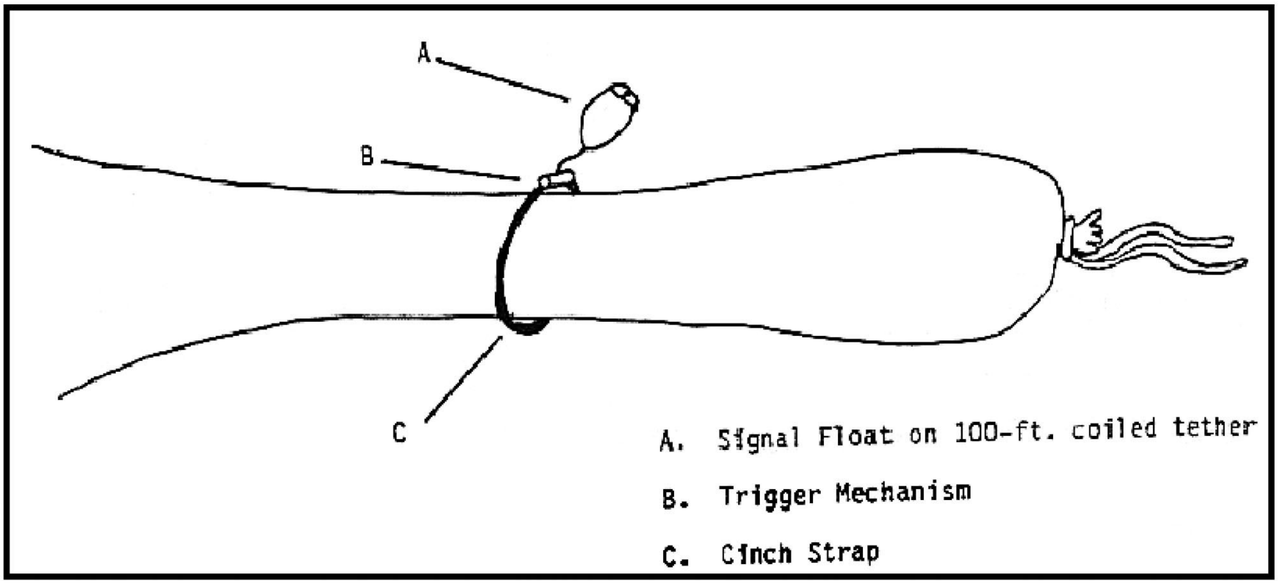

Figure 11.—Turtle Detection Device (Source: NMFS, SEFC, Pascagoula Laboratory, Miss. [Available from Jenkins.]).

often about half that of bottom-opening TED's (64–177 sec).[2]

Soft TED Testing

In response to growing concerns that soft TED's were catching high numbers of sea turtles, NMFS evaluated soft TED's almost exclusively from 1996 through 1998. In 1996, NMFS obtained five Andrews Soft TED's from three different net shops to evaluate the consistency of installation and turtle exclusion. Of the five TED's, four apparently had installation problems that resulted in areas of slack webbing in the TED (Fig. 14). Small turtles released near the wings of the TED had significantly higher relative capture rates (70%) than those released in the center position (0%).[3]

NMFS then convened a soft TED advisory panel in March 1997 to develop technical solutions to the operational problems with soft TED's. Panel members included soft TED designers and shrimp industry representatives. The industry panel developed ideas for soft TED modifications and submitted them to NMFS for testing and diver evaluation. Of 18 soft TED designs evaluated during the project, seven were variations of the Andrews Soft TED and eleven were variations of the Morrison Soft TED.

NMFS identified design problems that prevented the escape of juvenile turtles in 15 of the 18 soft TED's. Of the 18 designs, one successfully passed the test protocol by excluding 22 of 25 turtles. The successful design was the Morrison 4×8 inch Soft TED (later known as the Parker Soft TED), constructed with 8 inch webbing in the main panel and 4 inch webbing in the wings and at the exit hole apex. In addition, the researchers developed and conducted preliminary tests of an Andrews Soft TED with a combination of 6, 3 and 5 inch webbing panel.[4]

Later that year, NMFS continued its evaluation of soft TED's, focusing on further evaluations of the Morrison 4×8 inch Soft TED installation in various trawl types and sizes and continued testing of Andrews TED designs. The Morrison 4×8 inch Soft TED was installed in the following trawl types: 1) 2-seam balloon with and without a bib (i.e., a section of webbing extending forward from the net's top panel and connecting to a third central bridle); 2) 4-seam balloon with and without a bib; 3) mongoose; and 4) straight wing flat. On the trawl designs with bibs (which helps to maintain optimal spread of the mouth of the trawl), NMFS evaluated TED panel configuration at different center wire adjustments. The Andrews Soft TED evaluation and testing resulted in the development of three designs which successfully passed the test protocol. These designs were the Andrews 4×8 inch Soft TED , Andrews 6×3×5 inch Soft TED, and Andrews 5 inch Soft TED.[5]

Following the 1997 tests, members of the Soft TED Advisory Panel evaluated shrimp retention of the Andrews 4×8 inch Soft TED aboard a commercial

[2]Mitchell, J. F., D. Foster, and J. Watson. 1996. 1996 TED testing: summary of evaluations and results. NMFS, SEFC, Pascagoula Laboratory, Miss. Available from the author of this paper. NMFS. 1995. 1995 TED certification test. NMFS, SEFC, Pascagoula Laboratory, Miss. Available from Jenkins.

[3]Mitchell, J. F., D. Foster, and J. Watson. 1996. 1996 TED testing: summary of evaluations and results. NMFS, SEFC, Pascagoula Laboratory, Miss. Available from Jenkins.

[4]Mitchell, J. F., and W. Taylor. 1997. Report of small turtle TED test: phase 1 soft TED testing. NMFS, SEFC, Pascagoula Laboratory, Miss. Available from Jenkins.

[5]Mitchell, J. F., and W. Taylor. 1997. Report on small turtle TED test: phase 2 soft TED testing. NMFS, SEFC, Pascagoula Laboratory, Miss. Available from Jenkins.

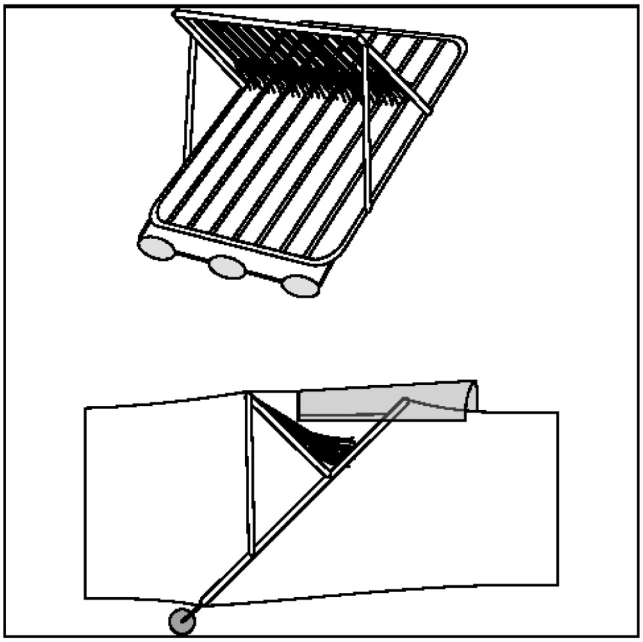

Figure 12.—Pierce Shrimp Broom (Source: NMFS. 1995. 1995 TED certification test. NMFS, SEFC, Pascagoula Laboratory, Miss. [Available from Jenkins.]).

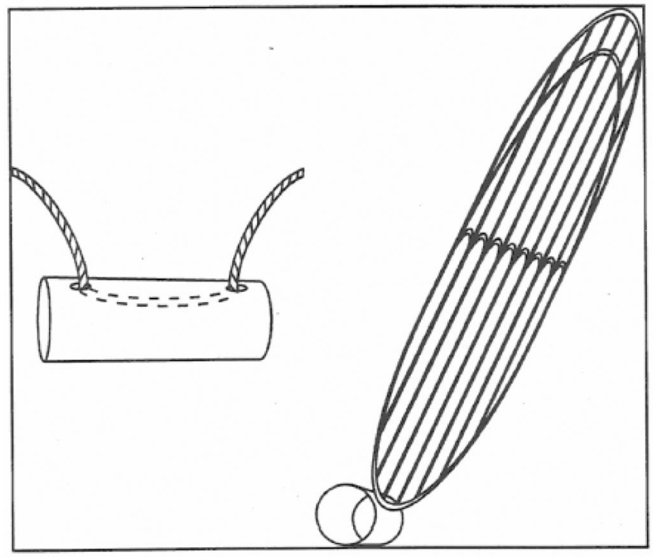

Figure 13.—Darien Roller (Source: J. F. Mitchell. 1994. 1994 TED certification test. NMFS, SEFC, Pascagoula Laboratory, Miss. [Available from Jenkins.]).

shrimp trawler and estimated a 20% loss of shrimp in comparison to a hard TED. Based on these findings, a subsequent meeting of the Soft TED Advisory Panel recommended that NMFS take no further action to certify any of the Andrews Soft TED designs which passed the field tests in 1997. The panel did, however, recommend that NMFS focus the 1998 TED testing on modifications to improve the shrimp retention of the Andrews Soft TED. In 1998, NMFS certified the Parker Soft TED; this was the only certification awarded of all the soft TED designs explored during these 3 yr of intensive research.[6]

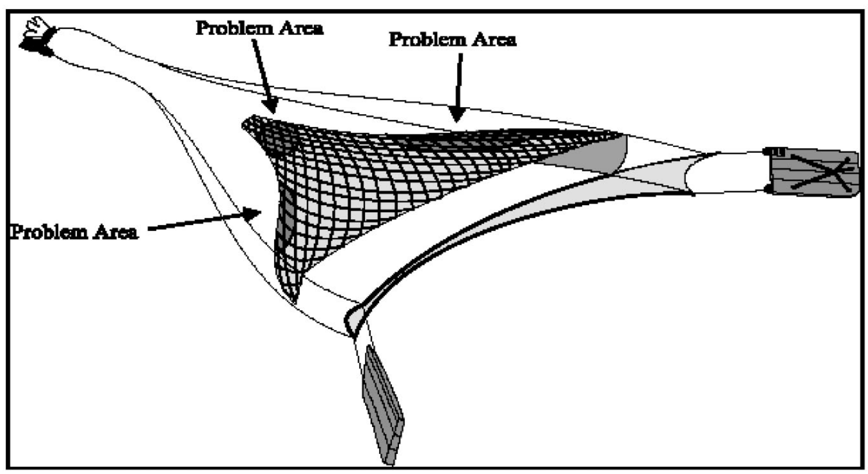

Figure 14.—Andrews Soft TED indicating observed areas of slack webbing and pocketing. (Source: Mitchell, J. F., D. Foster, and J. Watson. 1996. 1996 TED testing: summary of evaluations and results. NMFS, SEFC, Pascagoula Laboratory, Miss. [Available from Jenkins.]).

Taylor Soft TED

In addition to the NMFS TED, NMFS scientists and gear specialists developed other distinct TED designs. One of these was the Taylor Soft TED. Charles "Wendy" Taylor, an NMFS gear specialist and former commercial net builder invented the Taylor Soft TED (Fig. 15). The need for this device evolved from industry's desire for a smaller mesh size soft TED with a flap and the need for a soft TED suitable for small trawls. The TED was a modification of the Morrison Soft TED. It was a top-opening TED made from a triangular piece of 6 inch mesh polyethylene webbing that formed a shortened panel and had a flap weighted with a chain over the exit hole. There were two designs of the Taylor Soft TED: in one design the panel ends in a single mesh

[6]Mitchell, J. F., and W. Taylor. 1998. Report on small turtle TED test: modified Andrews TED testing. NMFS, SEFC, Pascagoula Laboratory, Miss. Available from Jenkins.

(an apex) and in the other design the panel is squared-off.

During testing in 1991, diver observation revealed that the panel of the Taylor Soft TED was too far aft, preventing lateral expansion so the meshes were partially closed. This resulted in the blockage of the codend entrance and the misdirection of water flow. Taylor corrected the problem by moving the TED forward 5 ft and increasing the hanging ratio of the mesh. Following this adjustment, the TED successfully excluded 100% of turtles placed in the net with no statistically significant loss of shrimp.

Super Shooter TED

Another TED that NMFS had a significant role in inventing was the Super Shooter TED. Noah Saunders of TED, Inc., in Biloxi, Miss., began developing the Super Shooter TED around 1989 in cooperation with NMFS personnel, particularly Dale Stevens and John Watson. A modification of the Georgia Jumper, the aluminum rod bars of this TED were bent at a 45° angle just above the bottom of the frame to prevent clogging by debris. This design differs from the Georgia Jumper in that it does not have a crossbrace because its greater width and larger diameter material adds stability.

This TED was manufactured in three sizes. The large size Super Shooter TED consists of a 42×51 inch frame spaced 4 inch apart. The Mini Super Shooter (also known as the small size or mid size Super Shooter TED) (Fig. 16) had a 33×41 inch frame with bars spaced 3.5 inch apart. The Inshore Super Shooter TED had a 32×35 inch frame with bars spaced 3.75 inch apart. During field tests the Super Shooter TED had no statistically significant loss of shrimp and excluded 100% of turtles placed in the net.

Cooperative Work with Mexico

In addition to inventing the NMFS TED and working with industry to test and modify shrimper-invented TED's, NMFS also cooperated with the governments of several foreign nations in developing new TED designs. One of the first such relationships was with Mexico. In 1992, NMFS and the Instituto Nacional de La Pesca (INP), the primary agency for scientific and technological advice on fisheries development and assessment in Mexico, conducted comparative trawl tests of the Super Shooter and Anthony Weedless TED's in Mexico's Gulf waters.

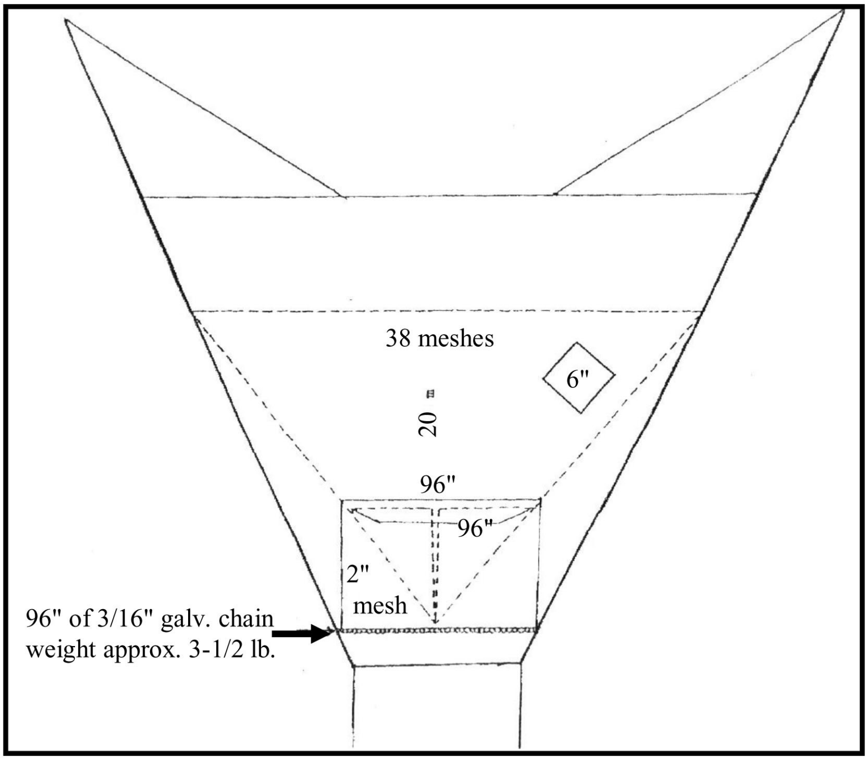

Figure 15.—Taylor Soft TED (Source: NMFS, SEFC, Pascagoula Laboratory, Miss. [Available from Jenkins.]).

In 1994, NMFS observed and suggested modifications to two TED's designed by the INP. The most unique of the two designs was the INP 3-bag TED (Fig. 17), which had an oval grid and three codends. Two baffles, one in each wing, led to two outer codends. Behind the baffles was the TED leading to the center codend. The Mexican gear specialists explained that shrimp travel along the trawl wings and so will enter the baffles before reaching the TED, thus reducing loss of shrimp.

Based on initial observations, the baffles were modified by lacing nylon line along the perimeter to keep them open. During subsequent tests, the TED caught 3 of 5 turtles; the captured yearling turtles became entangled in one of the baffles. NMFS suggested the TED be modified by placing a barrier over the baffles and adding side hoops to the TED frame to assure that the outer codends remain open.

The second design, the FEDINP TED was more traditional in appearance. This was a top-opening TED with a 31.5×50.5 inch rectangular grid made of 1.5 inch aluminum tubing. The exit hole had nylon rope laced to the perimeter and was covered by a 1 inch stretched mesh flap that extended 23.5 inch beyond the frame. During testing, this TED successfully excluded all turtles.

Leatherback TED's

The early 2000's brought sweeping changes to TED regulations; this resulted in a new focus for the TED research program. The regulatory changes were prompted in part by a study published

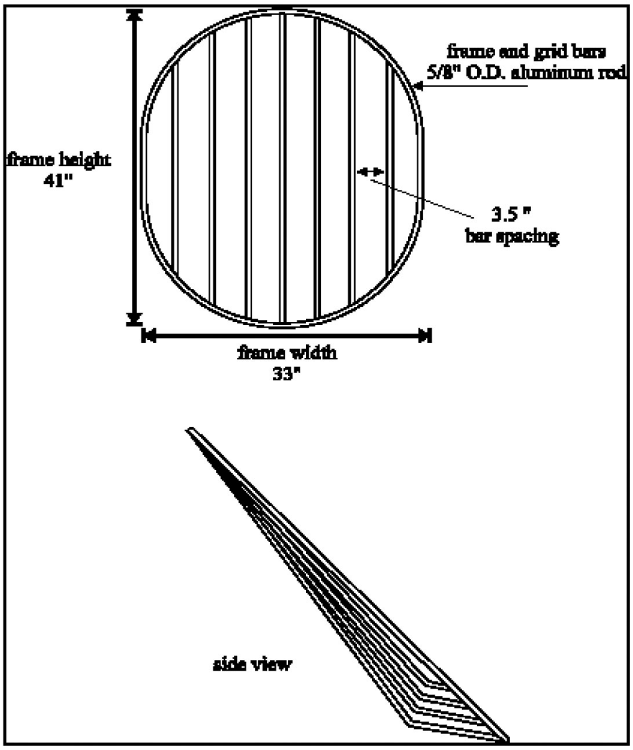

Figure 16.—Mid-size Super Shooter TED (Source: NMFS. 1995. 1995 TED certification test. NMFS, SEFC, Pascagoula Laboratory, Miss. [Available from Jenkins.]).

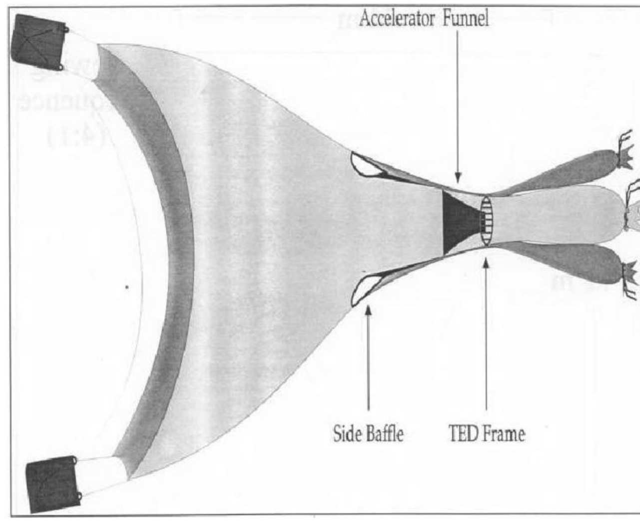

Figure 17.—INP 3-bag TED (Source: J. F. Mitchell. 1994. 1994 TED certification test. NMFS, SEFC, Pascagoula Laboratory, Miss. [Available from Jenkins.]).

in 2002 that showed that as many as 47% of stranded (i.e., recovered carcasses) loggerhead turtles and 7% of stranded green turtles had body depths that exceeded the minimum legal TED opening height (Epperly and Teas, 2002). The study indicated that these large sea turtles might be drowning in trawl nets.

On 21 Feb. 2003, in response to the mounting scientific evidence that sea turtle conservation measures were inadequate for protecting large turtles, NMFS enacted several changes to the TED regulations (NOAA, 2003). Notably, these new regulations required all offshore single-grid hard TED's to have a grid with a minimum measurement of 32×32 inch. They also required that all offshore TED's be equipped with either a 6 inch overhang double-cover flap (Fig. 18), which has an escape opening of at least 56×20 inch, or the 71 inch standard leatherback modification (Fig. 19), which has an escape opening with a minimum of 71 inch straight-line stretched mesh. These regulatory changes effectively decertified many of the previously certified TED's. This caused NMFS' TED research to shift focus into modification of previously certified TED's, such as the Georgia Jumper, whose opening required modification to meet the larger escape opening requirement.

Flat Bar TED

To handle the rigors of deepwater fishing, offshore shrimpers began using larger TED's made of sturdy aluminum or steel pipe to prevent bending of the frame. But some shrimpers noted that there was an increased loss of shrimp in these TED's in comparison to TED's made from thinner materials. In 2005, using a flume tank facility, NMFS gear specialists determined that the minimal grid surface area of a TED made from aluminum flat bar led to almost no water flow diversion when compared to an aluminum pipe TED. Less water flow diversion leads to more shrimp remaining in the net rather than flowing out the TED escape opening.

The Flat Bar TED (Fig. 20) was also equal to a pipe TED in frame strength. The Gulf and South Atlantic Fisheries Foundation, Inc., completed a study in 2007 and found that the aluminum Flat Bar TED had statistically significant increases in shrimp catch rates when compared to an aluminum pipe TED.[7] In 2006, a Flat Bar TED with deflector bars constructed from aluminum flat bar stock, 1/4 inch in thickness and 1 1/2 inch in depth, successfully passed the small turtle test protocol by excluding 24 of 25 turtles (NOAA, 2010).

[7]Gulf and South Atlantic Fisheries Foundation, Incorporated. 2008. An assessment of turtle excluder devices within the Southeastern shrimp fisheries of the United States. NOAA/NMFS Cooperative Agreement No. NA04NMF4540112; #92.

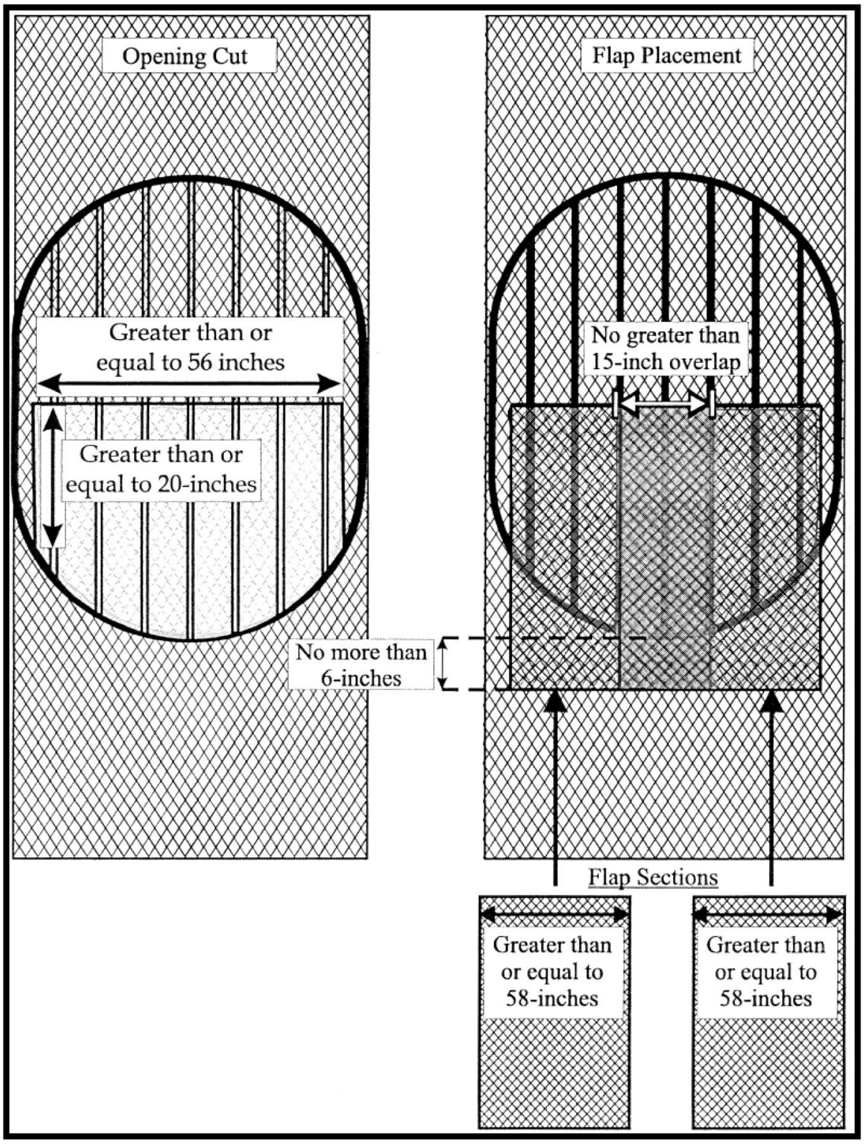

Figure 18.—Double Cover Flap (Source: NOAA, 2001a).

Double Shoot TED

Debris clogging TED's is a chief concern for shrimpers, especially after hurricanes. NMFS gear specialists tackled this concern by creating the Double Shoot TED (Fig. 21). This TED has two openings. One opening on the bottom discharges heavy debris and another opening on the top allows escape of turtles. The TED also has a fixed fishing angle of the TED deflector bars through a dual-angle design that resembles a less than symbol (<). In 2010, this Double Shoot TED passed the small-turtle TED testing protocol by excluding all 25 turtles. A paired-trawl test with a standard top-opening grid TED showed that the Double Shoot TED reduced finfish bycatch by 11.6% with a 5.5% reduction in shrimp catch (USDOC, 2011).

TED's in Other Trawl Fisheries

In 2007 NMFS published an Advance Notice of Proposed Rulemaking to require TED's in other fisheries (NOAA, 2007). Then, in 2009, NMFS published a notice of intent to prepare an environmental impact statement in preparation for possible regulatory changes that would require the use of TED's in trawl fisheries with documented sea turtle interaction, such as those for knobbed whelk, *Busycon carica*, and Atlantic sea scallops, *Placopecten magellanicus* (NOAA, 2009). In anticipation of this potential regulatory change, NMFS began testing TED's for these fisheries. Much of the initial work was based on a device

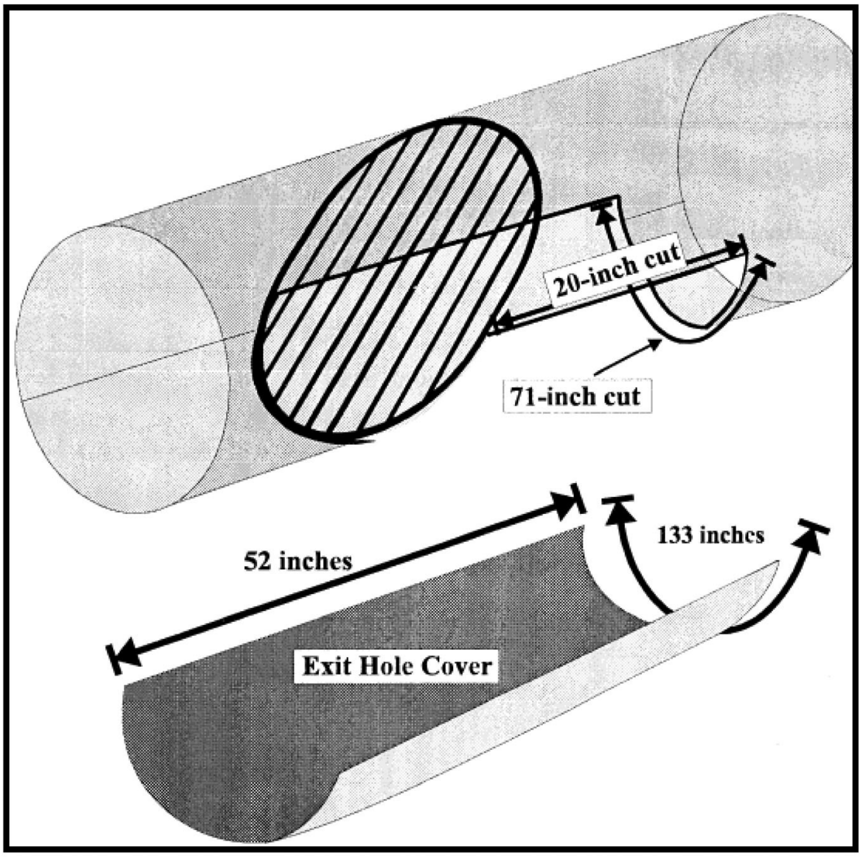

Figure 19.—Leatherback Modification (Source: NOAA, 2001b).

Figure 20.—Flat Bar TED leaning against a mooring. (Source: J. Watson. 2005. Sea Turtle Bycatch Reduction Research in the U.S. 1st Annual Meeting of the Bycatch Reduction Consortium, 1–2 June 2005, Boston, Ma. http://www.neaq.org/documents/conservation_and_research/bycatch_consortium/2005_meeting/john_watson.pdf).

called the flounder TED (Fig. 22). This TED features large holes at the bottom of the TED that will allow the passage of flounder into the codend but will still block the passage of sea turtles. Since 1992, all boats using bottom trawls to catch summer flounder, *Paralichthys dentatus*, at certain times and areas off Virginia and North Carolina have been required to use TED's in their nets (NOAA, 1992). In 2010, NMFS approved the use of a Modified Flounder TED (Fig. 23), which consisted of two grid frames that allowed the TED to be rolled onto a net reel. The Northeast Fisheries Science Center and industry developed this TED to improve catch retention by reducing clogging (NOAA, 2010).

Because whelk and flounder are both larger bottom dwelling organisms, modifying the flounder TED was a

Figure 21.—The Double Shot TED frame prior to installation in webbing extension tube (Source: USDOC, 2011).

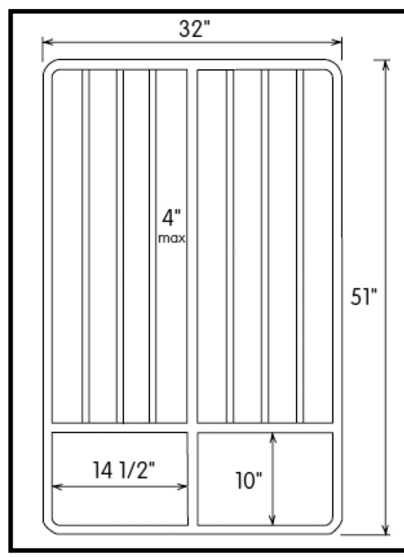

Figure 22.—Flounder TED (Source: Belcher, C., R. Vendetti, G. Gaddis, and L. Parker. 2001. Results of gear testing to reduce turtle capture in the whelk trawl fishery. Georgia Sea Grant College Program. [Available from Jenkins, and online at georgiaseagrant.uga.edu/images/uploads/media/whelk_pub23.pdf.]).

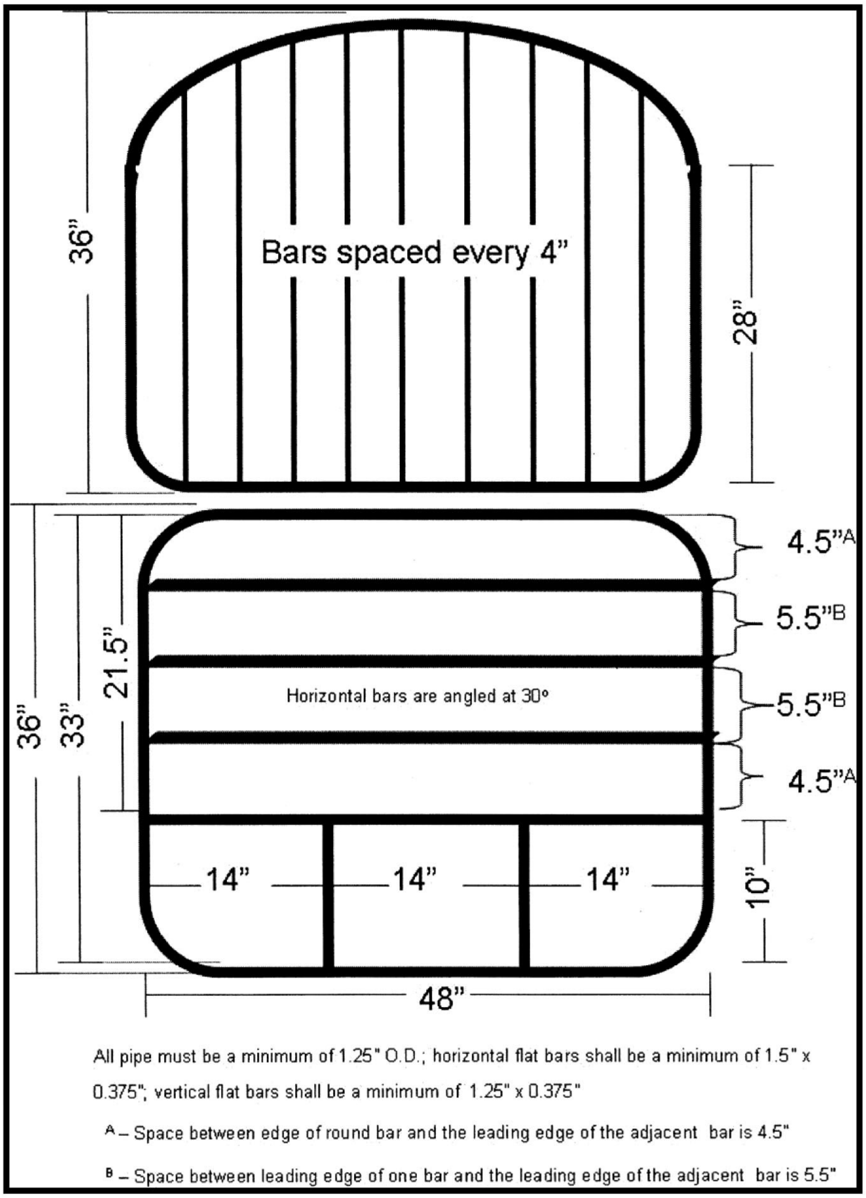

Figure 23.—Modified Flounder TED (Source: NOAA, 2010).

starting point for developing a TED appropriate for whelk. The whelk fishery occurs primarily in Georgia and South Carolina and arose as an alternative fishery during times when the shrimp fishery was closed. The whelk TED was developed in cooperation with the Georgia Department of Natural Resources (GADNR) and the UGA MAREX.

NMFS evaluated these potential TED designs in 2000–01. During the 2000 TED testing, the whelk TED excluded all 25 turtles placed in the TED, but fishermen thought that the frame was too large for their trawls. In 2001, NMFS tested the Whelk TED II (Fig. 24). The height of this TED had been reduced from 52 to 36 inch and the outer frame was constructed from 2 inch flat bar. The flat bar allowed whelk to roll through the bottom openings of the TED more efficiently than a pipe frame.

The flat bar, however, caused small turtles to be trapped on the lip of the bar, over which they could not maneuver. NMFS gear specialists recommended that the top section of the outer frame near the escape opening should be replaced with pipe rather than flat bar. Following this modification, the whelk TED II passed the NMFS small-turtle testing protocol, capturing only 1 of 24 turtles. Currently, GADNR requires the use of

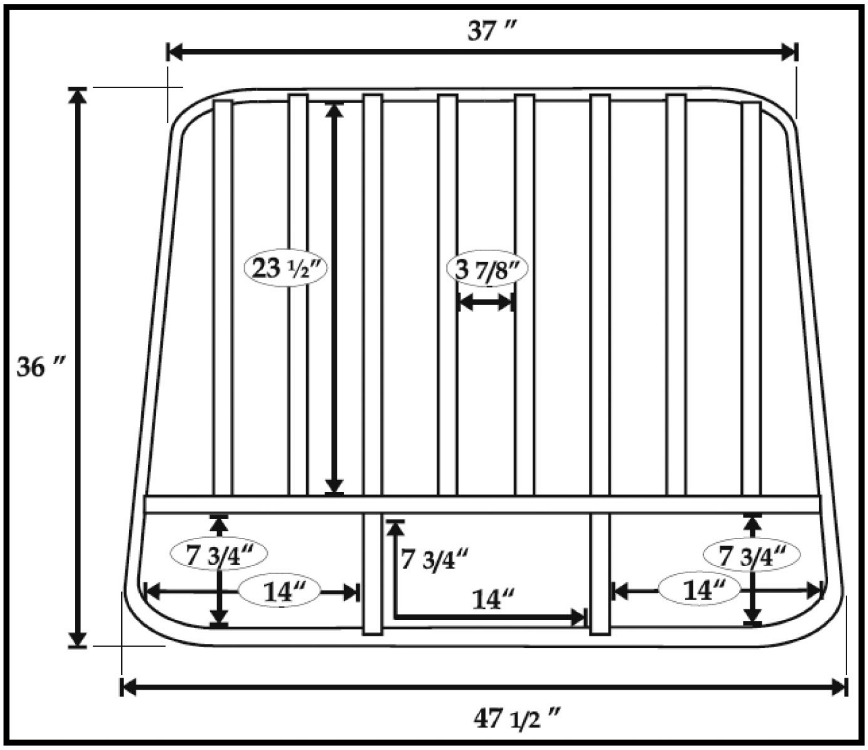

Figure 24.—Whelk TED II (Source: NMFS. 2001. Report on FY 2001 Small Turtle TED Test. NMFS, SEFC, Pascagoula Laboratory, Miss. [Available from Jenkins.]).

this TED in the whelk trawl fishery in Georgia waters.

Sea turtle bycatch has also been documented in the Atlantic sea scallop trawl fisheries. In 2005 and 2006, NMFS tested the feasibility of using a whelk TED modified with chaffing gear in the sea scallop trawl fishery. This TED design passed the NMFS testing criteria, and NMFS is now considering requiring the use of TED's in the Mid-Atlantic sea scallop trawl fishery. Also, the Atlantic sea scallop dredge fishery has worked with NMFS to develop a turtle excluding dredge.

The flynet fishery is another trawl fishery with documented sea turtle bycatch. Flynets are high-profile trawls of 80–120 ft width and are fished just above the seafloor. The flynet fishery is a multispecies fishery that operates along the east coast from New York to North Carolina. Depending on fishing location and depth, target species include Atlantic croaker, *Micropogonias undulatus;* weakfish, *Cynoscion regalis*; Atlantic mackerel, *Scomber scombrus*; bluefish, *Pomatomus saltatrix*; squid, Teuthida; black sea bass, *Centropristis striata*; scup, *Stenotomus chrysops*; and other finfishes.

NMFS began developing a TED for this fishery in 1999. Initially, two of these TED's passed the NMFS small-turtle TED testing protocol. Both TED's had folding, hinged frames to facilitate winding around the vessel net reel, but the industry was concerned that this design could cause excessive loss of fish.

In response to this concern, NMFS developed a bifolding TED called the Staggered Bar Flynet TED (Fig. 25). The staggered bar configuration was designed to let more fish into the net bag by reducing the number of fish that are deflected through the exit hole of the TED. After correcting the installation position of the TED so that the offset bars faced into the water flow, this TED excluded all 25 turtles that were placed in the net.

Since about 2009, NMFS returned to exploring a flexible grid design for the flynet fishery. They have had considerable success with a TED constructed of aluminum flat bar with a center section made of stainless steel cable, which allows it to flex for storage around the net reel. Versions of this device have successfully passed the turtle test protocol and have reduced bycatch of spiny dogfish, *Squalus acanthias,* by 40% and clearnose skates, *Raja eglanteria,* by 63% without significant loss of target catch (USDOC, 2010, 2011). If NMFS decides to require the use of a TED in the flynet fishery, it might initially only require TED's for vessels targeting weakfish and croaker.

Conclusion

In this article I have chronicled the contributions of NMFS to the invention and development of TED's. I summarized the impetus for and results of major events, including the initial

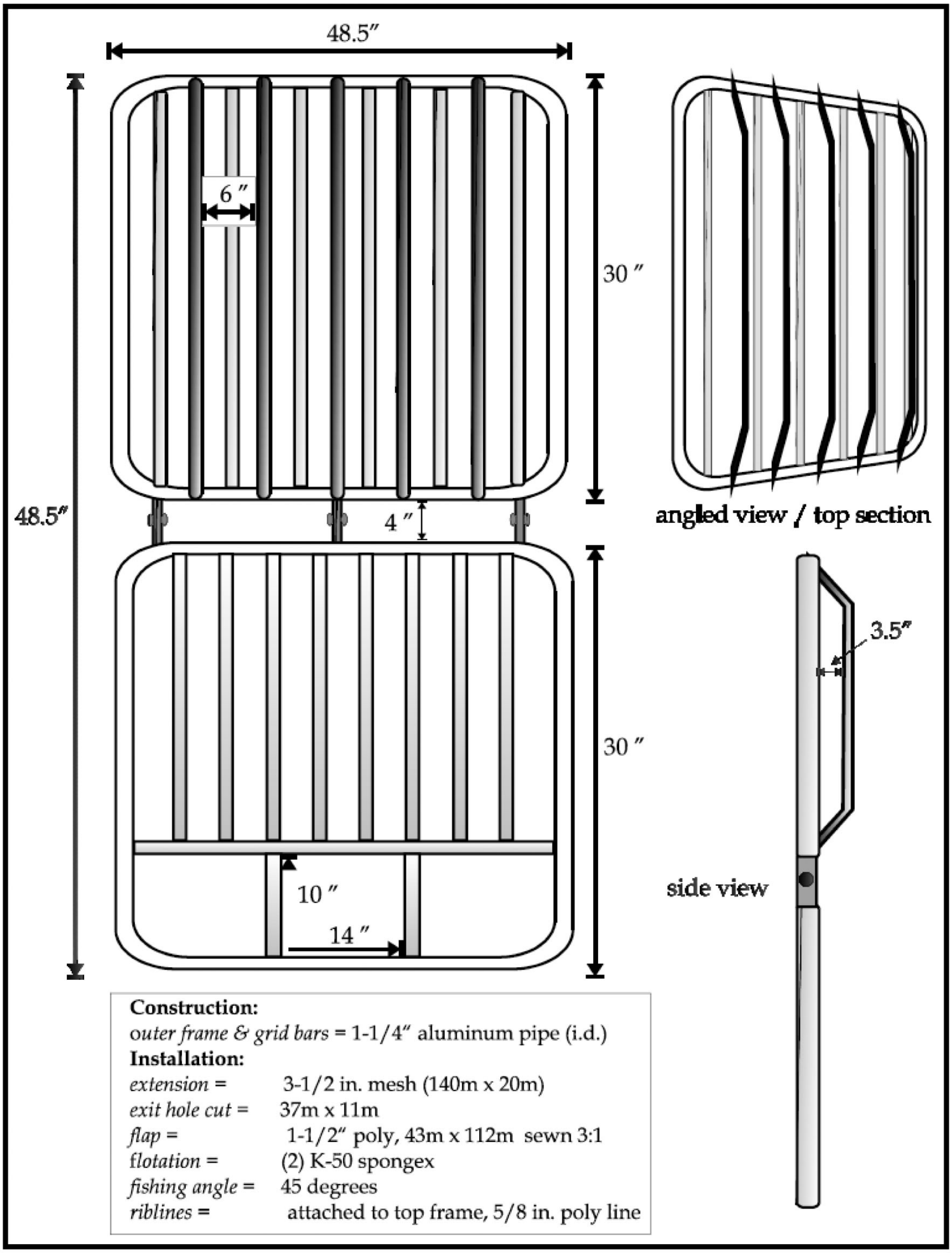

Figure 25.—Staggered Bar Flynet TED (Source: NMFS. 2000. Report on FY 2000 Small Turtle TED Test. NMFS, SEFC, Pascagoula Laboratory, Miss. [Available from Jenkins.]).

attempts to develop a barrier device; development of the NMFS invented and the NMFS modified TED's, such as the NMFS TED, Taylor Soft TED, and Super Shooter TED; and testing and development of industry-invented TED's, such as the Georgia Jumper, Morrison Soft TED, and Anthony Weedless TED. I have also recorded details of little known events in the TED research, such as the testing of novel TED designs invented by gear specialists from the Mexican government and alerting devices, such as the Sonic TED and Turtle Detection Device.

This summary of 36 years of history, shows how the NMFS program to reduce mortality of sea turtles in trawls has grown. The program has progressed from reactive research in response to the regulatory change of the listing of sea turtles under the Endangered Species Act to anticipatory research in preparation for potential TED requirements in additional trawl fisheries. As a result of efforts of NMFS and numerous stakeholders, many trawl fisheries around the world now use a version of the turtle excluder device (TED). I hope that this record of TED research will further aid the development of TED's for appropriate trawl fisheries worldwide.

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