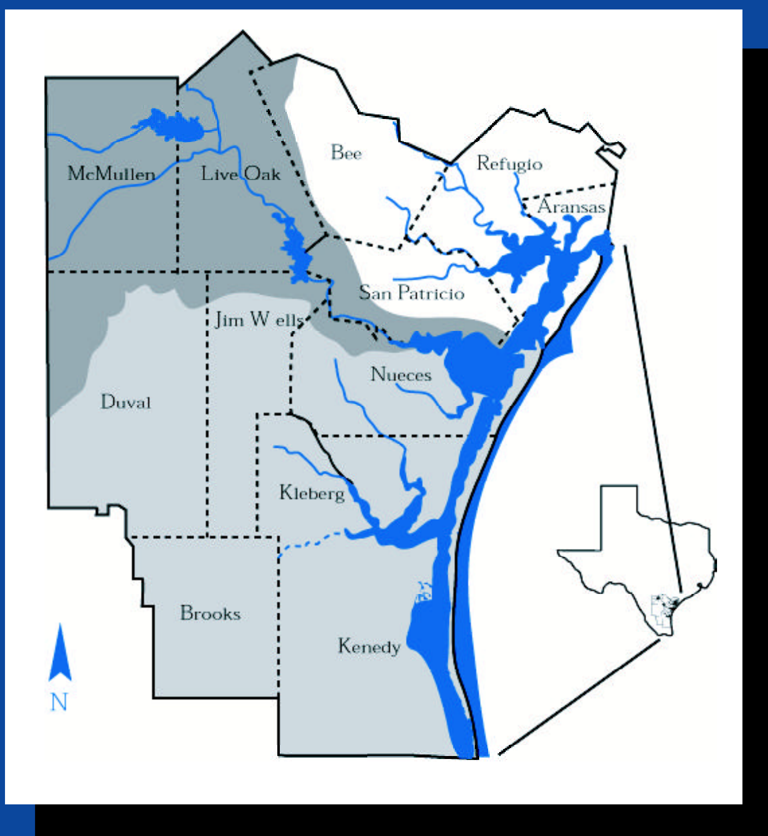
Evaluation of Bycatch Reduction Devices in Aransas Bay During the 1997 Spring and Fall Commercial Bay-Shrimp Season



Corpus Christi Bay National Estuary Program

CCBNEP-33 • August 1998

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Evaluation of Three Bycatch Reduction Devices in Aransas Bay During the 1997 Spring and Fall Commercial Bay-Shrimp Seasons

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CORPUS CHRISTI BAY NATIONAL ESTUARY PROGRAM

The Corpus Christi Bay National Estuary Program (CCBNEP) is a four-year, community based effort to identify the problems facing the bays and estuaries of the Coastal Bend, and to develop a long-range, Comprehensive Conservation and Management Plan. The Program's fundamental purpose is to protect, restore, or enhance the quality of water, sediments, and living resources found within the 600 square mile estuarine portion of the study area.

The Coastal Bend bay system is one of 28 estuaries that have been designated as an **Estuary of National Significance** under a program established by the United States Congress through the Water Quality Act of 1987. This bay system was so designated in 1992 because of its benefits to Texas and the nation. For example:

- Corpus Christi Bay is the gateway to the nation's sixth largest port, and home to the third largest refinery and petrochemical complex. The Port generates over $1 billion of revenue for related businesses, more than $60 million in state and local taxes, and more than 31,000 jobs for Coastal Bend residents.
- The bays and estuaries are famous for their recreational and commercial fisheries production. A study by Texas Agricultural Experiment Station in 1987 found that these industries, along with other recreational activities, contributed nearly $760 million to the local economy, with a statewide impact of $1.3 billion, that year.
- Of the approximately 100 estuaries around the nation, the Coastal Bend ranks fourth in agricultural acreage. Row crops -- cotton, sorghum, and corn -- and livestock generated $480 million in 1994 with a statewide economic impact of $1.6 billion.
- There are over 2600 documented species of plants and animals in the Coastal Bend, including several species that are classified as endangered or threatened. Over 400 bird species live in or pass through the region every year, making the Coastal Bend one of the premier bird watching spots in the world.

The CCBNEP is gathering new and historical data to understand environmental status and trends in the bay ecosystem, determine sources of pollution, causes of habitat declines and risks to human health, and to identify specific management actions to be implemented over the course of several years. The 'priority issues' under investigation include:

- altered freshwater inflow
- declines in living resources
- loss of wetlands and other habitats
- bay debris
- degradation of water quality
- altered estuarine circulation
- selected public health issues

The **COASTAL BEND BAYS PLAN** that will result from these efforts will be the beginning of a well-coordinated and goal-directed future for this regional resource.

STUDY AREA DESCRIPTION

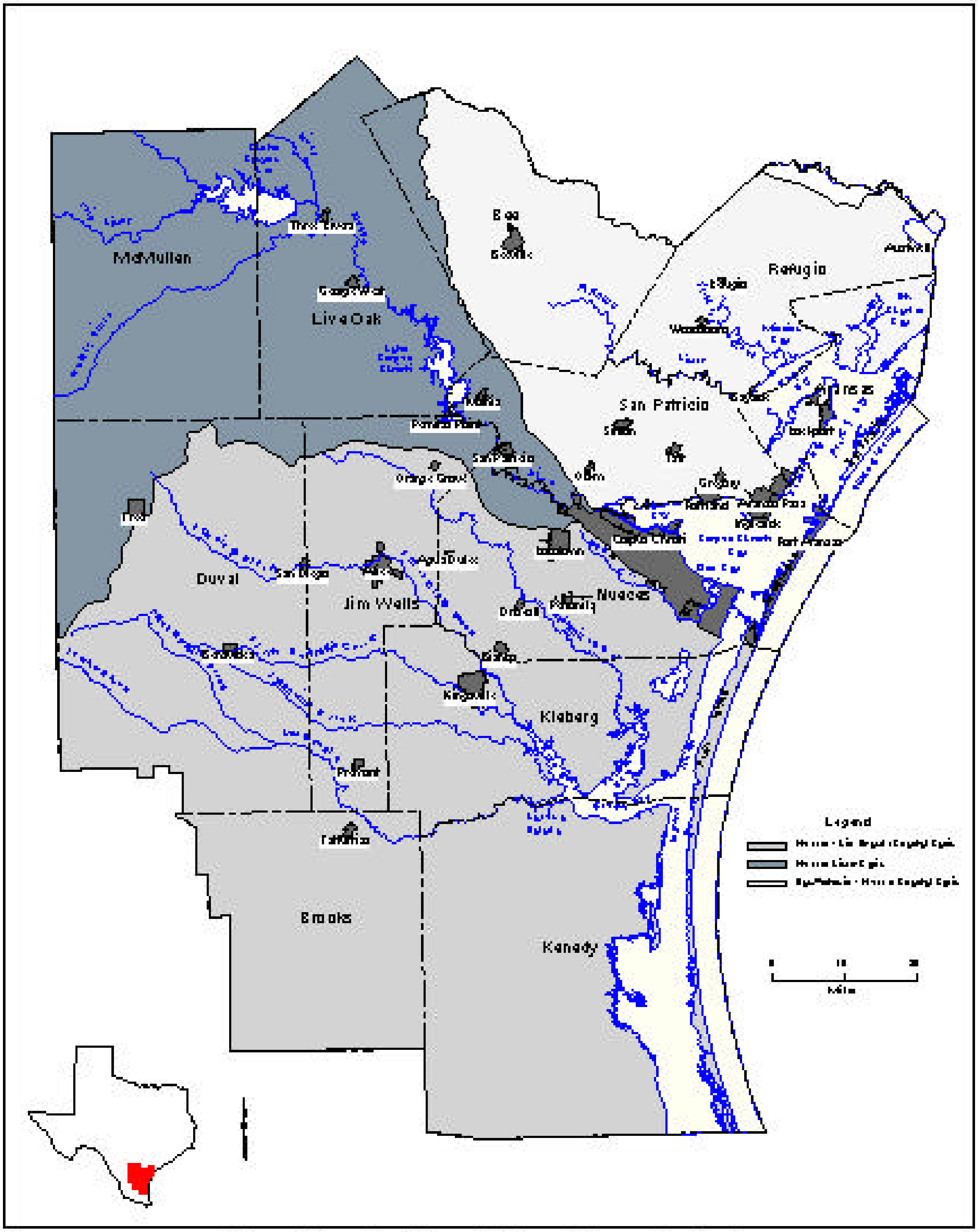
The CCBNEP study area includes three of the seven major estuary systems of the Texas Gulf Coast. These estuaries, the Aransas, Corpus Christi, and Upper Laguna Madre are shallow and biologically productive. Although connected, the estuaries are biogeographically distinct and increase in salinity from north to south. The Laguna Madre is unusual in being only one of three hypersaline lagoon systems in the world. The study area is bounded on its eastern edge by a series of barrier islands, including the world's longest -- Padre Island.

Recognizing that successful management of coastal waters requires an ecosystems approach and careful consideration of all sources of pollutants, the CCBNEP study area includes the 12 counties of the Coastal Bend: Refugio, Aransas, Nueces, San Patricio, Kleberg, Kenedy, Bee, Live Oak, McMullen, Duval, Jim Wells, and Brooks.

This region is part of the Gulf Coast and South Texas Plain, which are characterized by gently sloping plains. Soils are generally clay to sandy loams. There are three major rivers (Aransas, Mission, and Nueces), few natural lakes, and two reservoirs (Lake Corpus Christi and Choke Canyon Reservoir) in the region. The natural vegetation is a mixture of coastal prairie and mesquite chaparral savanna. Land use is largely devoted to rangeland (61%), with cropland and pastureland (27%) and other mixed uses (12%).

The region is semi-arid with a subtropical climate (average annual rainfall varies from 25 to 38 inches, and is highly variable from year to year). Summers are hot and humid, while winters are generally mild with occasional freezes. Hurricanes and tropical storms periodically affect the region.

On the following page is a regional map showing the three bay systems that comprise the CCBNEP study area.



Corpus Christi Bay National Estuary Program Study Area

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LIST OF ACRONYMS

2-in TED	-2-inch space bar TED
4-in TED	-4-inch space bar TED
BRD	-Bycatch reduction device
CBBEP	-Coastal Bend Bays and Estuaries Program
CPL	-Central Power & Light
CPUE	-Catch per unit effort
EEZ	-Exclusive economic zone
FE	-Fish eye
GCCA	-Gulf Coast Conservation Association
LMEF	-Large mesh extended funnel
NMFS	-National Marine Fisheries Service
SAFDF	-South Atlantic Fisheries Development Foundation
TED	-Turtle excluder device
TL	-Total length
TPWD	-Texas Parks & Wildlife Department
TSPA	-Texas Seafood Producers Association

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ACKNOWLEDGMENTS

The authors wish to thank all reviewers of this report for their helpful critiques and suggestions. We also wish to thank all TPWD Coastal Fisheries Division Ecosystem staff from the Port O'Connor, Aransas, Corpus Christi and upper Laguna Madre field stations, GCCA-CPL Marine Development Center staff, and Americorp personnel for assistance in sample collection and processing. Thanks are extended to Paul Choucair for the excellent graphics for BRD and trawling gear figures. A special thanks is extended to Erin Keller, Texas A & M/Corpus Christi, for her hours of work assisting with all aspects of the project as well as her help with initial summary of the data. Special thanks is also extended to the NMFS at Pascagoula, Mississippi facility for supplying the LMEF, and to Dale Stevens (NMFS gear specialist) for installing the BRD and helpful suggestions for its use. Thanks are also extended to the numerous commercial bay shrimp captains who supplied valuable suggestions and hands-on assistance in setting and adjusting trawling gear used in the demonstration project. A special thanks goes to Talton James (Cove Harbor Shrimp Company) for docking facilities and ice supplied free of charge.

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EXECUTIVE SUMMARY

The TSPA in conjunction with TPWD and Texas A & M Sea Grant researchers conducted a CBBEP-funded BRD Demonstration Project during the 1997 spring (15 May-15 Jul) and fall (15 Aug-15 Dec) commercial bay-shrimp seasons. Three BRD's (LMEF, 2-in TED, and FE) were evaluated for their effectiveness to reduce bycatch and limit shrimp loss. One hour comparative trawl tows were conducted in Aransas Bay using 32-ft trawls during the spring season, and 45-ft trawls during the fall season.

Bycatch varied between seasons and among BRD's, but indicated BRD's have potential for reducing bycatch organisms while at the same time limiting shrimp loss. The LMEF had highest total bycatch reduction rates in weight and second highest reduction in number, with no significant shrimp loss during spring. The 2-in TED was first in total bycatch reduction in number during spring, but had significant loss in shrimp weight. This shrimp loss was greater than the total bycatch reduction rate. Weight reduction rates for total bycatch and total other invertebrates were significant during spring with the LMEF. Overall, the LMEF significantly reduced bycatch in number and weight at higher rates than the other two BRD's during fall. However, high significant shrimp loss with the LMEF is a concern during fall. Both the FE and 2-in TED reduction rates varied among groups in fall.

Spot (*Leiostomus xanthurus*), the most abundant bycatch species, was reduced best by the LMEF during spring and fall. During spring, economically important species of management concern had greatest reduction rates with the 2-in TED and FE for Atlantic croaker (*Micropogonias undulatus*), 2-in TED for sand seatrout (*Cynoscion arenarius*), LMEF for blue crab (*Callinectes sapidus*), and FE for southern flounder (*Paralichthys lethostigma*). During fall, Atlantic croaker and sand seatrout had greatest reduction rates with the LMEF, whereas blue crab had highest reduction rates with the 2-in TED.

Differences in bycatch reduction among studies and BRD's can be affected by many factors such as variations in bottom substrate, water depth, and temporal and spatial biodiversity in size and population of shrimp and other organisms within commercial trawling areas. Other variables are size and placement of BRD's, size and type of trawl, length of trawl bag used, and speed and duration of tow. All these factors working independently or in concert affect bycatch reduction and shrimp loss.

Low reduction rates in spring compared to fall are a concern because major bycatch organisms are, overall, smaller in size and found in greater abundance and weight in spring than in fall. Future development of BRD's for use in bays should be directed at reducing smaller bycatch organisms during the spring season, as well as maintaining equal or greater reduction rates during fall, with minimal shrimp loss. It is recommended that further studies are conducted on the three BRD's tested in this demonstration project, and on other configurations that may hold promise at reducing bycatch.

More BRD research is needed before specific recommendations for BRD use in Texas waters can be proposed. Although BRD reduction rates in this demonstration project are promising, differences between BRD's and control nets were not significant for many groups and species, probably due to small sample sizes. Continued proactive participation of the bay shrimp industry in research and development of BRD's will help speed resolution of the bycatch issue. This cooperative process will benefit Texas ecosystems as well as the Texas bay shrimping industry. It is recommended that the bay shrimp industry adopt a proactive approach to fisheries conservation by supporting the voluntary use of BRD's.

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INTRODUCTION

Bycatch (catch other than target species) in world fisheries is at the forefront of concern by fishery managers, the fishing industry, conservationists, and the public. There have been numerous local, national, and worldwide symposiums and meetings to address bycatch concerns and possible solutions to bycatch in marine fisheries. Specific bycatch concerns associated with the commercial shrimping industry have been addressed by the federal government and several regional fishery management councils and commissions. Regional council and commission mandates have been made to reduce shrimp trawl bycatch of weakfish (*Cynoscion regalis*) by 50% in the south Atlantic within state (Atlantic States Marine Fisheries Commission 1995) and federal (South Atlantic Fishery Management Council 1995) waters by 1996, and reduce red snapper (*Lutjanus campechanus*) bycatch by 50% within the Gulf of Mexico by 1994 (Gulf of Mexico Fishery Management Council 1991). To date, the south Atlantic states of North Carolina, South Carolina, Georgia, and Florida have imposed laws requiring use of BRD's in shrimp trawls. All shrimp trawls in south Atlantic federal waters (EEZ[1]) are required to use BRD's. In the Gulf of Mexico, the NMFS implemented Amendment 9 of the Fishery Management Plan for the Shrimp Fishery of the Gulf of Mexico on 14 May 1998 (Gulf of Mexico Fishery Management Council 1996, Department of Commerce 1998). This amendment requires use of certified BRD's in shrimp trawls within the EEZ shoreward of the 183-m depth contour west of Cape San Blas, Florida. At present, neither Texas nor any other Gulf state has concurrent regulations for use of BRD's within state territorial waters[2]. TED's are required in all EEZ and state territorial waters.

Most research on the effectiveness of various BRD's to reduce shrimp trawl bycatch has been conducted in both Atlantic and Gulf of Mexico offshore waters. However, limited research has been conducted within Atlantic and Gulf of Mexico coastal bays to ascertain effectiveness of BRD's to reduce bycatch. Bay shrimp trawl fisheries characteristically catch mostly small juvenile species as bycatch compared to the general larger size of species comprising the bycatch in Gulf of Mexico offshore waters (Fuls and McEachron 1997, TPWD unpublished data). Additionally, shrimp trawl and mesh size regulations are more restrictive in coastal bay shrimp fisheries, in contrast to offshore waters where larger and greater numbers of trawls can be used by vessels. These different regulations are related to commercial shrimp found in the two areas. Juvenile and sub-adult shrimp are found in bay waters, and sub-adult and adult shrimp are in offshore waters.

Shrimp (*Penaeus sp.*) are the most important commercial seafood product in Texas, annually accounting for more than 90% of the value and 80% of the weight of all reported Texas seafood landings and 20-30% of the value and weight landed from Texas bays (Robinson et. al 1998). Coastal areas that support commercial shrimp fisheries within the CBBEP area are Aransas Bay, Corpus Christi Bay, and upper Laguna Madre. Shrimp fishery bycatch impacts on population

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[1]>3 to 200 nautical miles offshore

[2]Out to 9 nautical miles off Texas and Florida; out to 3 nautical miles off Alabama, Mississippi and Louisiana

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and biodiversity within these and other Texas marine ecosystems are a concern to Texas managers, the fishing industry, conservation groups, and the public. To minimize impacts to marine ecosystems and this valuable Texas fishery, operational BRD testing mimicking bay shrimping activities are needed to identify and improve upon BRD's that have potential to reduce bycatch without adversely reducing shrimp catch.

The TSPA (representing the commercial bay-shrimp industry) in conjunction with TPWD and Texas A & M Sea Grant researchers combined efforts to find solutions to reduce Texas bay shrimp trawl bycatch. This process was initiated by conducting a CBBEP-funded BRD demonstration project during the 1997 spring (15 May-15 Jul) and fall (15 Aug-15 Dec) commercial bay-shrimp seasons. This demonstration project was designed to evaluate three BRD's, two approved (FE, LMEF) in south Atlantic waters, and a 2-in TED identified by local bay shrimpers as having potential in reducing bycatch. Specific project objectives were to:

- Evaluate the effectiveness of three BRD's (LMEF, 2-in TED, FE) through paired-trawl studies.

- Estimate the cost of installing each BRD for use in commercial shrimp trawls.

- Produce a final report presenting bycatch and shrimp reduction rates (in number and weight) for the three BRD's.

LITERATURE AND HISTORICAL REVIEW

Over the past 30 years some Texas commercial bay shrimpers have used various methods and devices within their trawls to reduce unwanted bycatch when they experience high abundance of fish, jellyfish, and other unwanted organisms. However, the configurations and efficiency of these devices and methods have not been documented.

TPWD conducted bycatch characterization studies along the Texas coast and within the CBBEP areas of Aransas and Corpus Christi Bays from 1993 to 1995 (Fuls 1995, 1996; TPWD unpublished data). The following is a summary of seasonal bycatch to shrimp ratios derived from 264 commercial bay-shrimp tows for Aransas and Corpus Christi Bays:

	Aransas		Corpus Christi	
Year	Number	Weight	Number	Weight
Spring (15 May-15 Jul)				
1993	1.2:1	2.4:1	2.3:1	6.8:1
1994	2.4:1	6.7:1		
1995			1.0:1	2.7:1
Fall (15 Aug-15 Sep)				
1993	1.9:1	4.8:1	2.5:1	5.1:1
1994	1.5:1	4.7:1		
1995			1.3:1	5.6:1

Branstetter (1997) states that bycatch characterization work analyzed by the NMFS revealed a bycatch to shrimp ratio (by wt.) within the south Atlantic of 4.5:1, and 5.25:1 within the Gulf of Mexico.

Prior to the present demonstration project, research has been conducted utilizing various BRD's (sizes, shapes, and configurations) and placements within trawls. However, most work has been conducted offshore within the south Atlantic and Gulf of Mexico. Branstetter (1997) summarized SAFDF-funded bycatch reduction work conducted in the Gulf of Mexico and the south Atlantic shrimp fisheries during 1993-1996. A total of 1,696 comparative tows in the Gulf of Mexico and 689 tows within the south Atlantic were conducted using BRD's (Branstetter 1997). Various sizes, shapes, and placements of FE's were researched resulting in total finfish reduction rates (by wt.) ranging from 4 to 46%, with shrimp loss ranging from 0 to 16%. LMEF research (four different configurations) resulted in total finfish reduction rates of 18 to 32% (by wt.), with shrimp loss from 0 to 4%. Other limited research on four other BRD types resulted in total finfish reduction rates of 0 to 31%, with shrimp loss from 0 to 8% (Branstetter 1997).

Watson et al. (1997) summarized NMFS-supported bycatch reduction research in Gulf of Mexico and south Atlantic offshore waters, including most of the work reported by Branstetter (1997). Watson et al. (1997) reported that 145 various BRD/TED design combinations were evaluated in offshore waters of the south Atlantic and Gulf of Mexico between 1990-1996. Overall total fish reduction rates (by wt.) were 58% for the Jones/Davis BRD, 57% for the Andrews TED, 37% for the FE, and 35% for the LMEF. Overall shrimp loss for devices tested were 0% for the LMEF, 4% for the Jones/Davis BRD, 6% for the FE, and 16% for the Andrews TED.

Bycatch research in coastal bays is limited compared to offshore research. Before the present BRD demonstration project, published comprehensive coastal bay research has been limited to North Carolina (McKenna et al. 1996, McKenna and Monaghan 1993), Florida (Steele 1997), and Louisiana (Rogers et al. 1997). Even more limited is operational BRD research (TED and BRD used at same time). All research to date indicates size and placement of a BRD, trawl size, and bag size are factors critical to reduction of bycatch and retention of shrimp. The common trawl bag used by shrimpers in Texas bays is longer than bags used by most shrimpers in the bays of North Carolina, Florida and Louisiana. These factors, along with different species diversities and habitats, make comparisons of BRD research for specific devices difficult among areas.

Prior to operational BRD research, McKenna et al. (1996) and McKenna and Monaghan (1993) conducted BRD proof-of-concept tests (BRD used without TED) within North Carolina bays. Operational BRD research by McKenna et al. (1996) in North Carolina bays was conducted with various size vessels, trawls, TED's, and trawl bags in conjunction with various size FE's in different trawl bag locations. Operational tests with FE's resulted in total finfish reduction rates from 0 to 76% in weight and 0 to 64% in number; shrimp loss ranged from 3 to 29% in weight and 3 to 25% in number. The LMEF's total finfish reduction rates ranged from 0 to 65% in weight and 0 to 74% in number; shrimp loss ranged from 0 to 32% in weight and 0 to 25% in number. Snake eye BRD's total finfish reduction rates ranged from 0 to 12% in both weight and number, and shrimp loss from 0 to 11% in both weight and number.

Steele (1997) conducted BRD/TED combination research in Florida using a FE and LMEF in three sizes of trawls (float lines of about 20-, 22-, and 26-ft). Each trawl conformed to the 500 ft^2 mesh trawl limitation in Florida. Total bycatch reductions (by wt.) among trawls for the FE ranged from 14 to 37%, total finfish reduction from 11 to 26%, and total shrimp loss from 0 to 14%. Total bycatch reductions for the LMEF ranged from 36 to 41%, total finfish reduction from 26 to 46%, and shrimp loss from 0 to 21%.

Rogers et al. (1997) published BRD evaluations conducted in Louisiana coastal bays during 1992. This research was conducted using 20-ft trawls that are smaller than common commercial trawls used in Louisiana and most other state coastal waters. No TED's were used in these studies. The FE ("Cameron Shooter") had an overall fish reduction rate of 33% (by wt.) and a shrimp loss of 14%. A device somewhat similar to the LMEF ("Eymard Accelerator") had an overall fish reduction rate of 19% and no shrimp loss. Two other BRD's ("Authement-Ledet", "Lake Arthur") had an overall fish reduction rate of 42 and 21% by weight and shrimp loss of 14 and 17%, respectively.

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MATERIALS AND METHODS

A LMEF, 2-in TED, and FE (Figures 1, 2, and 3) were tested to evaluate effectiveness in reducing bycatch during the 1997 spring and fall commercial bay-shrimp seasons in Aransas Bay. The spring season is historically a brown shrimp (*Penaeus aztecus*) season. The fall season is historically a white shrimp (*P. setiferus*) season.

Total cost for each BRD was:

- LMEF: **Total cost = *$235***
  - Cost of LMEF: $200
  - Labor to install: $35
- 2-in TED: **Total cost = *$292***
  - TED frame: $55
  - TED panel insert: $75
  - Labor to install TED frame: $110
  - Two floats for TED: $17
  - Labor to install TED in net: $35
- FE: **Total cost = *$55***
  - Cost of FE: $20
  - Labor to install: $35

The LMEF supplied by the NMFS was constructed of 1 3/8-in stretch mesh webbing with the funnel being 120 meshes in circumference at the end closest to the 4-in TED and 77 meshes in circumference at the end leading to the tail bag tie-off (Figure 1). The funnel was surrounded in part by 120 mesh circumference 1 3/8-in mesh webbing six meshes long (where funnel was attached to the 4-in TED), then attached to a larger escape section of 10-in stretched mesh webbing (three meshes long continuing the tube surrounding the small mesh funnel), and then attached to a 23-in length of 1 3/8-in mesh webbing (120 meshes in circumference) continuing the outer tube to where it attaches to the bag of the trawl. A single extension of the small end of the small mesh funnel was extended and attached vertically within the outer trawl tube to direct the trawl catch toward the cod end of the bag.

A 2-in TED was used as a BRD (Figure 2). TED's were top-shooting with frame and vertical bars angled up to a flap opening on the top side of the net for escapement of turtles. TED's were constructed of a main aluminum frame within which a separate frame panel with vertical spaced bars could be inserted and easily attached to the main frame. The 2-in TED had a frame panel with 2-in spaces between bars. Two yellow floats were attached to the top of the TED to keep it upright in the water column and to reduce chances of flipping over during towing. The TED was attached between the body and the bag of the trawl.

The FE was a half circle shape constructed of 1/4-in stainless steel with an opening height of 4 inches (bottom width of 8.5 in) with a total open area of 26 in^2, with supports 13-in long tapering back to a point (Figure 3). The device was sewn into the top of the trawl bag (opening facing toward the body of the trawl) at a BRD to tail bag ratio of 70% (distance from tailbag tie-off to opening of BRD was 125 in).

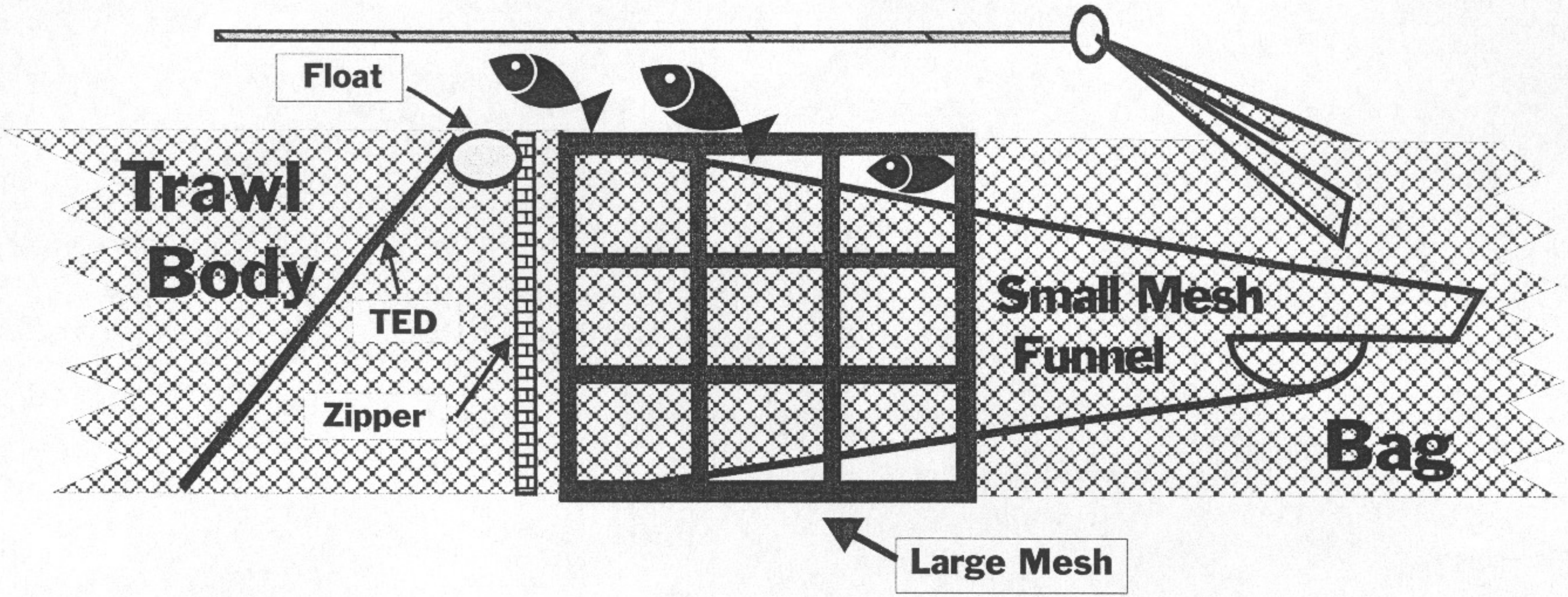

Figure 1. Side view of a large mesh extended funnel located behind the TED.

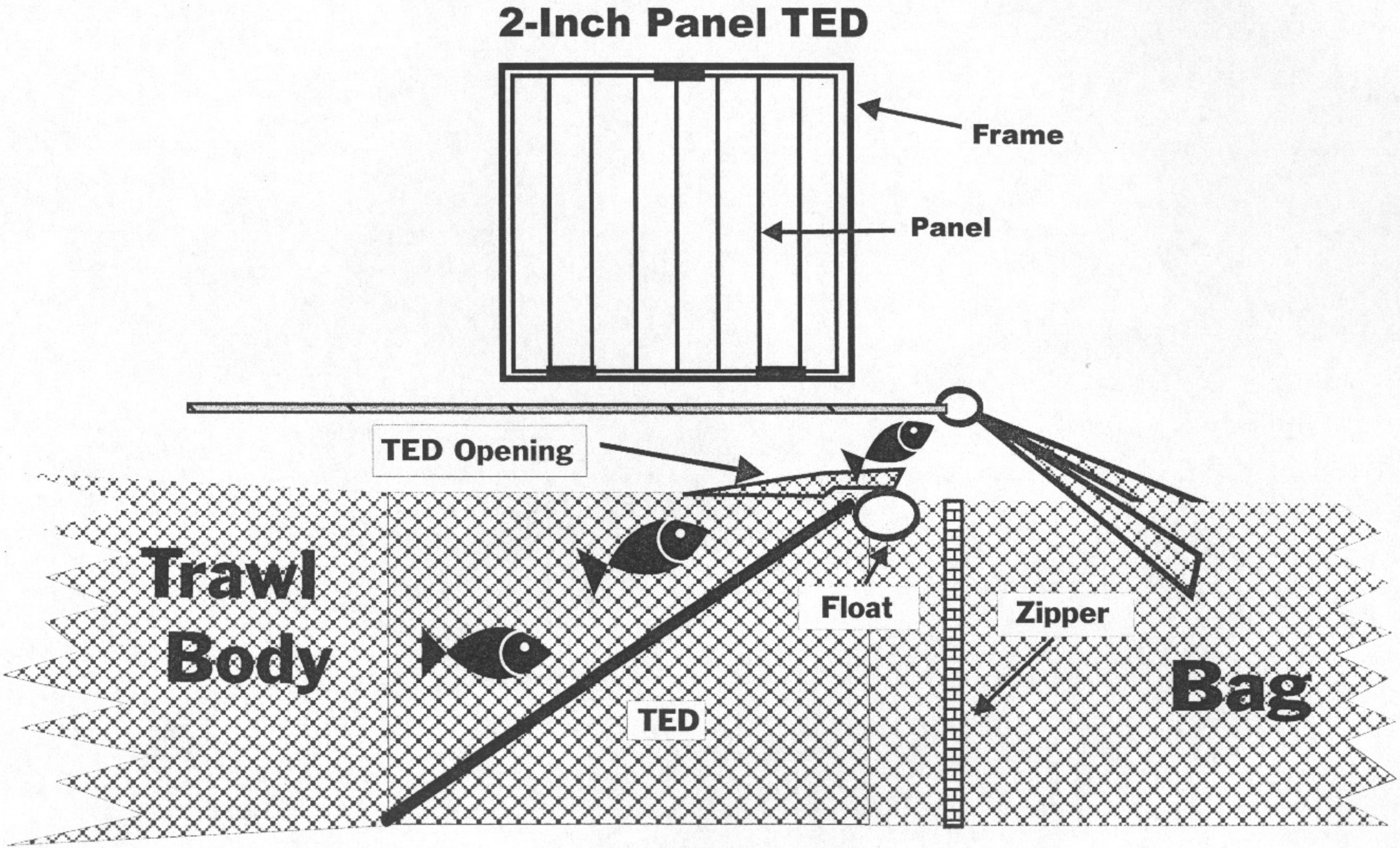

Figure 2. Side view of a TED with interchangeable 2-inch panel which was used as a bycatch reduction device.

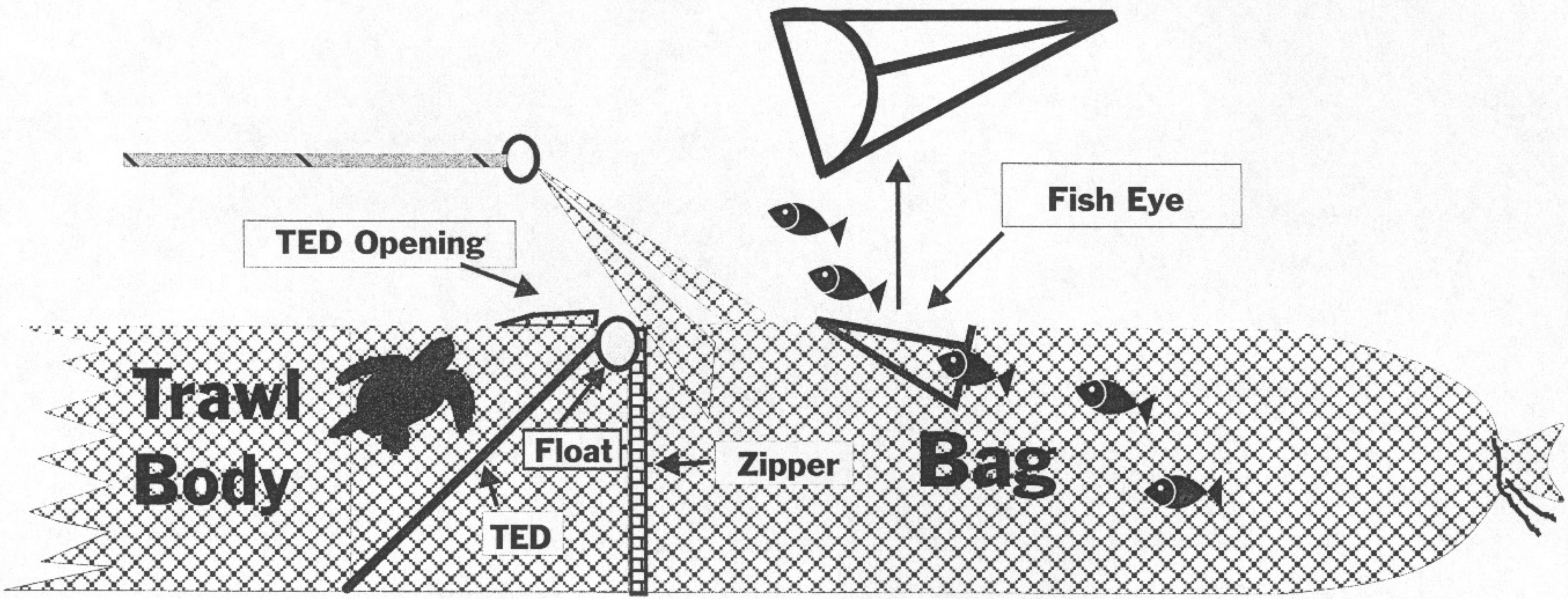

Figure 3. Side view of fish eye located along the top center line of the trawl bag with the opening facing towards the body of the trawl.

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During the spring commercial bay-shrimp season, the following 32-ft head rope shrimp trawl was used:

- Flat net with 1 ½-in stretched mesh webbing in the body of the trawl and 1 3/8-in stretched mesh in the bag of the trawl,

- trawl bag, 178 inches from start of bag to bag tie-off, and

- a three-cable 245-ft bridle attached to two 8-ft x 40-in wooden doors and a 6-ft metal sled between the two doors (Figure 4).

- The trawl lead line was weighted with multiple placements of four lengths of 1/4-in chain 3 ft apart for extra lead line weight. A 1/4-in tickler chain was spread between each door and the metal sled at least 2 ft in length shorter than the lead line of each trawl. This enables the tickler chain to precede the lead line of the trawl. Tickler chains are commonly used by shrimpers to enhance shrimp catch.

During the fall commercial bay-shrimp season, the following 45-ft head rope shrimp trawl was used:

- Mongoose net with bibs (extra triangle shaped piece of webbing attached to trawl float line); 1 3/4-in stretched mesh webbing in the body and in the bag of the trawl,

- trawl bag, 178 inches from start of bag to bag tie-off, and

- a five-cable 245-ft bridle attached to 9-ft x 44-in wooden doors in the same manner as previously described for the 32-ft nets. The two extra cables were attached with a float to the bib of each trawl to maximize the height of the float line of the trawl as it was being towed through the water. Bibs are commonly used by shrimpers to increase white shrimp catch during fall.

- Extra lead line chain weights and tickler chains were attached as previously described for the 32-ft nets.

Evaluations were made by towing two trawls simultaneously:

- A control with a 4-in TED (4-in spaces between bars; maximum legally required).

- A trawl with both a 4-in TED and a BRD, except when the trawl had a 2-in TED (acting as both a TED and a BRD). The trawl with the 2-in TED did not have an additional 4-in TED.

All trawls were equipped with trawl zippers behind the TED's for easy removal of trawl bags, with or without BRD's installed.

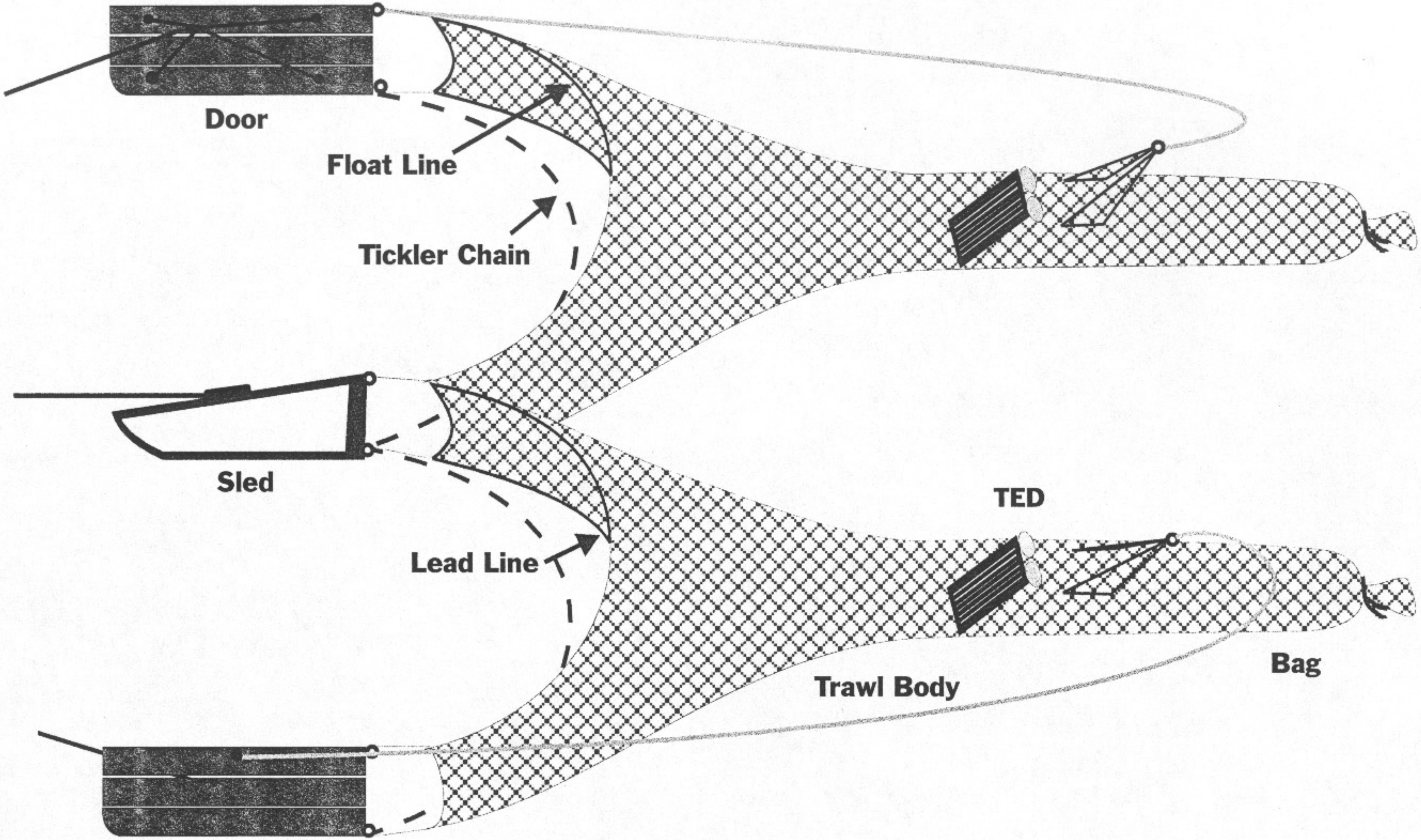

Figure 4. Paired trawls with doors and sled showing approximate location of trawl body, TED, and bag.

Comparative trawl tows were conducted aboard the 46-ft single diesel powered F/V Erin Lynn captained by Terry Ricks (TSPA). Tows were made with a control trawl attached to one outside door and then to the metal sled, while the BRD trawl was attached to the other door and the metal sled (Figure 4). Vessel speed was 2.5 knots. Tow time was set at 1 hour from lock-down of winch to the beginning of retrieval.

Twenty comparative tows were conducted with each BRD during each of the spring and fall commercial bay-shrimp seasons near or among the commercial fleet. Ten tows were conducted with each BRD at the beginning of each season, and then 10 with each BRD about a month later. Sampling occurred during the following dates:

Spring Season
- 26 May-1 Jun
- 22 Jun-2 Jul

Fall Season
- 5-14 Sept
- 8-19 Oct

Before BRD comparative trawl sampling began, all nets were tested (without BRD's) numerous times and adjusted for equal catchability by comparing the total catch (wt.) between the two nets towed simultaneously. A gear advisory panel made up of select commercial shrimpers assisted with making adjustments to trawls and gear to achieve equal catchability among nets. This process resulted in pre-sampling overall variability within 8% after final tuning of trawls.

To minimize side-to-side catch variation, trawl bags (control and BRD) were unzipped from each trawl and switched after each tow. When testing the 2-in TED as a BRD, only the TED panels (2- or 4-in) were switched after each tow. For randomness and temporal change of species diversity and abundance, only one BRD was tested per day. On the next sampling day another BRD was tested. This procedure was followed until each BRD was towed 20 times during both spring and fall. Each trawl sample was placed in a separate partitioned area of the deck where the catch was mixed thoroughly. A 25-lb sub-sample was then collected from each tow. The remainder of the catch from each tow was separated into commercial shrimp and bycatch and weighed (g) en masse aboard the vessel.

The 25-lb sub-samples were placed on ice and taken back to TPWD facilities, where each sub-sample was sorted by species. Each species was then weighed enmasse (g) and counted. Up to 19 individuals of each species were measured (TL mm) except for commercial penaeid shrimps and blue crabs (*Callinectes sapidus*); up to 50 shrimp per species and up to 35 blue crabs were measured. Data were recorded on TPWD data sheets and subsequently computerized.

For each comparative tow, CPUE was determined for all species (no./h and g/h). Data were summarized to obtain percent reduction for major groups and major species for each season and each BRD. CPUE for major groups and major species within tows were analyzed to determine statistical significance of reduction rates. Only tows in which the control trawl or the BRD trawl contained a select species were used for statistical analyses. Therefore, analyses test the significance of a BRD to reduce the select species when it is actually caught. Before all analyses, a Shapiro-Wilk test was used to determine normality. Because most data sets were not normally distributed, and no single data transformation was found to normalize data, nonparametric Wilcoxon Signed-Rank tests were performed on all data sets. SAS (SAS 1990) was used for analyses.

Because excessive aquatic vegetation could affect reduction rates of BRD's and would not represent normal commercial operations, sampling protocol voided a tow if excessive aquatic vegetation was caught. Commercial fishermen who encounter great amounts of vegetation normally do not continue to shrimp within such areas. Samples were recollected twice during fall LMEF sampling[3] because aquatic vegetation weight was equal to or more than the total biomass weight of the control and BRD nets. One fall FE sample[4] was not recollected due to time constraints. Therefore, only 19 FE tows were used for analyses during fall. Vegetation was minimal[5] in all other tows.

[3]1st tow: control with 100 lb of vegetation, LMEF with 52 lb; 2nd: control with 98 lb of vegetation, LMEF with 52 lb.

[4]Control with 141 lb of vegetation, FE with 107 lb.

[5]15 lb in one control net, with at least 94% of all other samples having <4 lbs of aquatic vegetation in a trawl sample.

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RESULTS

Spring Samples

The LMEF had significant weight reduction in both total bycatch (13.1%) and total other invertebrates (17.9%) (Table 1). The 2-in TED had highest reduction in number for both total bycatch (6.3%) and total other invertebrates (10.3%), but neither rate was significant. Finfish was best reduced by the 2-in TED in number (5.7%) and by the LMEF in weight (10.9%), though neither rate was significant.

During spring, brown shrimp comprised almost 100% of the commercial shrimp in comparative tows (Table 2). White shrimp and pink shrimp (*P. duorarum*) catches were so low that comparisons were not made for these species. The 2-in TED had significant shrimp loss in weight (8.3%), but not in number (Tables 1 and 3). Shrimp loss for both the LMEF and FE was lower than the 2-in TED and was not significant.

The dominant bycatch species by number in spring were spot (*Leiostomus xanthurus*), Atlantic croaker (*Micropogonias undulatus*), blue crab, Gulf menhaden (*Brevoortia patronus*), Atlantic threadfin (*Polydactylus octonemus*), and sand seatrout (*Cynoscion arenarius*) (Tables 2 and 3). Spot was significantly reduced in number (13.9%) with the LMEF, but not in weight (18.6%). Atlantic croaker had greatest reduction rates with the FE in number (6.8%) and with the 2-in TED in weight (11.2%), but neither was significant. Blue crab was significantly reduced in number (13.8%) and weight (18.3%) with the LMEF. Gulf menhaden (7.2% by no.; 8.0% by wt.) and Atlantic threadfin (3.7% by no.; 5.3% by wt.) had greatest reduction rates with the FE, but rates were not significant. Sand seatrout had best reduction rates with the 2-in TED (14.6% by no.; 22.1% by wt.), but neither rate was significant.

Other major species had variable reduction rates depending on the BRD used (Table 3). Reduction rates for most of these species were not significant. However, significant reduction rates during spring were found for the hardhead catfish (*Arius felis*) with the LMEF (76.7% by no.; 86.2% by wt.), bay anchovy (*Anchoa mitchilli*) with the 2-in TED (29.5% by no.; 29.3% by wt.), and Gulf butterfish (*Peprilus burti*) with the FE (77.1% by wt.).

Table 1. Percent difference (%) in number and weight (g) for BRD paired trawl studies conducted in Aransas Bay during the spring (15 May-15 Jul) and fall (15 Aug-15 Dec) 1997 commercial bay-shrimp seasons. A negative percent indicates reduction by the BRD. P-Value (P) indicates alpha for a non parametric Wilcoxon Signed-Rank test (significance level is [a]$\leq$0.05; [b]$\leq$0.01; [c]$\leq$0.001).

	Shrimp				Bycatch				Finfish				Other invertebrates			
	Number		Weight		Number		Weight		Number		Weight		Number		Weight	
BRD	%	P	%	P	%	P	%	P	%	P	%	P	%	P	%	P
SPRING																
LMEF	1.08	0.452	- 0.5	0.522	-4.72	0.452	-13.11	0.008[b]	-3.89	0.812	-10.87	0.105	-10.19	0.105	-17.9	0.012[a]
2-in TED	-7.71	0.083	-8.28	0.006[b]	-6.33	0.097	-5.21	0.294	-5.72	0.177	- 4.07	0.546	-10.31	0.498	- 7.57	0.312
FE	-6.77	0.368	0.72	0.728	-3.24	0.123	- 1.91	0.177	-3.87	0.143	- 3.50	0.202	0.74	0.841	1.06	0.870
FALL																
LMEF	-20.73	0.001[c]	-15.46	0.003[b]	-43.71	<0.001[c]	-43.93	<0.001[c]	-49.17	<0.001[c]	-53.64	<0.001[c]	-25.47	<0.001[c]	-21.79	0.007[b]
2-in TED	-3.25	0.756	- 2.56	0.349	0.78	0.985	-12.22	0.070	3.65	0.577	1.82	0.927	-10.92	0.325	-46.79	0.001[c]
FE	- 1.68	0.734	- 2.90	0.289	- 1.38	0.595	0.36	0.999	- 1.06	0.595	- 1.01	0.651	-3.47	0.945	7.19	0.418

Table 2. Mean number (No./h), weight (g/h) and TL (mm) for major species caught in the control and BRD trawls during the spring 1997 commercial bay-shrimp season (15 May-15 Jul). N = number of comparative tows with species present. ND = no length taken.

		LMEF					
		Number		Weight		TL	
Species	N	Control	BRD	Control	BRD	Control	BRD
SHRIMP							
Brown shrimp	20	2,979.3	3,011.6	12,367.4	12,307.2	85	84
FINFISH							
Spot	20	690.8	594.6	7,455.5	6,071.6	97	94
Atlantic croaker	20	312.7	359.4	2,718.2	2,889.0	96	95
Gulf menhaden	20	64.3	62.5	1,730.5	1,631.4	138	138
Atlantic threadfin	20	56.8	68.8	376.3	448.4	91	92
Sand seatrout	20	59.0	61.5	657.9	569.2	101	95
Bay anchovy	20	43.7	39.0	61.7	54.7	59	61
Pinfish 19	18.9	14.0	149.0	100.8	81	79	
Bay whiff	20	7.9	8.5	20.3	17.9	66	64
Atlantic cutlassfish	17	5.3	6.8	183.3	199.1	342	327
Southern flounder	18	5.9	5.7	156.0	196.6	133	146
Hardhead catfish	12	4.5	1.0	337.0	46.6	191	179
Silver perch	12	3.2	1.5	47.6	19.2	100	101
Gulf butterfish	8	13.8	9.5	150.7	127.4	87	99
OTHER INVERTEBRATES							
Blue crab	20	157.0	135.4	6,282.4	5,132.8	87	83
Lesser blue crab	19	26.8	30.9	36.9	50.3	31	33
Atlantic brief squid	9	6.7	8.7	65.4	91.2	39	44
Sea nettle jellyfish	9	6.8	4.1	92.2	52.8	ND	ND

Table 2. (Cont'd.)

		2-in TED					
		Number		Weight		TL	
Species	N	Control	BRD	Control	BRD	Control	BRD
SHRIMP							
Brown shrimp	20	2,393.2	2,210.2	10,871.0	9,969.4	86	87
FINFISH							
Spot	20	836.9	794.9	8,430.8	7,812.4	93	93
Atlantic croaker	20	335.7	314.8	3,056.2	2,714.7	98	94
Gulf menhaden	20	45.6	53.2	1,177.9	1,513.9	137	140
Atlantic threadfin	20	50.4	49.2	234.9	319.7	89	92
Sand seatrout	20	48.3	41.3	405.4	315.8	92	90
Bay anchovy	20	47.5	33.4	55.0	38.9	58	57
Pinfish	19	14.9	10.3	156.1	132.8	88	89
Bay whiff	18	8.4	7.0	26.4	19.1	71	69
Atlantic cutlassfish	20	10.9	10.4	246.8	308.7	318	341
Southern flounder	19	4.9	5.0	185.5	196.8	153	152
Hardhead catfish	18	3.4	2.6	190.0	150.1	174	182
Silver perch	12	1.7	5.6	24.3	85.4	106	102
Gulf butterfish	11	2.3	3.4	38.9	61.6	98	101
OTHER INVERTEBRATES							
Blue crab	20	158.4	146.1	6,459.2	5,980.4	85	84
Lesser blue crab	18	25.5	18.6	51.9	32.3	34	32
Atlantic brief squid	10	15.2	25.0	64.3	152.6	33	36
Sea nettle jellyfish	10	52.0	36.2	908.5	767.4	ND	ND

Table 2. (Cont'd.)

		FE					
		Number		Weight		TL	
Species	N	Control	BRD	Control	BRD	Control	BRD
SHRIMP							
Brown shrimp	20	2,271.3	2,115.3	10,126.0	10,192.9	88	87
FINFISH							
Spot	20	493.9	498.2	5,069.3	5,078.4	92	94
Atlantic croaker	20	271.8	253.2	2,415.9	2,153.9	99	97
Gulf menhaden	20	62.7	58.2	1,748.4	1,608.5	138	139
Atlantic threadfin	20	40.2	38.7	303.4	287.2	97	96
Sand seatrout	20	28.2	27.5	315.2	255.3	94	91
Bay anchovy	19	50.7	39.2	65.0	43.3	60	58
Pinfish	20	11.6	11.3	99.5	110.1	80	87
Bay whiff	18	7.1	6.2	29.5	17.4	76	69
Atlantic cutlassfish	18	15.1	14.9	570.2	674.4	379	399
Southern flounder	19	3.4	2.9	122.0	100.3	144	141
Hardhead catfish	18	3.1	4.1	362.6	314.9	214	193
Silver perch	13	5.6	4.6	33.5	58.1	75	80
Gulf butterfish	10	12.4	3.5	384.6	88.2	120	114
OTHER INVERTEBRATES							
Blue crab	20	128.8	123.6	5,840.2	5,873.4	89	87
Lesser blue crab	20	15.2	21.6	28.8	56.4	33	34
Atlantic brief squid	11	6.8	6.6	34.8	56.5	34	42
Sea nettle jellyfish	13	11.1	11.2	222.2	176.1	ND	ND

Table 3. Percent difference (%) in number and weight (g) for major species caught in BRD paired trawl studies conducted during the spring 1997 commercial bay-shrimp season (15 May-15 Jul). A negative percent indicates reduction by the BRD. P-Value (P) indicates alpha for a non parametric Wilcoxon Signed-Rank test (significance level is [a]≤0.05; [b]≤ 0.01; [c]≤0.001). Species are in order of number of comparative tows (N) with species in one or both nets, and secondly in order of abundance.

	LMEF					2- in TED					FE				
	Number			Weight		Number			Weight		Number			Weight	
Species	N	%	P	%	P	N	%	P	%	P	N	%	P	%	P
SHRIMP															
Brown shrimp	20	1.1	0.452	-0.5	0.522	20	- 7.6	0.083	- 8.2	0.006[b]	20	- 6.9	0.388	- 0.6	0.756
FINFISH															
Spot	20	-13.9	0.048[a]	-18.6	0.058	20	- 5.0	0.123	- 7.3	0.105	20	0.9	0.349	0.2	0.368
Atlantic croaker	20	14.9	0.022[a]	6.3	0.648	20	-6.2	0.409	-11.2	0.083	20	- 6.8	0.388	-10.8	0.202
Gulf menhaden	20	- 2.8	0.785	- 5.7	0.756	20	16.6	0.475	28.5	0.261	20	-7.2	0.189	- 8.0	0.261
Atlantic threadfin	20	21.2	0.430	19.2	0.388	20	-2.3	0.927	36.1	0.230	20	- 3.7	0.728	-5.3	0.294
Sand seatrout	20	4.3	0.277	-13.5	0.728	20	-14.6	0.452	-22.1	0.177	20	- 2.6	0.756	-19.0	0.596
Bay anchovy	20	-10.7	0.058	-11.3	0.090	20	-29.5	<0.001[c]	-29.3	0.001[c]	19	-22.8	0.490	-33.4	0.123
Pinfish	19	-25.7	0.352	-32.3	0.225	19	-31.1	0.241	-14.9	0.595	20	- 3.0	0.784	10.6	0.812
Bay whiff	20	8.2	0.571	-12.0	0.430	18	-16.6	0.393	-27.8	0.369	18	-12.3	0.670	-41.2	0.325
Atlantic cutlassfish	17	28.1	0.306	8.6	0.548	20	- 4.9	0.728	25.1	0.522	18	- 1.1	0.832	18.3	0.966
Southern flounder	18	- 4.0	0.865	26.0	0.670	19	2.4	0.768	6.1	0.465	19	-15.0	0.768	-17.8	0.829
Hardhead catfish	12	-76.7	0.016[a]	-86.2	0.007[b]	18	-24.1	0.442	-21.0	0.393	18	33.5	0.212	-13.1	0.799
Silver perch	12	-53.0	0.151	-59.6	0.233	12	>100.0	0.129	>100.0	0.301	13	-17.5	0.839	73.6	0.455
Gulf butterfish	8	-30.6	0.945	-15.6	0.999	11	49.0	0.520	58.6	0.520	10	-71.4	0.064	-77.1	0.014[a]
OTHER INVERTEBRATES															
Blue crab	20	-13.8	0.022[a]	-18.3	0.017[a]	20	- 7.7	0.498	- 7.4	0.312	20	-4.1	0.927	0.6	0.498
Lesser blue crab	19	15.0	0.182	36.0	0.104	18	-26.9	0.060	-37.8	0.074	20	41.9	0.033[a]	95.4	0.027[a]
Atlantic brief squid	9	30.4	0.301	39.6	0.652	10	64.7	0.010[b]	>100.0	0.027[a]	11	-3.2	0.831	62.4	0.577
Sea nettle jellyfish	9	-39.7	0.129	-42.7	0.359	10	-30.4	0.922	-15.5	0.695	13	1.1	0.414	-20.7	0.216

Fall Samples

The LMEF significantly reduced total bycatch (43.7% by no.; 43.9% by wt.), finfish (49.2% by no.; 53.6% by wt.), and other invertebrates (25.5% by no.; 21.8% by wt.) (Table 1). However, the 2-in TED had greatest significant reduction in weight of other invertebrates (46.8%). All other FE and 2-in TED reduction rates varied among groups at lower rates and were not significant.

During fall, brown shrimp comprised 60% by number and 48% in weight of commercial shrimp, white shrimp comprised 33% by number and 47% in weight, and pink shrimp comprised 7% by number and 5% in weight (Table 4). The LMEF had significant overall (20.7% by no.; 15.5% by wt.) and individual species shrimp loss, except for white shrimp weight which was not significant (Tables 1 and 5). Shrimp loss for both the FE and the 2-in TED was lower than the LMEF and was not significant.

The dominant bycatch species by number in fall were spot, Gulf menhaden, lesser blue crab (*C. similis*), hardhead catfish, blue crab, Atlantic croaker, and sand seatrout (Tables 4 and 5). Spot (72.9% number; 70.5% weight), Gulf menhaden (41.8% by no.; 37.4% by wt.), hardhead catfish (60.4% by no.; 69.5% by wt.), and Atlantic croaker (39.1% by no.; 40.7% by wt.) were significantly reduced with the LMEF. Number of lesser blue crab (18.2%) and weight of sand seatrout (51.0%) were also significantly reduced with the LMEF. Blue crab had significant reduction in both number (20.2%) and weight (33.3%) with the 2-in TED.

Other major species had various reduction rates depending on the BRD used, but most were not significant (Table 5). Bay anchovy (70.4% by no.; 70.5% by wt.), gafftopsail catfish (*Bagre marinus*) (56.2% by no.; 54.6% by wt.), sea nettle jellyfish (*Chrysaora quinquecirrha*) (49.6% by no.; 68.6% by wt.), and mantis shrimp (*Squilla empusa*) (49.0% by no.; 50.7% by wt.) were significantly reduced with the LMEF. Bay anchovy was also significantly reduced in number (31.8%) and weight (31.3%) with the 2-in TED but at lower rates than the LMEF. Sea nettle jellyfish weight (38.8%) was significantly reduced with the FE but at a lower rate than the LMEF.

Spring vs. Fall Comparative Tows

The total number of species recorded in comparative tows was greater in fall than in spring (Appendix, Table A). The size of most species caught in spring were smaller than those caught in fall (Tables 2 and 4). Total bycatch weight of organisms recorded in spring was about twice that caught in fall, and in number at least three times that caught in fall.

Table 4. Mean number (No./h), weight (g/h), and TL (mm) for major species caught in the control and BRD trawls during the fall 1997 commercial bay-shrimp season (15 Aug-15 Dec). N = number of comparative tows with species present. ND = no length taken.

		LMEF					
		Number		Weight		TL	
Species	N	Control	BRD	Control	BRD	Control	BRD
SHRIMP							
Brown shrimp	20	320.6	236.5	1,894.4	1,469.3	94	94
White shrimp	20	182.8	167.7	1,876.0	1,756.8	113	116
Pink shrimp	20	35.5	22.9	193.6	124.8	86	86
FINFISH							
Spot	20	99.0	26.8	2,970.4	877.1	133	133
Gulf menhaden	20	60.4	35.1	1104.2	690.9	120	124
Hardhead catfish	20	34.8	13.8	306.8	93.6	95	94
Atlantic croaker	20	27.3	16.6	832.9	493.6	140	140
Sand seatrout	20	29.1	18.3	730.9	358.0	134	129
Bay anchovy	19	11.8	3.5	13.1	3.9	55	56
Pinfish	20	13.5	5.7	303.1	131.2	116	116
Bay whiff	20	6.1	4.3	68.0	42.2	103	101
Gafftopsail catfish	18	5.1	2.2	160.6	72.9	152	156
Silver jenny	16	8.1	7.7	71.1	61.7	81	82
Silver perch	11	62.7	49.7	979.3	742.7	111	110
Threadfin shad	9	19.5	10.9	312.0	170.5	119	117
OTHER INVERTEBRATES							
Lesser blue crab	20	40.1	32.8	289.8	263.0	50	52
Blue crab	20	31.1	24.5	1,916.0	1,726.6	92	99
Sea nettle jellyfish	19	14.5	7.3	288.7	90.7	ND	ND
Atlantic brief squid	14	10.4	8.7	107.7	114.0	44	46
Mantis shrimp	14	7.5	3.8	40.1	19.8	76	77
Cabbagehead jellyfish	9	7.8	6.7	1,731.8	1,215.4	ND	ND

Table 4. (Cont'd.)

		2-in TED					
		Number		Weight		TL	
Species	N	Control	BRD	Control	BRD	Control	BRD
SHRIMP							
Brown shrimp	20	244.4	232.0	1,522.1	1,448.8	93	92
White shrimp	20	147.0	148.9	1,585.3	1,594.8	117	116
Pink shrimp	18	36.2	32.5	196.4	173.8	88	88
FINFISH							
Spot	20	174.2	168.2	5,153.3	5,001.6	132	132
Gulf menhaden	20	59.9	70.8	1,079.3	1,259.9	120	121
Hardhead catfish	20	29.4	40.2	290.3	292.1	99	93
Atlantic croaker	20	21.5	23.0	823.2	781.8	145	144
Sand seatrout	19	17.1	18.0	289.8	356.9	118	122
Bay anchovy	19	12.4	8.5	13.4	9.2	55	56
Pinfish	16	1.6	1.7	38.2	39.2	117	114
Bay whiff	16	4.0	4.9	49.0	57.6	106	106
Gafftop catfish	19	4.7	4.8	168.9	166.5	160	162
Silver jenny	15	2.9	4.4	24.5	33.1	82	80
Silver perch	12	15.4	14.3	214.1	221.1	106	107
Threadfin shad	11	12.7	9.3	197.8	142.9	116	118
OTHER INVERTEBRATES							
Lesser blue crab	20	40.2	38.3	264.6	245.6	52	51
Blue crab	20	26.2	20.9	1,987.9	1,326.5	103	93
Sea nettle jellyfish	18	4.9	4.0	73.4	89.3	ND	ND
Atlantic brief squid	13	10.8	12.5	111.8	131.8	44	51
Mantis shrimp	14	5.2	4.6	23.6	25.6	73	71
Cabbagehead jellyfish	4	9.0	2.5	4,722.0	223.5	ND	ND

Table 4. (Cont'd.)

		FE					
		Number		Weight		TL	
Species	N	Control	BRD	Control	BRD	Control	BRD
SHRIMP							
Brown shrimp	19	323.0	319.1	1,775.7	1,702.6	89	88
White shrimp	19	138.0	137.6	1,382.1	1,400.6	112	114
Pink shrimp	19	33.1	29.1	194.4	151.5	86	84
FINFISH							
Spot	19	195.6	192.7	5,650.8	6,030.3	135	134
Gulf menhaden	19	59.2	55.4	1,023.7	954.7	117	120
Hardhead catfish	19	26.0	37.5	311.8	429.9	107	100
Atlantic croaker	19	30.6	30.2	967.3	990.0	141	143
Sand seatrout	19	29.7	24.3	571.8	483.6	125	122
Bay anchovy	19	13.5	10.3	14.6	10.5	55	55
Pinfish	15	33.1	34.3	797.7	842.0	117	119
Bay whiff	12	3.0	3.2	31.9	33.7	100	102
Gafftop catfish	17	4.9	3.2	147.7	96.2	154	154
Silver jenny	17	2.5	4.0	20.4	32.8	83	82
Silver perch	13	25.4	26.2	417.9	426.9	112	110
Threadfin shad	11	15.3	17.1	235.7	277.7	117	119
OTHER INVERTEBRATES							
Lesser blue crab	19	28.1	30.0	223.6	223.7	51	50
Blue crab	19	17.3	17.9	1,418.8	1,681.5	101	111
Sea nettle jellyfish	18	10.0	5.5	116.8	71.5		
Atlantic brief squid	12	8.7	8.6	74.3	67.1	37	39
Mantis shrimp	11	3.3	3.1	19.7	14.1	75	72
Cabbagehead jellyfish	4	13.5	6.1	1,519.8	1,075.8	ND	ND

Table 5. Percent difference (%) in number and weight (g) for major species caught in BRD paired trawl studies conducted during the fall 1997 commercial bay-shrimp season (15 Aug-15 Dec). A negative percent indicates reduction by the BRD. P-Value (P) indicates alpha for a non parametric Wilcoxon Signed-Rank test (significance level is; [a]≤0.05, [b]≤0.01, [c]≤0.001). Species are in order of number of comparative tows (N) with species in one or both nets and secondly in order of abundance.

	LMEF					2- in TED					FE				
	Number			Weight		Number			Weight		Number			Weight	
Species	N	%	P	%	P	N	%	P	%	P	N	%	P	%	P
SHRIMP															
Brown shrimp	20	-26.2	0.001[c]	-22.4	<0.001[c]	20	- 5.1	0.701	- 4.8	0.294	19	- 1.2	0.558	- 4.1	0.182
White shrimp	20	- 8.2	0.054[a]	- 6.3	0.430	20	1.3	0.993	0.6	0.985	19	- 0.3	0.298	1.3	0.442
Pink shrimp	20	-35.5	0.001[c]	-35.5	0.002[b]	18	-10.2	0.975	-11.5	0.890	19	-11.9	0.199	-22.0	0.142
FINFISH															
Spot	20	-72.9	0.001[c]	-70.5	0.001[c]	20	- 3.4	0.589	- 2.9	0.546	19	- 1.5	0.435	6.7	0.484
Gulf menhaden	20	-41.8	0.002[b]	-37.4	0.008[b]	20	18.1	0.564	16.7	0.571	19	- 6.4	0.922	- 6.7	0.860
Hardhead catfish	20	-60.4	0.014[a]	-69.5	0.004[b]	20	36.8	0.108	0.6	0.956	19	44.2	0.018[a]	37.9	0.169
Atlantic croaker	20	-39.1	0.001[c]	-40.7	0.001[c]	20	7.1	0.475	- 5.0	0.860	19	- 1.3	0.369	2.3	0.241
Sand seatrout	20	-37.1	0.156	-51.0	0.004[b]	19	5.3	0.979	23.1	0.441	19	-18.4	0.623	-15.4	0.798
Bay anchovy	19	-70.4	<0.001[c]	-70.5	<0.001[c]	19	-31.8	0.016[a]	-31.3	0.022[a]	19	-23.8	0.992	-28.2	0.556
Pinfish	20	-58.0	0.177	-56.7	0.290	16	5.0	0.934	2.6	0.495	15	3.8	0.903	5.6	0.999
Bay whiff	20	-29.8	0.233	-37.9	0.084	16	20.5	0.333	17.7	0.163	12	5.9	0.954	5.7	0.970
Gafftopsail catfish	18	-56.2	0.003[b]	-54.6	0.009[b]	19	3.0	0.881	-1.4	0.709	17	-35.4	0.102	-34.8	0.145
Silver jenny	16	- 4.9	0.773	-13.2	0.489	15	50.5	0.186	35.1	0.268	17	58.4	0.368	60.8	0.410
Silver perch	11	-20.7	0.999	-24.2	0.831	12	7.6	0.915	3.2	0.569	13	3.2	0.933	2.2	0.839
Threadfin shad	9	-43.8	0.098	-45.3	0.098	11	-26.9	0.506	-27.7	0.413	11	11.4	0.413	17.8	0.465
OTHER INVERTEBRATES															
Lesser blue crab	20	-18.2	0.037[a]	- 9.2	0.230	20	- 4.6	0.414	- 7.2	0.701	19	6.8	0.807	0.1	0.651
Blue crab	20	-21.3	0.089	- 9.9	0.498	20	-20.2	0.017[a]	-33.3	0.001[c]	19	3.0	0.270	18.5	0.568
Sea nettle jellyfish	19	-49.6	0.003[b]	-68.6	0.001[c]	18	-17.6	0.216	21.8	0.679	18	-44.4	0.106	-38.8	0.019[a]
Atlantic brief squid	14	-15.8	0.624	5.8	0.964	13	16.4	0.507	17.9	0.635	12	- 1.5	0.911	- 9.7	0.967
Mantis shrimp	14	-49.0	0.009[b]	-50.7	0.007[b]	14	-11.4	0.612	8.1	0.932	11	- 6.9	0.910	-28.3	0.910
Cabbage head jellyfish	9	-14.2	0.188	-29.8	0.301	4	-72.2	0.375	-95.5	0.125	4	-54.9	0.875	-29.2	0.875

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DISCUSSION

Results of this demonstration project varied between seasons and among BRD's, but indicate BRD's have potential for reducing bycatch organisms while at the same time limiting shrimp loss. Bycatch reduction is a common goal of commercial shrimpers, fishery managers, regulators, conservationists, and the public. All user groups have a vested interest in stable and productive renewable resources in Texas bays. This joint demonstration project was a positive step in obtaining information about fishing technology that will allow the shrimping industry, as well as researchers, to expedite the development of more efficient BRD's. Continuation of this process will insure responsible long-term stewardship of the limited natural resources of Texas marine ecosystems.

Differences in bycatch reduction among studies and among BRD's can be affected by many factors such as variations in bottom substrate, water depth, and temporal and spatial biodiversity in size and population of shrimp and other organisms within commercial trawling areas. Other variables are size and placement of BRD's, size and type of trawl, length of trawl bag used, and speed and duration of tow. All these factors working independently or in concert affect bycatch reduction and shrimp loss. Therefore, a single BRD configuration will not meet all the criteria for reducing bycatch while limiting shrimp loss. Rather, several configurations may be needed to give the shrimping industry options when fishing conditions warrant. It is critical that additional studies are conducted on the three BRD's tested, and on other configurations that may hold promise at reducing bycatch.

Although BRD reduction rates in this demonstration project are promising, differences between the BRD's and control nets were not significant for many groups and species, probably due to small sample sizes. Overall, the LMEF reduced total bycatch more effectively than the other two BRD's during both spring and fall. Spot, the most abundant bycatch species, was significantly reduced best by the LMEF. Major economically important finfishes of Atlantic croaker, Gulf menhaden, and sand seatrout were significantly reduced best by the LMEF only during fall. During spring, no single BRD reduced all three of these species at significant rates. Blue crab had greatest significant reduction rates in number and weight during spring with the LMEF, and with the 2-in TED during fall.

LMEF shrimp loss was significantly high during fall, but was very low in spring. Larger trawls were used in fall, and commercial shrimp composition was different between shrimping seasons. It is unclear why shrimp loss differed between spring and fall. Further work with this BRD may help identify factors affecting shrimp loss. Using larger TED's and LMEF's in the Gulf of Mexico, where it is common to pull four 45-ft and larger shrimp trawls concurrently, has resulted in minimal to no shrimp loss (Branstetter 1997, Watson et al. 1997).

Commercial bay shrimpers recommended testing the 2-in TED. This BRD is commonly used by bay shrimpers when cabbagehead jellyfish (*Stomolophus meleagris*) is in high abundance during bay shrimping. The 2-in TED best reduced total bycatch, finfish, and other invertebrates numbers in spring. However, in fall only total other invertebrates weight was reduced best with

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the 2-in TED. It is unclear why differences in reduction rates occurred between spring and fall. Shrimp loss documented in this study with this BRD is a concern, especially during spring when shrimp loss exceeded bycatch reduction. Based on the results of this demonstration project, further testing of similar BRD's is warranted.

The FE has been extensively researched in different trawl bag positions in offshore waters and in other states, eventually resulting in adequate reduction rates (Branstetter 1997, Watson et al. 1997). Although various FE's have shown total finfish reduction rates of up to 40% and greater in offshore and other state coastal areas, the FE in this study reduced overall bycatch less than the other two BRD's. However, it had low shrimp loss and actually reduced a major economic species of management concern, southern flounder (*Paralichthys lethostigma*), in number and weight better than the other two BRD's. Although FE reduction rates were relatively low in this study for the major bycatch species of Atlantic croaker, spot, and sand seatrout, other researchers have shown bay reduction rates of up to 50% and more for these species (McKenna et al. 1996, Rogers et al. 1997).

RECOMMENDATIONS

More research is needed before specific regulations for BRD use in Texas waters can be recommended. Continued proactive participation of the bay shrimp industry in research and development of BRD's will help speed resolution of the bycatch issue. This cooperative process will benefit Texas ecosystems as well as the Texas bay shrimping industry. Based on anecdotal information from bay shrimpers and observations by researchers, several types of BRD's are periodically used when jellyfish or fish are abundant in some Texas bays. It is recommended that the bay shrimp industry adopt a proactive approach to fisheries conservation by supporting the voluntary use of BRD's.

The number of comparative tows in the present study was limited due to funding and manpower constraints. It is recommended that future studies in Texas bays conduct a minimum of 30 comparative tows for each BRD tested. This is the NMFS' recommended minimum number of tows to establish BRD certification within the Gulf of Mexico EEZ (Gulf of Mexico Fishery Management Council 1996), and this minimum number, also, appears to be appropriate for bay studies. However, BRD evaluations evaluating a select species may require additional tows above the 30 recommended if insufficient quantities of the select species are caught in comparative tows.

More research is needed with the FE to determine the most advantageous position in the net for best reduction rates in Texas coastal bays. This device and similar devices have been used by commercial shrimpers in Texas bays for many years with conflicting anecdotal results. Studies indicate that BRD placement distance from the tail bag tie-off is important to bycatch reduction effectiveness. Most coastal TED/BRD research in states other than Texas placed the FE at a distance of 95 inches or less from the tail bag tie-off. Most other studies also used shorter trawl bags than are commonly used by Texas bay shrimpers. The FE in the present demonstration project was placed 125 inches from the tail bag tie-off, a 70% BRD to tail bag ratio. This 70% placement was chosen because it has been the most successful placement for the device in Gulf of Mexico waters off Texas. Most Texas bay shrimpers commonly place the FE further from the tail bag tie-off than the 70% placement. In North Carolina and Georgia a FE with a 20 in^2 opening is legal, and in some studies (Branstetter 1997) has resulted in greater bycatch reduction rates than the 26 in^2 FE used in the present demonstration project. However, most FE's tested in offshore waters and other states had larger openings than used in the present study.

Low reduction rates in spring compared to fall are a concern, as smaller size organisms are found in greater abundance and weight in the spring than in fall. Future development of BRD's for use in bays should be directed at reducing smaller bycatch organisms characteristic of the spring shrimping season, as well as maintaining equal or greater reduction rates during fall, with minimal shrimp loss.

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Appendix, Table A. Species collected during comparative trawl BRD studies in Aransas Bay during the spring (15 May-15 Jul) and fall (15 Aug-15 Dec) 1997 commercial bay-shrimp seasons. X indicates that the species was caught during respective season.

SPRING	FALL	COMMON NAME	SCIENTIFIC NAME
		FINFISH	
X	X	Atlantic thread herring	*Opisthonema oglinum*
X	X	Atlantic threadfin	*Polydactylus octonemus*
X		Atlantic midshipman	*Porichthys plectrodon*
	X	Atlantic needlefish	*Strongylura marina*
X	X	Atlantic stingray	*Dasyatis sabina*
X	X	Atlantic bumper	*Chloroscombrus chrysurus*
X	X	Atlantic cutlassfish	*Trichiurus lepturus*
X	X	Atlantic croaker	*Micropogonias undulatus*
	X	Atlantic spadefish	*Chaetodipterus faber*
X	X	Atlantic moonfish	*Selene setapinnis*
X	X	Bay whiff	*Citharichthys spilopterus*
X	X	Bay anchovy	*Anchoa mitchilli*
X	X	Bighead searobin	*Prionotus tribulus*
X	X	Black drum	*Pogonias cromis*
X	X	Blackcheek tonguefish	*Symphurus plagiusa*
X		Bluefish	*Pomatomus saltatrix*
X	X	Bluntnose jack	*Hemicaranx amblyrhynchus*
X	X	Cownose ray	*Rhinoptera bonasus*
X		Crevalle jack	*Caranx hippos*
	X	Dwarf sand perch	*Diplectrum bivittatum*
X	X	Fringed flounder	*Etropus crossotus*
X	X	Gafftopsail catfish	*Bagre marinus*
X	X	Gizzard shad	*Dorosoma cepedianum*
	X	Gray snapper	*Lutjanus griseus*
X		Gulf butterfish	*Peprilus burti*
X	X	Gulf flounder	*Paralichthys albigutta*
X	X	Gulf menhaden	*Brevoortia patronus*
X	X	Gulf toadfish	*Opsanus beta*
X	X	Hardhead catfish	*Arius felis*
X	X	Harvestfish	*Peprilus alepidotus*
X	X	Hogchoker	*Trinectes maculatus*
X	X	Inshore lizardfish	*Synodus foetens*
	X	Irish pompano	*Diapterus auratus*
X		King mackerel	*Scomberomorus cavalla*
X	X	Least puffer	*Sphoeroides parvus*
	X	Lined seahorse	*Hippocampus erectus*
X	X	Lined sole	*Achirus lineatus*
X	X	Lookdown	*Selene vomer*
X	X	Ocellated flounder	*Ancylopsetta quadrocellata*
	X	Orange filefish	*Aluterus schoepfi*
X	X	Pigfish	*Orthopristis chrysoptera*
X	X	Pinfish	*Lagodon rhomboides*
	X	Planehead filefish	*Monacanthus hispidus*
X		Red drum	*Sciaenops ocellatus*
X	X	Sand seatrout	*Cynoscion arenarius*

Appendix, Table A. (Cont'd.)

SPRING	FALL	COMMON NAME	SCIENTIFIC NAME
		FINFISH (Cont'd.)	
	X	Scaled sardine	*Harengula jaguana*
X	X	Sharptail goby	*Gobionellus hastatus*
	X	Sheepshead	*Archosargus probatocephalus*
	X	Shoal flounder	*Syacium gunteri*
	X	Shrimp eel	*Ophichthus gomesi*
X	X	Silver perch	*Bairdiella chrysoura*
	X	Silver jenny	*Eucinostomus gula*
	X	Silver seatrout	*Cynoscion nothus*
	X	Southern hake	*Urophycis floridana*
X	X	Southern kingfish	*Menticirrhus americanus*
X	X	Southern flounder	*Paralichthys lethostigma*
X	X	Spanish mackerel	*Scomberomorus maculatus*
X	X	Spot	*Leiostomus xanthurus*
	X	Spotfin mojarra	*Eucinostomus argenteus*
X	X	Spotted seatrout	*Cynoscion nebulosus*
	X	Star drum	*Stellifer lanceolatus*
	X	Striped mullet	*Mugil cephalus*
X	X	Striped anchovy	*Anchoa hepsetus*
X	X	Striped burrfish	*Chilomycterus schoepfi*
X	X	Threadfin shad	*Dorosoma petenense*
	X	Tripletail	*Lobotes surinamensis*
		INVERTEBRATES	
X	X	Atlantic brief squid	*Lolliguncula brevis*
X		Bay scallop	*Argopecten irradians*
X		Blood ark	*Anadara ovalis*
X	X	Blue crab	*Callinectes sapidus*
X	X	Brown shrimp	*Penaeus aztecus*
X	X	Cabbagehead	*Stomolophus meleagris*
X	X	Class sessile tunicates	*Class Ascidiacea*
X		Class sea cucumbers	*Class Holothuroidea*
X	X	Flatclaw hermit	*Pagurus pollicaris*
	X	Florida rocksnail	*Thais haemastoma floridana*
X	X	Gulf stone crab	*Menippe adina*
	X	Gulf grassflat crab	*Dyspanopeus texana*
	X	Iridescent swimming crab	*Portunus gibbesii*
X	X	Lesser blue crab	*Callinectes similis*
	X	Longnose spider crab	*Libinia dubia*
X	X	Mantis shrimp	*Squilla empusa*
	X	Moon jellyfish	*Aurelia aurita*
X	X	Phylum Sponges	*Phylum Porifera*
X	X	Pink shrimp	*Penaeus duorarum*
	X	Roughback shrimp	*Trachypenaeus similis*
X	X	Sea nettle	*Chrysaora quinquecirrha*
X	X	Shark eye	*Neverita duplicata*
X	X	Southern quahog	*Mercenaria campechiensis*

Appendix, Table A. (Cont'd.)

SPRING	FALL	COMMON NAME	SCIENTIFIC NAME
		INVERTEBRATES (Cont'd.)	
X		Texas quahog	*Mercenaria campechiensis texana*
X		Texas venus	*Agriopoma texasianum*
X		Thinstripe hermit	*Clibanarius vittatus*
	X	Trachypenaeid-unidentified)	*Trachypenaeus sp.*
	X	Two-spined starfish	*Astropecten duplicatus*
X	X	White shrimp	*Penaeus setiferus*

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