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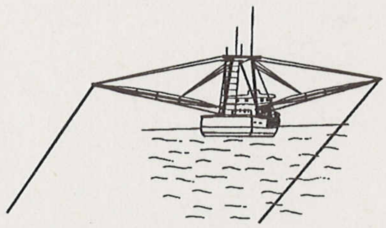
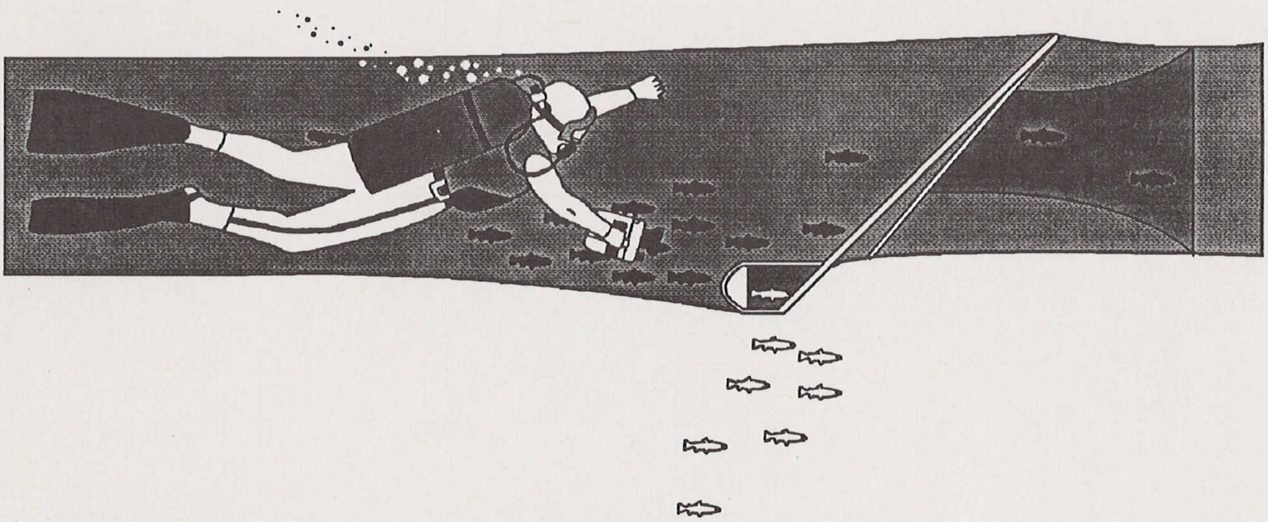
# NMFS - SEFC - 327



**STATUS REPORT ON THE POTENTIAL OF GEAR MODIFICATIONS TO REDUCE FINFISH BYCATCH IN SHRIMP TRAWLS IN THE SOUTHEASTERN UNITED STATES**

**1990 - 1992**



MARCH 1993

U.S. DEPARTMENT OF COMMERCE
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SOUTHEAST FISHERIES SCIENCE CENTER
MISSISSIPPI LABORATORIES
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NOAA TECHNICAL MEMORANDUM NMFS-SEFSC-327

# STATUS REPORT ON THE POTENTIAL OF GEAR MODIFICATIONS TO REDUCE FINFISH BYCATCH IN SHRIMP TRAWLS IN THE SOUTHEASTERN UNITED STATES 1990 - 1992

***BY***

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***Arvind Shah, James Barbour, Dominy Hataway***

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**U.S. DEPARTMENT OF COMMERCE**
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**March 1993**

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NOTICE:



This report should be cited as follows:

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## TABLE OF CONTENTS

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# EXECUTIVE SUMMARY


In 1990, Congressional amendments to the Magnuson Fishery Conservation and Management Act required the Secretary of Commerce to establish a program to assess the impact on fishery resources of incidental harvest by the shrimp trawl fishery under the jurisdiction of the South Atlantic and Gulf of Mexico Fishery Management Councils. In response to this requirement, the National Marine Fisheries Service (NMFS) Southeast Region developed a research requirements document (NMFS, 1991), and a research plan was developed by the Gulf and South Atlantic Fisheries Development Foundation (GSAFDF, 1992), addressing the shrimp trawl bycatch problem. One of the objectives of the plan is to identify, develop, and evaluate gear (bycatch reduction devices, BRDs), non-gear and tactical fishing options for reducing bycatch.

The Harvesting Systems Division of the NMFS Southeast Fisheries Science Center's Mississippi Laboratories was tasked to investigate the potential for developing gear modifications to mitigate the problem of shrimp trawl bycatch mortality. The objectives of the research are to: (1) evaluate existing bycatch reduction techniques, (2) collect data on the behavior of fish and shrimp when encountering shrimp trawls and, (3) develop and evaluate new bycatch reduction techniques.

Fifty-one bycatch reduction device conceptual designs have been evaluated by Harvesting Systems Division scientist scuba divers. These designs were developed by the commercial shrimping industry, the Harvesting Systems Division, and other researchers working cooperatively with commercial fishermen and net shops. New prototypes incorporate design features developed to stimulate fish escapement based on behavioral responses.

This status report presents data from scuba diver evaluations and bycatch reduction/shrimp retention test results for prototype bycatch reduction device (BRD) designs. It is intended to document research results to date, and to stimulate new gear development.

Included in this report are descriptions, diagrammatic drawings, and diver evaluation comments for 39 bycatch reduction device designs. Fish bycatch reduction and shrimp retention data are presented for 30 prototype BRD designs. A discussion of fish and shrimp behavior in trawls and in response to bycatch reduction devices is also included.

Thirty design combinations have been tested on commercial fishing grounds. Of these, 12 have demonstrated overall fish bycatch reduction rates between 43% and 67% and 7 had shrimp retention rates between 90% and 100%. Prototype designs that show the best potential for achieving a 50% reduction in total fish bycatch with better than 90% shrimp retention are the large mesh funnel design, the extended funnel design, the HSB design, and the fisheye design.

Total fish reduction rates varied according to catch composition, and reduction rates for individual species varied among designs. Croaker, spot, catfish, Atlantic bumper, longspine porgy, butterfish, trout, and whiting were the predominant fish species encountered during BRD evaluation testing.

The large mesh funnel design had 34% or greater reduction rates for predominant species and was the only design that significantly reduced longspine porgy. All of the predominant species were reduced by at least 36% by the extended funnel design except longspine porgy and croaker. Reduction rates greater than 45% were achieved with the HSB for all predominant species except trout. The fisheye designs, had good reduction rates for all of the predominant species except longspine porgy. The double fisheye design had a low reduction rate for trout.

Data collected on economically important species, including shrimp, showed the best shrimp retention rates were achieved with the extended funnel, the large mesh funnel, and the HSB designs. The best reduction rates for red snapper were achieved with the RWF fisheye, the double fisheye, the bottom position fisheye and the HSB design. Reduction rates for Spanish and king mackerel were best with the large mesh funnel, the extended funnel, and the fisheye designs.

# INTRODUCTION

The penaeid shrimp fishery is one of the most valuable fisheries resources in the United States. Approximately 6,500 "offshore" and 11,000 "inshore" commercial vessels annually harvest over 250 million pounds of shrimp valued at $478 million dollars in 1991 (NMFS, Fisheries of the United States, 1991).

The traditional otter trawl is the primary gear used for harvesting shrimp. Unfortunately, the otter trawl is inherently nonselective, unavoidably catching many other species of fish and invertebrates found in association with shrimp. These species are collectively called bycatch.

In the Northern Gulf of Mexico as much as 70% of the shrimp trawl discards are scianids and other species important to the industrial bottomfish fishery (Moore, et al. 1970, and Chittenden and McEchran, 1976). The annual discard of fish bycatch by the shrimp fleet has been estimated at around 10 billion fish, with most of the catch composed of croaker, seatrout, porgies, and spot (Pellegrin et al. 1981).

The Atlantic croaker is an example of a fish stock which is being impacted by incidental shrimp trawl bycatch. Croaker populations have declined steadily since the 1950s (Chittenden et al. 1975). Both the size and number of year classes have been reduced. In 1991, the average croaker catch consisted of a single year class of small fish in spawning condition, indicating a severe reduction in the adult spawning stocks (NMFS, 1991).

Other species, harvested both commercially and recreationally, are also impacted by shrimp trawl bycatch. Red snapper, for example, occur in association with penaeid shrimp during early life stages and are vulnerable to incidental capture and mortality by shrimp trawlers (Nichols et al. 1987). Gutherz and Pellegrin (1988) observed the highest catch rates of juvenile red snapper by shrimp trawlers occurred from July through December, corresponding with the primary fishing months in the Northern Gulf of Mexico. Nichols, et al. (1990) estimated that 20 million red snapper were caught by Gulf shrimp trawlers in 1989.

Red snapper have been significantly overfished in the Southeastern United States and this has resulted in the Gulf of Mexico Fishery Management Council initiating a program in 1993 to restore them to a 20% spawning stock potential by the year 2009. Limiting red snapper harvest to a total allowable catch of 6.0 million pounds will restore the stock by the targeted date if trawl-induced mortality is also reduced. A 50% reduction in juvenile snapper mortality in shrimp trawls is considered necessary to achieve the 2009 goal.

In response to mandates of the Magnuson Fishery Conservation and Management Act amendments passed by congress in 1990, the National Marine Fisheries Service Southeast Region has developed a program in cooperation with the Gulf and South Atlantic Fisheries Development Foundation to address the shrimp trawl bycatch problem. One of the objectives of this program is to identify, develop, and evaluate gear options for reducing bycatch in the Gulf and South Atlantic shrimp fisheries. The research plan calls for gear modification studies to be conducted in inshore, nearshore, and offshore waters focusing on key FMP managed species (i.e., Gulf red snapper, Atlantic weakfish, king mackerel and Spanish mackerel), and coordinated through a technical review panel (TRP). The technical review panel will select the best prototypes for commercial evaluation, monitor testing in different shrimping areas, and prioritize gear modification options for management consideration.

The research plan developed by the Gulf and South Atlantic Fisheries Development Foundation (GSAFDF, 1992) identified a four phase gear development program which includes:

1. ***Initial Design and Prototype Development*** - The full technical range of trawl design and modification approaches will be identified. Initial emphasis will be placed on existing TED and prototype TED designs. Industry techniques, ideas solicited from fishermen, net shop designs, and research studies conducted by various research groups will be evaluated. Fish behavior, gear interaction, and gear performance studies will be conducted on each design using SCUBA, acoustic instrumentation, remote video cameras, and other techniques. This work is intended to evaluate fish behavior and feasibility of concept. The results of this phase will be subjectively evaluated based on the experience and expertise of the designer and research team. Operational data will be taken on the modified net, and preliminary catch performance data will be obtained during comparative gear trials. The second phase of development will begin once a design has been determined to offer bycatch reduction potential and has been effectively integrated into the construction of a net.

2. ***Proof of Concept*** - Objectives during this phase will be to evaluate prototype devices on key species, determine total finfish reduction rates, and establish shrimp catch rates. Proof of concept testing will also evaluate adequacy of design for safety and for problems with operational use. NMFS has suggested that an appropriate initial design target would be a 35% reduction in bycatch. It is equally important that shrimp loss be minimized, and approach zero when possible. NMFS has suggested a criterion of a 50% bycatch reduction for any BRD/TED combination compared to a non-TED trawl. However, if results for a specific target bycatch species indicate a 50% reduction is not practical without significant shrimp loss, several levels of finfish reduction and shrimp loss will be provided for management consideration. The most successful designs will be prioritized based on proportional bycatch reduction and shrimp loss, prior to operational testing under commercial fishing conditions. Following proof of concept testing, devices with favorable results will be reviewed with the technical review panel. Once the committee concurs, the prototype devices will be released to the commercial shrimping industry for operational evaluation on shrimp grounds throughout the Southeast.

3. ***Operational evaluation*** - The main objective in this phase is to test the BRD/TED gear combination against a standard TED net under conditions encountered during commercial shrimping operations. Observers will be placed aboard cooperating commercial vessels to collect data on both shrimp and finfish catch rates as well as species composition. A BRD/TED combination will be tested on trawlers using the same TED employed in both the test and control gear. Testing will be conducted over a wide range of geographic areas, seasons, and conditions. Finfish reduction contributed by a particular TED will be credited toward whatever percent reduction is determined to be appropriate for each key FMP species. If the TED/BRD design is primarily a modified TED, testing will require comparison with the original TED design, or a controlled experiment comparing catch rates against an unmodified net.

4. ***Industry evaluation*** - The commercial shrimping industry will be responsible for fleet testing of candidate BRDs. Vessels will use the test devices on commercial shrimp grounds and maintain log books on results. Total finfish and total shrimp catches will be recorded for test nets and standard TED nets on at least one randomly selected tow per day. Observers will be placed on a subset of vessels whose captains agree to keep log books to collect bycatch data by species.

The Harvesting Systems Division of the NMFS Southeast Fisheries Science Center's Mississippi Laboratories has extensive experience in fishing gear development and unique capabilities and resources for evaluation of potential BRD candidates. The Harvesting Systems Branch was tasked to investigate the potential of BRDs to mitigate the problem of shrimp trawl bycatch mortality. The project is designed to provide gear development and testing expertise and capabilities to fishermen, net shops, and other research organizations and to apply the expertise within the division to developing viable bycatch reduction devices. The project objectives address the requirements of phase one and two of the finfish bycatch research plan.

A total of 51 bycatch reduction devices (BRDs) have been evaluated by Harvesting Systems SCUBA divers. These devices include designs in use by the commercial shrimping industry, and prototypes developed by commercial fishermen, net shops, state research agencies, and the Harvesting Systems Division.

This is a status report which presents the results of scuba diver evaluations and bycatch reduction/shrimp retention data for prototype bycatch reduction device (BRD) designs. It is intended to provide research results to the Technical Review Panel (TRP) and to disseminate information to fishermen, net shops, and research agencies in order to stimulate new gear development ideas. Included are descriptions, drawings, and diver evaluation comments for 39 bycatch reduction device designs, fish and shrimp behavioral observations, and bycatch reduction/shrimp retention data for 30 BRD designs.

A discussion of the test results, and results of other studies is presented, and recommendations are proposed for future research direction based on behavioral information and test results.

# METHODS

The initial approach in developing BRD design concepts was to conduct a review of previous work on the development of shrimp separator trawls for penaeid shrimp in the United States. This work was summarized and presented at the FAO Bycatch Conference held in Mazatlan, Mexico (Watson and Taylor, 1990).

A literature survey of fish and shrimp behavior in shrimp trawls and relevant papers were reviewed and abstracted. Behavioral observations of species occurring in association with shrimp trawls in the Southeastern United States, made and recorded on video by the NMFS Harvesting Systems divers in the 1970s and 1980s, were summarized by Watson, (1988).

This information was used to develop potential BRD design concepts for evaluation in the penaeid shrimp fishery. Design concepts were also contributed by commercial fishermen who have been using various bycatch reduction devices for many years, net shops, machine shops, private individuals, and state research agencies and universities.

Prototype evaluations were conducted to determine operating characteristics and to observe fish reactions in response to the designs. Evaluations were made by divers in 6 to 12 meters of water off the Northwest coast of Florida. These studies were conducted using the National Oceanic and Atmospheric Administration ships *OREGON II* and *CHAPMAN* and the commercial shrimp vessels *MISS CARRIE* and *SHELLY*. The *CHAPMAN*, a 39-meter stern trawler, was rigged to tow two trawls (twin rig) from a single towing cable. The *OREGON II*, a 53-meter research fishing vessel, and the commercial fishing vessels *MISS CARRIE* and *SHELLY*, measuring 22-meters and 20-meters respectively, were double rigged with a single trawl on each side of the vessels.

The BRD prototypes were installed in shrimp trawls: including flat, four-seam balloon, and Mongoose trawl designs described by Watson et al. (1984). Bridle lengths and trawl door sizes were matched to trawl size and standard commercial rigging was used (Watson et al. 1984). Tickler chains were adjusted to 107 cm shorter than the trawl footropes. Towing speeds ranged from 2.5 to 3.0 knots. Standard trawl diving techniques (Workman, 1987) were used to evaluate BRD performance. Trawl performance characteristics were evaluated using a diver operated sonar unit to measure horizontal and vertical openings. Diver evaluations included measuring water flow velocities, determining flow characteristics, and observing the reaction of fish and shrimp to the BRD prototypes. Water flow measurements were made using a General Oceanics diver operated current meter, and a dye flow injector was used to determine flow characteristics.

Fish and shrimp behavior studies were also conducted by divers and trawl mounted video cameras on commercial shrimp fishing grounds off Alabama and Mississippi. Divers observed, and trawl mounted video cameras recorded, fish and shrimp reactions to trawls and BRD prototypes under natural conditions.

Diver evaluations and behavioral observations were used to modify prototype designs, improve performance, and determine candidate designs for fishing trials. Fishing trials for prototype BRD designs were conducted using comparative towing methods according to the standardized testing protocol developed for the evaluation of bycatch reduction devices (NMFS, 1992). Candidate BRD designs were installed in shrimp trawls and towed simultaneously against a control net of the same size and design and with the same rigging as the test net. Both nets were equipped with an identical super shooter style TED (except for BRD designs which incorporated other TED types). Tows of 1 hour duration were conducted with each test design. To reduce possible net or towing side biases, the extension containing the candidate BRD and the codend of the test net were exchanged with the extension and codend of the control net after half of the tows were completed. After each tow, the catches from each trawl were compared by weight and species composition. Select species, including red snapper, and mackerel were separated from the catches, counted, weighed, and measured for comparison.

Data were entered into a computer data base file. Data summarization and statistical analyses were performed using the Statistical Analysis System (SAS). Catch differences were analyzed in terms of number, weight, and length. Statistical analyses were conducted to determine significant differences for total fish and shrimp catches, red snapper, king mackerel, Spanish mackerel, and the three predominant species by weight between the experimental net and the control net. Statistical procedures used included paired *t* test, two sample *t* test, and analysis of variance for unbalanced two-way design with interaction.

# RESULTS

## BRD DESCRIPTIONS AND SCUBA DIVER EVALUATIONS

Illustrations, descriptions, and scuba diver evaluation comments for 39 bycatch reduction device concepts are presented in Appendix I. The devices include modified shrimp trawl designs, modified turtle excluder devices (TEDs), devices designed to create fish escape openings in the trawl extension, and codend (fisheyes), designs which incorporated webbing funnels or lead panels in combination with large meshes or holes for fish escapement, and devices designed to stimulate fish to escape from trawls.

Divers recorded operational characteristics of the candidate BRDs, fish behavioral reactions, and water flow characteristics. This information was used to modify potential designs to improve performance and to select the best designs for "proof of concept" fishing evaluations. Some prototypes did not perform as designed and if their performance could not be corrected or the designs were determined to be impractical, they were eliminated from further consideration. Selection of designs for fishing evaluations was based on gear technician and BRD developer experience, operational performance characteristics, fish behavioral reactions, and water flow characteristics. Results are presented for all of the designs evaluated, including the designs which were eliminated after diver evaluation, to stimulate new ideas and possibly provide some "new slants on old ideas".

### *Modified Trawl Design*

The low profile trawl (Appendix I, fig. 1) was the only trawl modification evaluated. The trawl design and rigging appeared to be operationally feasible but the design has limited application due to restrictions in allowing adjustments to optimize shrimp production (i.e., the trawl would not be effective when maximum height is necessary for optimum shrimp production). The trawl was designed to open only 18 inches vertically to allow fish to pass over the trawl.

### *Modified TED Designs*

Ten modified TED designs were evaluated. Modifications to the NMFS TED were developed and tested in 1982 (Appendix I, fig. 2). Modifications included the addition of lead panels and fish escape openings on the sides of the TED. The NMFS TED has limitations which restrict its use, including size, weight, and complexity. It is also effective only in a top opening configuration which limits its use in some shrimping conditions.

A Morrison soft TED modification was evaluated (Appendix I, fig. 3). The leading edge of the excluder panel was replaced with small mesh webbing and a 20.3 cm mesh panel was installed in the bottom of the trawl below the small mesh section to allow fish to escape. Diver evaluation of this design indicated there was little clearance between the small mesh section of the TED and the bottom of the trawl. No further testing was conducted with this design.

An Andrews soft TED was modified by constructing the top and bottom panels of 20.3 cm webbing and the side panels of 12.7 cm webbing (Appendix I, fig. 4). Diver evaluations of this design indicated the TED panel was tight and the meshes were open square. This design was tested to determine the finfish reduction potential and shrimp retention rates.

A Golden design soft TED constructed of 15.2 cm mesh was evaluated for the manufacturer prior to testing on a commercial shrimp vessel for shrimp retention and finfish reduction potential (Appendix I fig. 5). This TED has not been certified for use under the endangered species regulations.

The super shooter style grid TED was selected as the standard TED for use in evaluating BRD designs that were not incorporated into other TED designs (Appendix I, fig. 6). It was selected based on shrimp retention rates and operational characteristics. Several modifications of this TED design were evaluated in an attempt to improve finfish reduction when the TED was used with different BRD designs. Additional grid bars were inserted in one design to discourage fish from passing through the grid (Appendix I, fig. 7). Another modification evaluated was the addition of small diameter wires between the grid bars (Appendix I, fig 8). The wires vibrate and act as a stimulus to discourage fish from passing through the grid. Side panels of polyethylene webbing were inserted behind the TED and openings cut in the extension in another modification (Appendix I, fig. 9). Diver evaluations indicated that without some type of support frame the panels did not allow sufficient clearance between the panels and the TED extension webbing.

The HSB design incorporates lead panels and side openings similar to the NMFS TED. It is positioned below a grid style TED instead of behind the TED as in the NMFS design (Appendix I, fig. 10). It is designed to regulate water flow rates to allow juvenile fish to escape and the placement is designed to optimize shrimp retention and juvenile fish reduction.

The top and bottom opening TED has escape openings on top and bottom and incorporates wedge shaped grid bars (Appendix I, fig. 11). It incorporates lead panels and side openings for fish escapement.

Of the 10 modified TEDs evaluated by divers, 6 were selected for further evaluation. They were the Andrews TED, the super shooter TED, the super shooter TED with double bars, the super shooter TED with hummer wires, the HSB excluder design, and the top and bottom opening TED.

***Fisheye Designs***

Six different "fisheye" designs were evaluated and one design was tested in three different positions. Fisheyes are industry developed fish excluders which have been in use in the shrimp industry for many years. They are constructed in several different shapes and sizes and are installed in trawls in several different locations. We evaluated a design referred to in the industry as the "Florida fish excluder" (Appendix I, fig. 12). This design was obtained from the North Carolina Division of Marine Fisheries. It consists of an aluminum frame with an opening of 44.5 cm by 23.5 cm and a length of 61 cm. It was evaluated in three positions in the trawl, on top of the codend, (60 meshes from the end of the codend), on the bottom of the TED extension ahead of the codend, and on the sides of the TED extension ahead of the codend.

The Lionel fisheye developed by a commercial fishermen from Alabama is constructed from steel rod and has an opening of 35.6 cm by 30.5 cm and is 45.7 cm in length (Appendix I, fig. 13). It was installed on the top of the codend (30 meshes back from the front of the codend).

The Barbour fisheye (Appendix I, fig. 14) was designed to incorporate an overlap over the fish escape opening. It was determined this design was very difficult to install and caused stress points at the corners which resulted in damage to the extension webbing. This design was eliminated from further consideration.

The RWF fisheye (Appendix I, fig. 15) is a modification of the Florida fisheye design. A webbing covered frame was added to the front section of the fisheye to reduce water flow coming into the device from outside the trawl. The reduced water flow allowed juvenile fish, particularly juvenile red snapper, to escape. This device was tested in the bottom of the TED extension ahead of the codend and on the sides of the TED extension ahead of the codend.

The soft fisheye (Appendix I, fig. 16) consists of a triangular hole cut in the top of the trawl codend (1.8 meters from the end of the codend). A polyethylene webbing flap was sewn over the hole on the inside of the codend. Diver evaluations determined that the flap remained closed due to water flow and attempts to keep the flap open by adding weight collapsed the codend. This design was eliminated from further consideration.

The double ***V*** excluder (Appendix I, fig. 17) is a modification of the bottom position fisheye. It consists of a metal frame covered by small mesh webbing designed to reduce water flow. It is installed under the trawl ahead of the codend where a ***V*** shaped exit opening is cut in the extension webbing creating panels leading to the escape openings.

Fisheye designs which were selected for proof of concept testing were the Florida fisheye in the top, bottom, and side positions, the Lionel fisheye, the RWF fisheye, and the double V excluder.

***Funnel and Lead Panel Designs***

Ten BRD designs which incorporate webbing funnels or lead panels to separate and exclude finfish were evaluated. The FSD design (Appendix I, fig. 18) was developed by NMFS in the late 1970s. It incorporates a webbing funnel and hoops patterned after a catfish trap. Webbing is removed between the hoops to allow fish escapement. This device has been evaluated in the Australian shrimp fishery by the Australian Maritime College (Drummond, 1989).

The large mesh/funnel design (Appendix I, fig. 19) consists of a small mesh webbing funnel surrounded by a large mesh section of webbing. The funnel is designed to carry shrimp past the large mesh openings. Fish swimming in the trawl pass around the funnel and exit through the large meshes. This design was tested in two positions, ahead of a grid TED in the TED extension, and behind a grid TED in the TED extension.

The extended funnel design (Appendix I, fig. 20) consists of a small mesh webbing funnel surrounded by a large mesh escape section held open by plastic coated cable hoops. One side of the funnel is extended to form a lead panel that creates an area of reduced water flow on the backside of the funnel. This device was tested behind a grid TED between the TED extension and the trawl codend.

The RWF large mesh/funnel design (Appendix I, fig. 21) is a modification of the large mesh/funnel design which incorporates a small mesh skirt around the outside of the large mesh section to reduce water flow coming through the meshes from outside the trawl. Diver evaluation determined the skirt was effective in slowing water flow entering the device and fish behavior observations indicated improved escapement of small fish.

The large mesh double funnel design (Appendix I, fig. 22) is another modification of the large mesh/funnel designed to reduce water flow around the funnel. This modification incorporates a second funnel inside the original funnel to reduce the water passing through the funnel meshes.

The WWF design (Appendix I, fig. 23) was an early funnel design which consisted of a small mesh funnel and diamond shaped holes cut in the trawl extension. Diver evaluations showed that fish escaped through the openings more efficiently when the funnel was modified to allow more clearance from the sides of the extension. This design evolved into the more efficient and stronger large mesh/funnel design.

The large funnel excluder design (Appendix I, fig. 24) consists of a large polyethylene funnel which is installed ahead of the intermediate section of the trawl. The trawl webbing over the funnel is replaced with 30.5 cm mesh webbing to allow fish escapement. Diver evaluations determined that drag forces on the large funnel caused it to balloon, closing off the space between the funnel and the large mesh webbing.

The lead panel design (Appendix I, fig. 25) consists of a polyethylene webbing panel placed on a downward angle behind a grid type TED. The trailing edge of the panel is attached to an aluminum hoop. Two rectangular frames are installed above the lead panel to allow fish escapement. Diver observations of fish reactions indicate the device was ineffective in releasing fish. A modification of this device, the lead panel, and skylight design (Appendix I, fig. 26), consisted of a lead panel and large mesh fish escape openings held taut by plastic coated cable hoops. Divers observed that clearance between the large mesh openings and the lead panel was inadequate to allow for fish escapement.

The side opening separator (Appendix I, fig 27.) consists of two aluminum frames inserted into the trawl extension. The frames are connected by stainless cables. The sides of the extension were sewn inward to form lead panels and fish openings. Diver evaluations determined the rigid frames were not practical for this application.

The designs which were selected for proof of concept evaluation from the funnel, lead panel designs were the large/mesh funnel, the extended funnel, the RWF large mesh funnel, and the large mesh double funnel designs.

Two modified codend designs were evaluated (Appendix I, figs. 28, 29). Divers observed during evaluations of BRD designs that standard codends had very small diameter openings when fishing, which restricted fish from swimming out of the codend and escaping through BRD openings. Two modified codends were constructed based on information from Paul Shuman of Shuman Trawls. The modified codends have a rope frame around the outside of the codend which supports the load and drag on the codend allowing the codend to maintain an opening diameter of 46-61 cm.

***Fish Stimulators***

Ten "fish stimulators" were evaluated to determine if these devices could be used in conjunction with BRDs to improve fish escapement. The hummer line (Appendix I, fig. 30) is an industry developed device designed to herd fish away from the trawl mouth reducing the number of fish entering the trawl. It consists of a line of low stretch material positioned between the doors ahead of the headrope. The other designs (Appendix I, figs. 31-39) consisted of various materials placed on frames and inserted into the trawl extensions or codend. The different designs were evaluated to determine if fish behavior could be modified to improve escapement from the trawl. The designs selected for further evaluation were the hummer wire stimulator, the ty wrap stimulator, the chain stimulator and the plastic strip stimulator.

The descriptions presented for the 39 devices evaluated are general descriptions only. Detailed information on construction and installation of these devices can be obtained by contacting Charles Taylor, NMFS, SEFSC, Pascagoula Laboratory, P.O. Drawer 1207, Pascagoula, MS 39568-1207.

***Other Designs***

In addition to the 39 designs presented in this report, 12 designs were evaluated by Harvesting Systems divers for other research partners. Four devices were evaluated for Louisiana State University researchers. They included the Autement-Ledet device, the Lake Arthur device, the Eymard accelerator, and the Cameron Shooter. Descriptions of these devices and results of the LSU research are available from the LSU Agricultural Center (Rogers et al., 1993). SCUBA diver evaluations were also provided to Florida State University for the seaweed FED designed by Robert Richards, a commercial fishermen in Tampa, FL (Coleman, et al. 1993). Other devices evaluated were a low opening trawl design for the University of Georgia Marine Extension Service, the Andrews excluder for Ralph Andrews, a net maker from Ft. Myers, FL, the North Carolina excluder for the UNC Sea Grant College Program (Rulifson, et al. 1992), the Ross trawl for the Mississippi Sea Grant Extension Service (Burrage et al. 1993), a beam trawl for Carl Hagencotter, a commercial fishermen from Key West, FL, the Burbank TED from Burbank Trawls in Fernandina Beach, FL, and the Nordemore grate.

## BRD PROOF OF CONCEPT TESTING

Thirty BRD combinations were evaluated to determine their potential for reducing the catch of key species and to determine total finfish reduction and shrimp retention rates. This information is provided to assess their potential as candidates for operational evaluation on commercial shrimp vessels. Data presented includes number of tows made with each design, total fish reduction rates, shrimp retention rates, reduction rates for key species (red snapper, Spanish mackerel, and king mackerel), and reduction rates for dominant species. Dominant species include fish species which comprise more than one percent of the catch from the standard (control) net. Statistical analyses were performed to determine significant differences between the catches of the test net and the control net for the total fish catch, shrimp catch, key species, and the three dominant species by weight for each test. Fish reduction rates and shrimp retention rates for test nets which were significantly different ($P < 0.05$) from the standard net are designated by the letter *s* after the value. Fish reduction rates and shrimp retention rates which were not significantly different ($P > 0.05$) from the standard net are designated by the letters ***ns*** after the value. Fish reduction rates for species which were not statistically analyzed are designated by the letters ***na*** after the value.

Data from Renaud et al. (1991) are presented for the super shooter TED (Appendix II, fig. 1) which was used as the standard TED for all BRD evaluations except those designs which incorporated a TED design. The super shooter style grid TED was selected for the standard TED because of its shrimp retention rate (99%), fish reduction rate (4%), and operational characteristics. A minimum fish reduction rate was desirable for the standard TED in order to determine the fish reduction rate of the BRD alone. The super shooter TED is a versatile design which can be installed in many different net designs and sizes with minimum difficulty and is operationally easy to install and use.

Prototype BRD designs were evaluated alone, in combinations, in different positions, and with fish stimulator designs to systematically evaluate the potential of each concept. The results of these evaluations are presented in Appendix II. The primary BRD prototype designs tested include the large mesh/funnel design (LMF), the extended funnel design (EF), the HSB design (HSB), the fisheye top position (FET), the fisheye bottom position (FEB), the double fisheye design (DFE), the reduced water flow fisheye (RFE), and the double reduced water flow fisheye (DRFE). Data for these eight basic designs were combined for all tests conducted to determine potential of the basic concepts and then analyzed with different modifications to determine individual effects of each modification.

Data for the modified Andrews TED design are presented in Appendix II, figure 2. This design had a total fish reduction rate of 25% and a shrimp retention rate of 77%.

Data are presented for the modified NMFS TED design from Watson et al. (1986) (Appendix II, fig. 3). This design showed a total fish reduction rate of 51% and a shrimp retention rate of 98%. Fish reduction rates for dominant species ranged from 40% for trout to 72% for spot. No data were available for key species.

Preliminary evaluations were also made for a new top and bottom opening TED design (Appendix II, fig. 5). Only three tows have been made with this design and more evaluations are planned to determine its fish reduction potential.

Data for the eight basic designs are presented in table 3 and text figures 1-13. Data for the eight basic designs was combined in this analysis and includes all combinations of the eight basic designs tested except the designs which incorporated the chain or plastic deflectors. These designs were determined to negatively impact fish reduction and were eliminated from the analysis. Differences in catch rates for total fish reduction, shrimp retention, dominant, and key species were statistically analyzed. Some species were not represented for every design tested. The letters **nd** in the figures indicates there is no data for these species.

Total fish reduction rates for the eight basic BRD designs are presented in figure 1. Total fish reduction rates between 41% and 70% were achieved with the reduced water flow fisheye (RFE), the extended funnel design (EF), the fisheye top position (FET), the HSB design (HSB), and the large mesh/funnel design (LMF). The double reduced water flow fisheye (DRFE) had a combined total fish reduction rate of 37%, the double fisheye (DFE) 32% and the fisheye bottom position (FEB) 23%.

The best shrimp retention rates were achieved with the extended funnel design (EF) and the large mesh/funnel design (LMF) with 100%. (fig. 2). The HSB design (HSB) had a shrimp retention rate of 94%, the fisheye top position (FET) and the fisheye bottom position (FEB) had shrimp retention rates of 85% and 81% respectively. The double fisheye (DFE) had a shrimp retention rate of 69%, the double reduced water flow fisheye (DRFE) 81%, and the reduced water flow fisheye (RFE) 79%.

Reduction rates for red snapper, king mackerel, and Spanish mackerel are presented in figures 3-5.

The double fisheye design (DFE) had a red snapper reduction rate of 51% and the reduced water flow fisheye (RFE) a rate of 48% (fig. 3). These reduction rates were statistically significant. Other designs had snapper reduction rates of between 23% and 54% but these rates were not statistically significant.

The large mesh/funnel design (LMF) had a statistically significant rate of 25% for king mackerel (fig. 4). The reduction rates for king mackerel ranged from 0% to 87% for the other designs but these rates were not statistically significant.

A statistically significant reduction rate of 56% for Spanish mackerel was achieved with the large mesh/funnel design (LMF) (fig. 5). Reduction rates for Spanish mackerel ranged from 0% to 56% for the other designs but these rates were not statistically significant.

Reduction rates for the dominant fish species are presented in figures 6-13 and table 3.

Croaker reduction rates (fig. 6) ranged between 37% and 46% for the fisheye bottom position (FEB), the double reduced water flow fisheye (DRFE), the HSB design (HSB), and the double fisheye design (DFE). The best croaker reduction rates were achieved with the fisheye top position (FET), and the large mesh/funnel design (LMF) with 83%, 56% respectively. The croaker reduction rates for the extended funnel design (EF) and the reduced water flow fisheye (RFE) were 14% and 77% but were not statistically significant.

The best reduction rates for butterfish (fig. 7) were achieved with the HSB design (HSB) and the reduced water flow fisheye (RFE) with statistically significant rates of 60% and 40%. The other designs had reduction rates between 20% and 62% but were not statistically significant.

Statistically significant reduction rates of 72%, 66% and 25% were achieved for spot by the HSB design (HSB), the large mesh/funnel design (LMF), and the double reduced water flow fisheye design (DRFE) respectively. (fig. 8). Other designs had spot reduction rates between 47% and 96%, but these rates were not statistically significant.

Statistically significant reduction rates of 59% for Atlantic bumper were achieved by the large mesh/funnel design (LMF) and the HSB design (HSB) and 52% for the extended funnel design (EF) (fig. 9). Other designs had reduction rates for Atlantic bumper between 0 and 100%, but these data were not statistically significant.

The large mesh/funnel design (LMF), the fisheye bottom position (FEB), the HSB design (HSB), and the reduced water flow fisheye (RFE) had statistically significant reduction rates for trout of 34%, 59%, 29% and 44% respectively (fig. 10). The other designs had trout reduction rates between 0 and 77%, but these rates were not statistically significant.

The only design effective in reducing longspine porgy was the large mesh/funnel design (LMF) which had a statistically signifcant reduction rate of 43%. (fig. 11).

All of the designs evaluated were effective in reducing catfish with rates between 73% and 89% (fig. 12). The reduction rates for the fisheye top position (FET) and the double fisheye (DFE) were not statistically significant.

Reduction rates for whiting (fig. 13) were not significant for any of the designs tested.

Results for BRD combinations, and modifications to basic designs tested are presented in figures 14-27. This testing was conducted to determine if combinations of BRD designs would improve fish reduction rates and to evaluate modifications to the basic designs. Codes used to designate total fish reduction, shrimp retention, and fish species for figures 14-27 are given in Table 1.

The fisheye design BRD is a commercially designed BRD which has been in use in the shrimp industry for many years. Information from shrimp fishermen indicate it is used in several different positions and configurations. Some fishermen use the fisheye in the top of the codend with the apex of the device facing forward and others with the apex facing aft. A comparison of these configurations is presented in figure 14. Total fish reduction rates for the two configurations was 67% and 58% respectively, and shrimp retention rates were 83% and 85% indicating that orientation of the device did not have a statistically detectable impact on device performance.

A comparison of data for the fisheye BRD installed in three different positions, in the top of the codend (FET), in the bottom of the codend (FEB), and on the sides of the codend (DFE) is presented in figure 15. The total fish reduction rates were 63% for the top position, 20% for the bottom position, and 25% for the side position. Shrimp retention rates were 84% for the top position, 100% for the bottom position, and 92% for the side position. The best fish reduction rates for key species and dominant species were achieved in the top position.

The double fisheye design (DFE) was tested with and without a hummer stimulator to determine if the stimulator could increase fish reduction rates (fig. 16). Total fish reduction rates were 25% without the stimulator and 38% with the stimulator. Shrimp retention rates were 92% without the stimulator and 75% with the stimulator. Reduction rates for key species, except for red snapper, and dominant species were increased with the stimulator.

The fisheye design was modified to reduce water flow entering the device from outside the net in an attempt to improve the reduction rate for juvenile fish including juvenile red snapper. A comparison between the standard fisheye bottom position (FEB) and the modified fisheye bottom position (RFE) is presented in figure 17. Total fish reduction rates were 20% for the standard fisheye and 50% for the modified fisheye. Shrimp retention rates were 100% for the standard fisheye and 85% for the modified fisheye. Reduction rates for red snapper were 0% for the standard fisheye and 51% for the modified fisheye. The reduction rate for red snapper with the modified fisheye was statistically significant.

The reduced water flow fisheye (RFE) was further modified by adding a webbing lead panel off the trailing edge of the device in an attempt to increase fish reduction rates. Data for the reduced water flow fisheye (RFE) and the reduced water flow fisheye modified with a webbing lead panel (RFEW) are presented in figure 18. Total fish reduction rates were 50% without the lead panel and 56% with the lead panel. Shrimp retention rates were 85% without the lead panel and 64% with the lead panel. Reduction rates for red snapper were 51% without the lead panel and 47% with the lead panel. The snapper reduction rates were statistically significant for both designs.

Observations of the reduced water flow fish eye in operation indicated that shrimp were exiting through the device by crawling out the exit opening. The device was modified by adding a clear plastic panel in back of the exit opening in an attempt to prevent shrimp from crawling out of the device. Data for the reduced water flow fisheye (RFE) and the reduced water flow fisheye with plastic panel modification (RFEP) are presented in figure 19. Total fish reduction rates were 50% for the reduced water flow fisheye and 15% for the reduced water flow fisheye with plastic panel modification. Shrimp retention rates were 85% for the reduced water flow fisheye and 80% for the device with plastic panel.

A comparison was made between the double fisheye and the double reduced water flow fisheye (fig. 20). Total fish reduction rates were 25% for the double fisheye and 36% for the reduced water flow fisheye. Shrimp retention rates were 92% for the double fisheye and 81% for the reduced water flow fisheye.

A comparison of the extended funnel with a hummer wire stimulator, a chain stimulator, and without a stimulator is presented in figure 21. Total fish reduction rates were 37% for the extended funnel design with no stimulator, 44% with the hummer stimulator, and 22% with the chain stimulator. Shrimp retention rates were 100% for the extended funnel and extended funnel with stimulators. A statistically significant reduction rate of 22% for red snapper was achieved for the extended funnel with hummer stimulator.

A comparison was made between the large mesh/funnel design installed ahead of a standard super shooter TED and installed ahead of a super shooter TED modified by adding additional grid bars to stimulate fish to exit through the excluder. Results of this evaluation are presented in figure 22. Total fish reduction was 37% for the large mesh/funnel design with standard TED and 48% with the large mesh/funnel design with the modified TED. Shrimp retention rates were 93% for the large mesh/funnel design with standard TED and 100% for the large mesh/funnel design with modified TED. Statistically significant reduction rates of 50% for king mackerel and 72% for Spanish mackerel were achieved with the large mesh/funnel design with the modified TED.

The super shooter TED was also modified by adding small stainless steel wires between the grid bars to stimulate fish to exit through the large mesh/funnel excluder installed ahead of the TED. A comparison between a standard super shooter TED and the super shooter TED modified with hummer wires in combination with the large mesh/funnel excluder is presented in figure 23. Total fish reduction was 37% for the standard TED with large mesh/funnel excluder and 23% with the modified TED. Shrimp retention rates were 93% with the standard TED and 100% with the modified TED.

The large mesh funnel was evaluated in the aft position behind a super shooter TED with a hummer wire stimulator and a super shooter TED with a ty wrap stimulator. The results of this comparison are presented in figure 24. Total fish reduction rates were 37% with the hummer wire stimulator and 36% with the ty wrap stimulator. Shrimp retention rates were 93% with the hummer stimulator and 100% with the ty wrap stimulator.

The large mesh/funnel design was also tested in combination with the extended funnel design and a plastic strip stimulator. The results of this comparison are presented in figure 25. Total fish reduction rates were 46% for the large mesh/funnel, and extended funnel combination, and 9% with the plastic strip stimulator. Shrimp retention rates were 100% with both configurations.

The large mesh/funnel excluder was evaluated in combination with the double fisheye design (fig. 26). Total fish reduction rates were 38% with the double fisheye alone and 56% when used with the large mesh/funnel design. Shrimp retention rates were 75% for the double fisheye and 100% with the double fisheye, large mesh/funnel combination.

A comparison was made between the large mesh/funnel design in combination with the double fisheye design and the large mesh/funnel in combination with the reduced water flow fisheye. The results of this comparison are presented in figure 27. Total fish reduction rates were 56% for the large mesh/funnel, double fisheye combination and 54% for the large mesh/funnel, reduced water flow fisheye combination. Shrimp retention rates were 100% for the large mesh/funnel, double fisheye combination and 92% for the large mesh/funnel, reduced water flow fisheye combination. A statistically significant reduction rate of 51% for red snapper was achieved with the large/mesh funnel, reduced water flow fisheye combination.

## BEHAVIORAL OBSERVATIONS

Evaluations of the prototype BRD design include observations by scuba divers and recordings made by remote video cameras of fish and shrimp behavior in shrimp trawls and in response to the different BRD designs. This information has been used to develop BRD designs and to modify designs in attempts to modify behavior and improve performance.

Observations of fish behavioral reactions to shrimp trawls indicate that most fish species react to the gear by orienting to trawl components and attempting to keep pace with the trawl. The ability to keep pace with the trawl is determined by the fish size and swimming ability which can be affected by environmental conditions. Fish exhibiting this reaction swim parallel to the trawl at approximately the same speed. This reaction is known as the optomotor reaction and is an unconditioned response to visual stimuli exhibited by most fish species. This response is less predominant when light levels and turbidity reduce the contrast of the trawl components. The visual reaction of fish to trawl components and BRDs changes between day and night and with changes in water clarity which may cause variation in the effectiveness of BRD designs. The optomotor response was found to be a determining factor in the efficiency of BRDs in reducing fish catch. Fish exhibiting the optomotor response orient to trawl components and will not exit through BRD escape openings until some other stimuli overrides the optomotor response. Species which do not exhibit the optomotor response respond to exit openings of the BRDs by swimming through the openings, and reduction rates for these species were excellent for all designs tested.

Fish were also observed responding to changes in water flow rates and characteristics within the trawl. Fish can sense velocity differences between adjacent bodies of water, local pressure gradients, and turbulent flow through the lateral line sensory system. Fish use this information to orient themselves without visual references. Water currents produced by trawling gear moving through the water were observed to have an effect on the visual reaction of fish which depended on the velocity of the water currents. Fish oriented within trawls in different locations depending on their size, swimming ability, visibility, contrast of trawl components and the velocity of the water in different sections of the trawl. When the velocity of the water flow through the trawl exceeds the swimming ability of a fish, the fish tires and the visual reaction is overridden. As the fish tire they fall back into the trawl until they reach an area with less water flow velocity and if not exhausted again exhibit the optomotor reaction. Escapement of fish through the use of BRDs depends on the ability of the fish to sustain a swimming speed equal to, or exceeding, the relative flow within the trawl. The ability of fish to maintain swimming speeds equal to the flow of water within the trawl is a function of fish size, anatomy, physiology, and water temperature.

The behavior of juvenile fish, particularly juvenile red snapper, was observed within operational trawls. Juvenile fish encountering shrimp trawls were observed to react initially to the tickler chain and ground rope of the trawl rising slightly in the water column and passing over the ground rope as the trawl passed. Fish between 20 mm and 320 mm (fork length) passed through the trawl body swimming only enough to keep from coming in contact with the passing webbing. As they entered the trawl extension they oriented into the direction of water flow and passed through the extension into the codend. Within the codend they were able to maintain station orienting to the codend webbing. This pattern of behavior changed when other objects were present within the trawl. Juvenile red snapper reacted to the water disturbance caused by objects in the trawl and took up station within the trawl body in the turbulent flow behind the object. Juvenile red snapper were also observed swimming on the outside of shrimp trawls taking up station behind the codend in the turbulent flow caused by the passing trawl. These observations stimulated research to develop BRD designs which create areas of turbulent flow adjacent to openings which would allow fish to escape the trawl.

The behavior of penaeid shrimp was observed to be distinctly different from fish due to their method of locomotion. Shrimp encountering shrimp trawls were observed to exhibit a "tail thrust" reaction when contacted by trawl components. This reaction is characterized by a strong ventral flexing of the abdominal muscles. The result is a rapid backward movement which can exceed 1-2 meters in distance. Shrimp were observed to exhibit this reaction when contacted by the tickler chain, groundrope, and webbing in the forward sections of the trawl. The reaction was often repeated three to five times in succession propelling the shrimp several meters. The direction of the movement appeared to be random but was generally in a vertical direction due to initial orientation of the shrimp. Penaeid shrimp were unable to keep pace with the speed of the trawl and were impinged on the webbing panels. Shrimp passing down the center of the trawl entered the codend. Shrimp in the wings of the trawl remained impinged on the webbing or tumbled down the webbing panels eventually arriving in the extension and codend of the trawl. Shrimp in the trawl extension and codend were observed clinging to the webbing with their walking legs and crawling forward against the flow of water. Shrimp clinging to the webbing were observed to exhibit the tail thrust reaction when contacted by other organisms or objects passing through the trawl.

Scuba divers conducted experiments with dye to determine water flow characteristics around BRD designs and measured water flow rates. This information was used to determine fish reactions to different flow rates and characteristics. Initial results of these experiments indicate that flow rates behind the BRD device were slower than the water flow within other sections of the trawl and that fish took up station in these areas of reduced water flow velocity and were able to maintain station in this position for extended periods. Escapement of fish through BRD escape openings occurred for most species during trawl haulback or when accumulation of fish caused crowding adjacent to the openings. Fish which exhibited the optomotor reaction remained within the trawl even when they were in close proximity to escape openings unless some other stimuli were present to override this reaction. Stimuli which appeared to override the optomotor response included crowding of fish within the trawl, slowing the trawl speed prior to haulback, trawl haulback, and change in ambient pressure as the trawl was hauled up in the water column. Juvenile fish were observed reacting to changes in flow velocities through the BRD exit openings. Changes in flow velocities appeared to modify the optomotor reaction. Juvenile fish were observed to exit through BRD escape openings when the flow rate through the escape openings was between 0.2 and 0.5 meters per second. Juvenile fish did not exit when the flow rates through the BRD exit openings were below 0.2 meters per second or above 0.5 meters per second.

Penaeid shrimp were observed accumulating in areas of reduced water flow by clinging to the webbing and crawling forward against the flow of water exiting through escape openings on some BRD designs. Shrimp were also observed accumulating in areas where trawl modifications caused pockets in the webbing or near upward sloping webbing sections which created areas of minimum water flow. Shrimp were observed being carried out of some BRD designs by water flowing out of the exit openings when webbing components of the BRDs were blocked with grass or other material.

# DISCUSSION

Proof of concept test results indicate six of the eight basic BRD designs evaluated reduced total finfish catches by at least 35% when compared to the control nets. These designs were the HSB design, the fisheye top position, the extended funnel design, the reduced water flow fisheye, the large mesh/funnel design, and the double reduced water flow fisheye. Designs which had shrimp retention rates of 90% or greater were the extended funnel design, the large mesh/funnel design, and the HSB design. Designs that have the best potential of achieving a total fish reduction rate of 50% with a shrimp retention rate of at least 90% are the large mesh/funnel design, the extended funnel design, the HSB design, and the fisheye top position.

Significant reductions in juvenile red snapper bycatch were achieved by the double fisheye design and the reduced water flow fisheye. Other designs which appear to have the potential to significantly reduce red snapper bycatch, but have not been adequately evaluated in red snapper concentrations, include the HSB design, and the RWF large mesh/funnel design.

Significant reductions in king mackerel bycatch were achieved by the large mesh/funnel design. The fisheye top position, and the fisheye bottom position and the extended funnel design also have potential for reducing king mackerel bycatch.

Spanish mackerel bycatch was significantly reduced by the large mesh/funnel design. The fisheye design in the top position, and bottom position, appear to have the potential to significantly reduce Spanish mackerel bycatch.

Reduction rates varied between designs for the dominant fish species. All of the BRD designs tested reduced croaker by at least 35%, except for the extended funnel design. Butterfish reduction rates of at least 35% were achieved by all of the designs, except for the fisheye top and bottom position. Spot reduction rates greater than 35% were demonstrated by all designs with the exception of the double reduced water flow fisheye. For Atlantic bumper the only devices which did not achieve a reduction rate of at least 35% was the reduced water flow fisheye and the double reduced water flow fisheye. The most effective designs for the reduction of trout were the top fisheye design, the large mesh/funnel design, the HSB design and the reduced water flow fisheye design. The only design which was effective in reducing longspine porgy was the large mesh/funnel design. All of the designs effectively reduced catfish, and only the large mesh/funnel, the HSB, and fisheye top position showed potential for reducing whiting.

Total fish reduction for different BRDs was dependent on the species composition of the catch. The effectiveness of different BRDs in reducing the bycatch of individual species appears to be related to fish size and swimming ability, whether the fish is demersal, or pelagic, the intensity of the optomotor response, water flow velocity entering the BRD exit opening, and the placement and configuration of the BRD.

The large mesh/funnel design was effective in reducing all dominant and key species except juvenile red snapper. The efficiency of this design appears to be related to its position in the net, modification of water flow characteristics within the net, and the location of the fish escape openings (large mesh) on the top, bottom, and sides of the trawl. The apparent ineffectiveness of the design in reducing bycatch of juvenile red snapper is due to the velocity of the water entering through the large mesh openings which inhibits small fish from exiting. The RWF large mesh/funnel design was developed late in 1992 in an attempt to improve the reduction rate of this design for juvenile red snapper. It employs a small mesh webbing skirt on the outside of the large mesh opening to reduce water flow velocity entering the openings. This design will be evaluated in 1993.

The extended funnel is similar in design to the large mesh/ funnel design except it is located farther back in the trawl directly ahead of the codend, and the accelerator funnel extends into the codend reducing water flow on one side of the codend. Its position allows more fish to escape the trawl during haulback due to its proximity to the codend. Both accelerator funnel designs had excellent shrimp retention rates due to the acceleration of water through the funnels which carries shrimp away from the exit openings.

The fisheye designs are located in the codend and are very effective for most fish species but are not as effective for shrimp retention due to their location. They were the most effective designs for reduction of trout and were very effective for mackerel reduction. The top position appeared to be the most effective placement of the fisheye design for fish reduction and shrimp retention. Fisheyes are the simplest and least expensive of the BRD designs developed to date, and more research is required to determine the effects of incremental changes in location on fish reduction and shrimp retention. Modifications to the fisheye design to reduce water flow rates entering the exit openings were effective in increasing the reduction of juvenile red snapper but at the expense of reduced shrimp retention.

The HSB device was designed with features to control water flow rates adjacent to and passing through the fish escape openings. Its location was determined by observing the reactions of juvenile red snapper passing through TED funnels and accumulating behind TED bars on the bottom of the trawl. The design appears to be effective in reducing bycatch of the dominant and key fish species except trout and mackerel and has good shrimp retention rates. It is designed to be a modification for grid style TEDs and can be added to existing TEDs. Three different prototypes of the HSB design are being developed for testing in 1993.

BRDs tested in combinations did not appear to increase fish reduction rates when compared to single designs. Modifications to BRDs tested did not significantly improve fish reduction rates except for modifications made to the fisheye design which reduced water flow. Other combinations such as the HSB design in combination with the large mesh or extended funnel may result in better reduction for a wider range of species without decreasing shrimp retention. Modifications which will be evaluated in 1993 include the RWF large mesh/ funnel design and modified codend designs.

Behavioral observations indicate that modifying fish optomotor reactions by introducing additional stimuli may be the best mechanism for improving fish reduction. One promising area is research on modifying water flow velocities within the trawl and through BRD escape openings to stimulate fish to exit the trawl while carrying shrimp away from fish escape openings. Ideas on BRD designs which allow for adjustment and control of water flow velocities through the device exit openings are needed for evaluation of this concept.

Other researchers have conducted testing of similar BRD designs in different conditions including inshore waters and off the Atlantic coast. Results of their research findings are comparable to the results of this study. The North Carolina Division of Marine Fisheries conducted tests to evaluate the bycatch reduction and shrimp retention rates for four different TED designs (Holland, 1989) and several BRD designs (McKenna and Monaghan, 1991) in waters off North Carolina. Holland, (1989) evaluated two designs of the Georgia Jumper TED, one with 10 cm grid bar spacing and one with 6 cm bar spacing, the Parrish TED and the Morrison TED. He reported a total fish reduction rate of 16.5% and a shrimp retention rate of 95% for the Georgia Jumper with 10 cm bar spacing and a total fish reduction rate of 20% and shrimp retention of 93% for the Georgia Jumper with 6 cm bar spacing. The fish reduction rates for the two Georgia Jumper designs was higher than rates for the super shooter design TED reported by Renaud et al, (1990). Holland reported a fish reduction rate of 75% for the Parrish TED with a shrimp retention rate of 47%. The Morrison soft TED had a fish reduction of 24% with a shrimp retention rate of 76% in the North Carolina study which is similar to the fish reduction rate of 25% and shrimp retention rate of 77% reported in this report for the Andrews soft TED (Appendix II, fig. 2).

McKenna and Monaghan (1991), reported fish reduction rates of 34% and shrimp retention rates of 80% for fisheyes positioned in the middle of codend in the side position when tested in inshore waters and 62% fish reduction with 96% shrimp retention when tested in offshore waters. Coleman et al. (1993) reported a fish reduction rate of 13% and shrimp retention rate of 96% for fisheyes in the same position in the codend when tested in inshore water in Florida. The University of Georgia Marine Extension Service reported fish reduction rates of between 33% and 72% with shrimp retention rates exceeding 100% for side positioned fisheyes tested in offshore waters of Georgia (Harrington, 1993). The fisheyes in the Georgia study were located in the forward third of the codend. The results reported in this report for the side position fisheye located in front of the codend was 32% fish reduction and 69% shrimp retention.

Several researchers have tested the fisheye in the top position including McKenna and Monaghan (1991) in offshore waters of North Carolina, Harrington, (1993) in offshore waters of Georgia, Coleman et al. (1993) in inshore waters of Florida, and Rogers et al. (1993) in inshore waters of Louisiana. McKenna and Monaghan (1991), tested fisheyes in the middle of the codend in the top and bottom position and reported fish reduction rates of 57% and shrimp retention rates of 94%. Harrington (1993), reported fish reduction rates of between 55% and 74% and shrimp retention rates exceeding 100% for the top position fisheye located in the forward third of the codend. Coleman et al. (1993), reported fish reduction rates of 48% and shrimp retention rates of 83% for the top positioned fisheye located in the back of the codend near the bag tie rings, and Rogers et al reported fish reduction rates of 51% and shrimp retention rates of 84% for the top position fisheye located in the forward third of the codend. Our results with the fisheye in the top position located at the midpoint of the codend were 70% fish reduction and 85% shrimp retention.

# RECOMMENDATIONS

This report is intended to provide information on BRD designs to assist in determining prototype designs for operational evaluations under phase three of the bycatch gear development research plan, and to provide direction and emphasis for new design development and evaluation. Based on the results of diver evaluations, behavioral observations, and proof of concept testing, the best candidates for operational testing of the BRDs evaluated in this study are the large mesh/funnel design, the extended funnel design, the HSB design and the top position fisheye design.

It is recommended that additional proof of concept testing be conducted for fisheye designs to provide a systematic evaluation of the effects of incremental changes in location of the fisheyes on fish reduction and shrimp retention rates. It is also recommended that additional research be conducted on fish behavior to determine methods to modify the optomotor response in fish, and in particular the effects of changes in water flow velocities and characteristics and other stimuli that affect the optomotor responses of dominant and key species. This information should be distributed to all research partners in order to generate design ideas which incorporate stimuli to modify behavior and improve fish reduction and shrimp retention.

Finally the data presented in this report are not conclusive in regard to the efficiency of the prototype devices tested. Reduction rates for some species which were not significantly different from the control net could be due to the small sample sizes and catch rates for individual species rather than the efficiency of the BRD. The data in this report are only intended to indicate relative potential for the different devices for use in determining designs for operational evaluation. Shrimp trawl bycatch is a complex problem due to the number of species involved, different trawl designs in use, and the different fishing conditions which occur within the Southeastern U.S. More extensive testing will be required to determine the efficiency of different BRD designs for specific species and fishing conditions. The complexity of the bycatch problem requires that priorities be identified and reduction goals be set for specific species in order to design a sampling program to collect the data necessary to make decisions on the potential of different BRD designs as management tools.

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## LIST OF TEXT FIGURES

## LIST OF APPENDICES

### APPENDIX I. BRD DIAGRAMS, DESCRIPTIONS, AND DIVER EVALUATIONS

## LIST OF APPENDICES

### APPENDIX II. BRD PROOF OF CONCEPT TEST RESULTS

*Table 1. Bycatch reduction device (BRD) codes used in text figures 1-27.*

***MODIFIED TEDS***

| Name | Code |
| --- | --- |
| *HSB Design* | HSB |
| *Double bar super shooter* | DBSS |
| *Hummer wire super shooter* | HWSS |

**FISHEYES**

| Name | Code |
| --- | --- |
| *Top position* | FET |
| *Bottom position* | FEB |
| *Double side position* | DFE |
| *Reduced flow* | RFE |
| *Double side position reduced flow* | DRFE |
| *Top position facing aft* | FETA |
| *Top position facing forward* | FETF |
| *Reduced water flow w/webbing lead panel* | RFEW |
| *Reduced flow w/plastic panel* | RFEP |

**FUNNEL DESIGNS**

| Name | Code |
| --- | --- |
| *Large mesh/funnel* | LMF |
| *Extended funnel* | EF |

**FISH STIMULATORS**

| Name | Code |
| --- | --- |
| *Hummer Wire* | HS |
| *Chain* | C |
| *Ty wrap* | TW |

***Table 2. Codes used in text figures 14-27 for total fish reduction, shrimp retention, key species, and dominant species.***

| ***Code*** | ***Common Name*** | ***Scientific Name*** |
|---|---|---|
| TF | Total Fish | |
| S(RET) | Shrimp Retention | |
| RS | red snapper | *Lutjanus campechanus* |
| KM | king mackerel | *Scomberomorus cavalla* |
| SPM | Spanish mackerel | *Scomberomorus maculatus* |
| CR | Atlantic croaker | *Micropogonias undulatus* |
| BF | gulf butterfish | *Peprilus burti* |
| SP | spot | *Leiostomus xanthurus* |
| AB | Atlantic bumper | *Chloroscombrus chrysurus* |
| TR | trout | *Cynoscion* |
| LSP | Long spine porgy | *Stenotomus caprinus* |
| CF | hardhead catfish | *Arius felis* |
| WT | whiting | *Menticirrhus* |

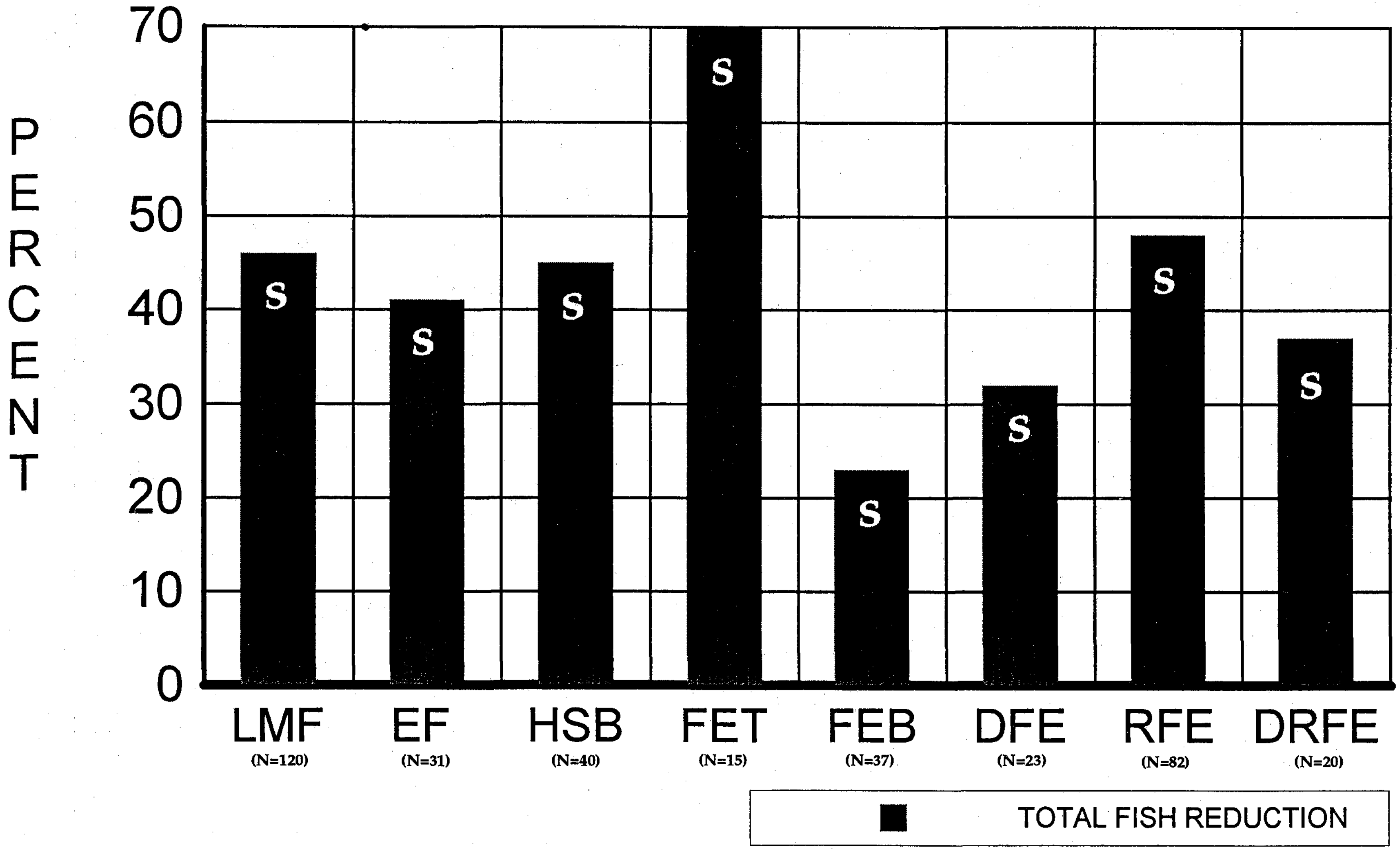
***Table 3. Shrimp retention and fish reduction rates for the large mesh funnel, extended funnel, HSB, fisheye top position, fisheye bottom position, double fisheye, reduced water flow fisheye, and double reduced water flow fisheye excluders.***

| | LMF | EF | HSB | FET | FEB | DFE | RFE | DRFE |
|---|---|---|---|---|---|---|---|---|
| **N** | **120** | **31** | **40** | **15** | **37** | **23** | **82** | **20** |
| Shrimp (Ret.) | 100% | 100% | ***94%*** | ***85%*** | ***81%*** | ***69%*** | ***79%*** | ***81%*** |
| Total Fish | ***46%*** | ***41%*** | ***45%*** | ***70%*** | ***23%*** | ***32%*** | ***48%*** | ***37%*** |
| Red Snapper | 0% | 23% | 40% | 37% | 54% | ***51%*** | ***48%*** | 36% |
| King Mac. | ***25%*** | 60% | 0% | 72% | 87% | 0% | 33% | 0% |
| Spanish Mac. | ***56%*** | 0% | 09% | 56% | 55% | 11% | 50% | 0% |
| Croaker | ***56%*** | 14% | ***46%*** | ***83%*** | ***38%*** | ***37%*** | 77% | ***44%*** |
| Butterfish | 40% | 62% | ***60%*** | 27% | 20% | 56% | ***40%*** | 40% |
| Spot | ***66%*** | 47% | ***72%*** | 59% | 67% | 53% | 96% | ***25%*** |
| Atlantic Bumper | ***59%*** | ***52%*** | ***59%*** | 100% | 40% | 64% | 22% | 0% |
| Trout | ***34%*** | 36% | ***29%*** | 77% | ***59%*** | 0% | ***44%*** | 38% |
| Longspine Porgy | ***43%*** | 08% | ND | ND | 01% | 25% | 0% | 38% |
| Catfish | ***73%*** | ***89%*** | ***78%*** | 84% | ***85%*** | 75% | ***83%*** | ***80%*** |
| Whiting | 66% | ND | 59% | 92% | 40% | ND | ND | 33% |

**LMF = LARGE MESH FUNNEL DESIGN**
**EF = EXTENDED FUNNEL DESIGN**
**HSB = HARVESTING SYSTEMS DESIGN**
**FET = FISHEYE TOP POSITION**
**FEB = FISHEYE BOTTOM POSITION**
**DFE = FISHEYE SIDE POSITION**
**RFE = REDUCED WATER FLOW FISHEYE**
**DRFE = REDUCED WATER FLOW SIDE POSITION**

***BOLD ITALIC NUMBERS = SIGNIFICANT DIFFERENCE ($p < 0.05$)***

**ND = NO DATA**




**S* = Significant difference (P<0.05)*

**Figure 1.** **Total fish reduction rates for large mesh funnel excluder (LMF), extended funnel excluder (EF), HSB excluder (HSB), fisheye top position (FET), fisheye bottom position (FEB), double fisheye (DFE), reduced water flow fisheye (RFE), and double reduced water flow fisheye (DRFE).**

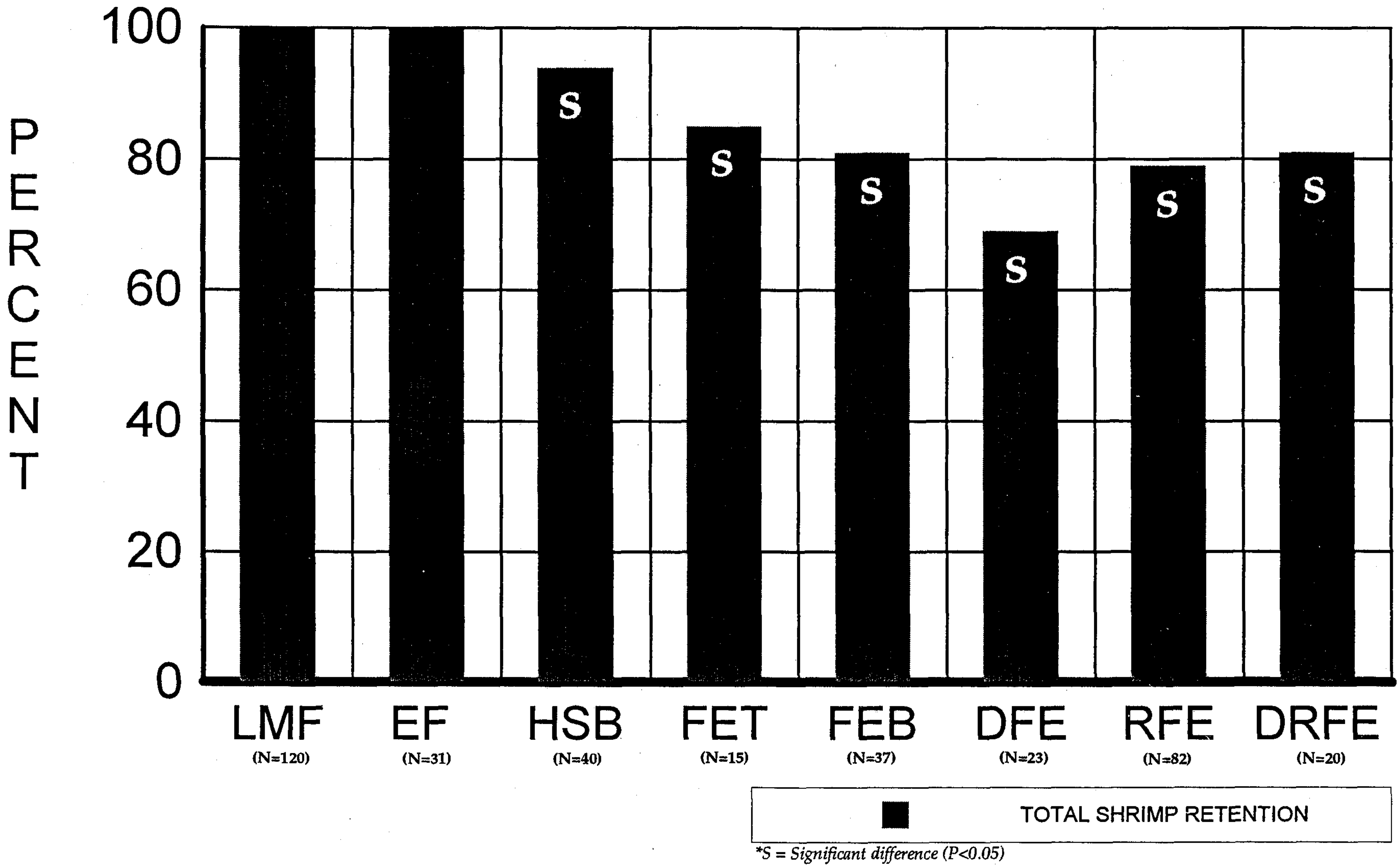



**Figure 2.** **Shrimp retention rates for large mesh funnel excluder (LMF), extended funnel excluder (EF), HSB excluder (HSB), fisheye top position (FET), fisheye bottom position (FEB), double fisheye (DFE), reduced water flow fisheye (RFE), and double reduced water flow fisheye (DRFE).**

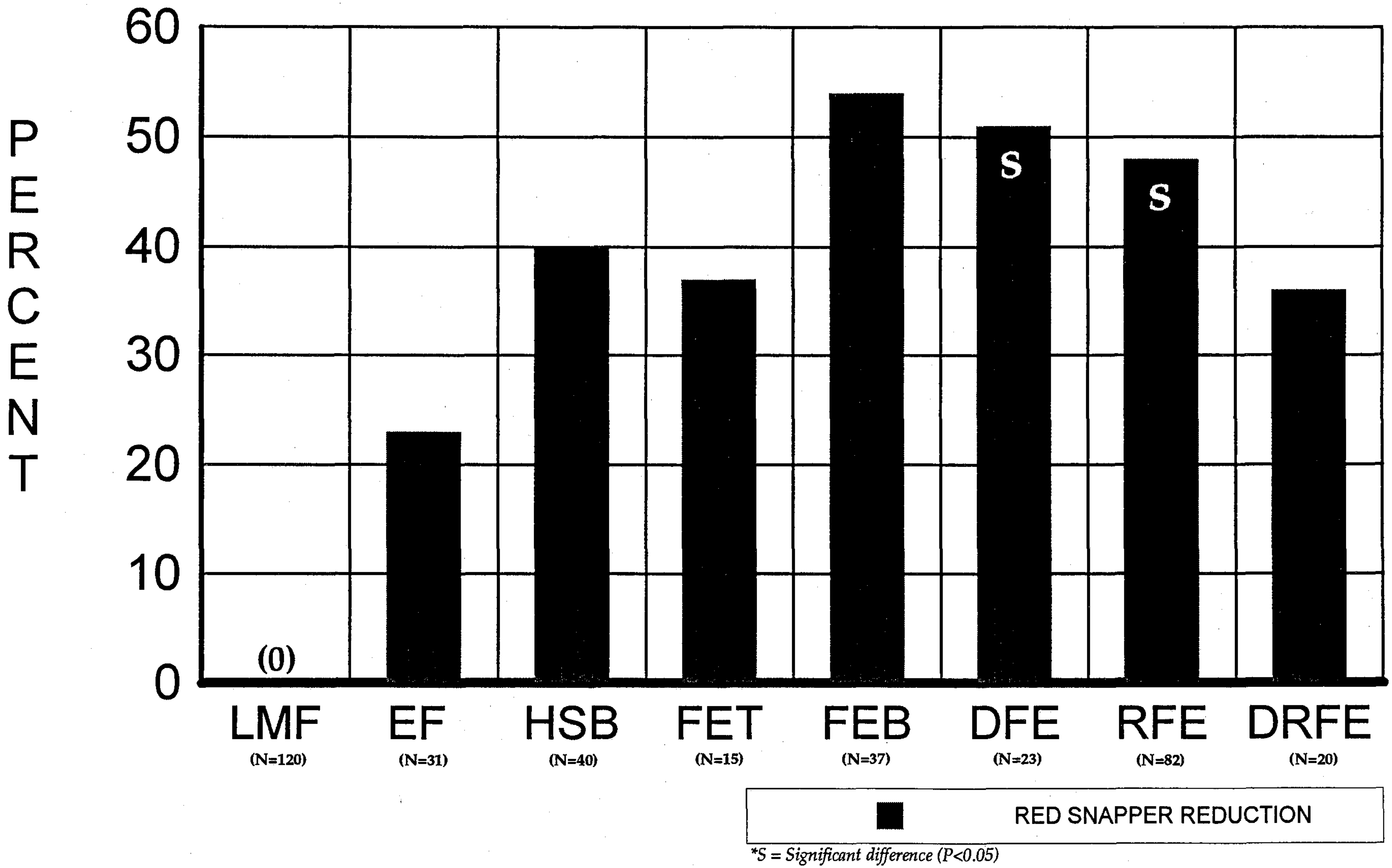



**Figure 3.** **Red Snapper reduction rates for large mesh funnel excluder (LMF), extended funnel excluder (EF), HSB excluder (HSB), fisheye top position (FET), fisheye bottom position (FEB), double fisheye (DFE), reduced water flow fisheye (RFE), and double reduced water flow fisheye (DRFE).**

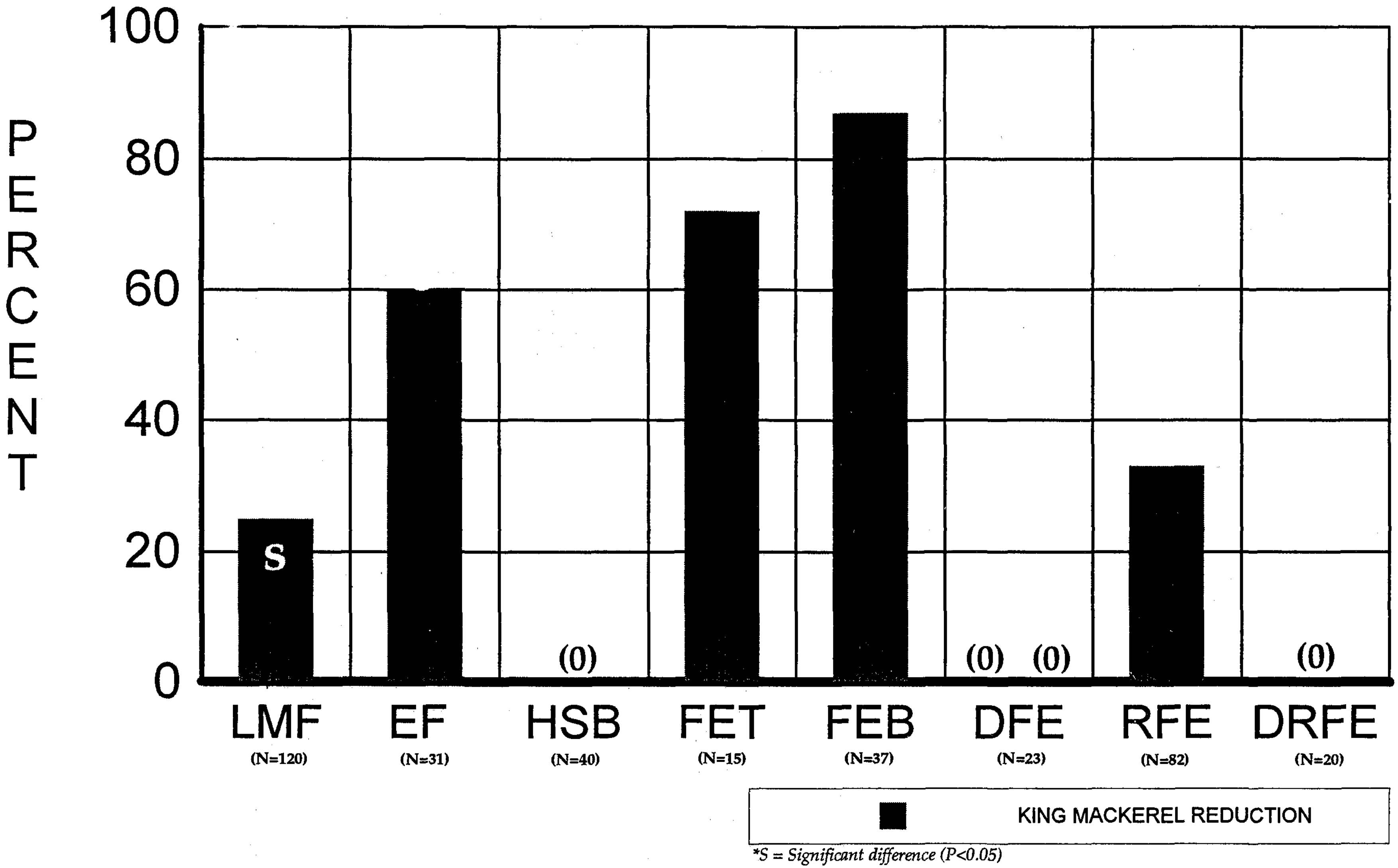





**Figure 4.** **King Mackerel reduction rates for large mesh funnel excluder (LMF), extended funnel excluder (EF), HSB excluder (HSB), fisheye top position (FET), fisheye bottom position (FEB), double fisheye (DFE), reduced water flow fisheye (RFE), and double reduced water flow fisheye (DRFE).**

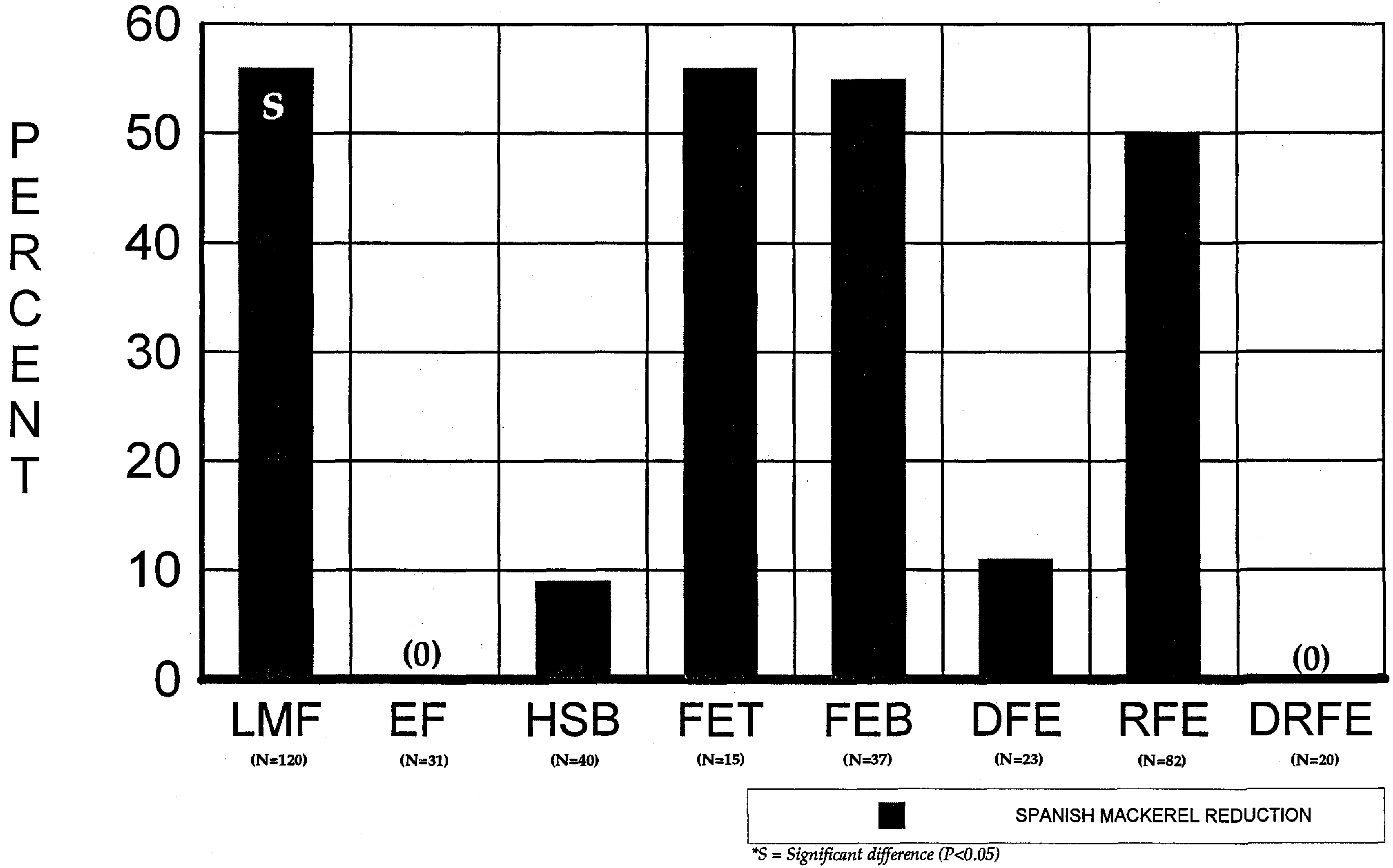



**Figure 5.** **Spanish Mackerel reduction rates for large mesh funnel excluder (LMF), extended funnel excluder (EF), HSB excluder (HSB), fisheye top position (FET), fisheye bottom position (FEB), double fisheye (DFE), reduced water flow fisheye (RFE), and double reduced water flow fisheye (DRFE).**

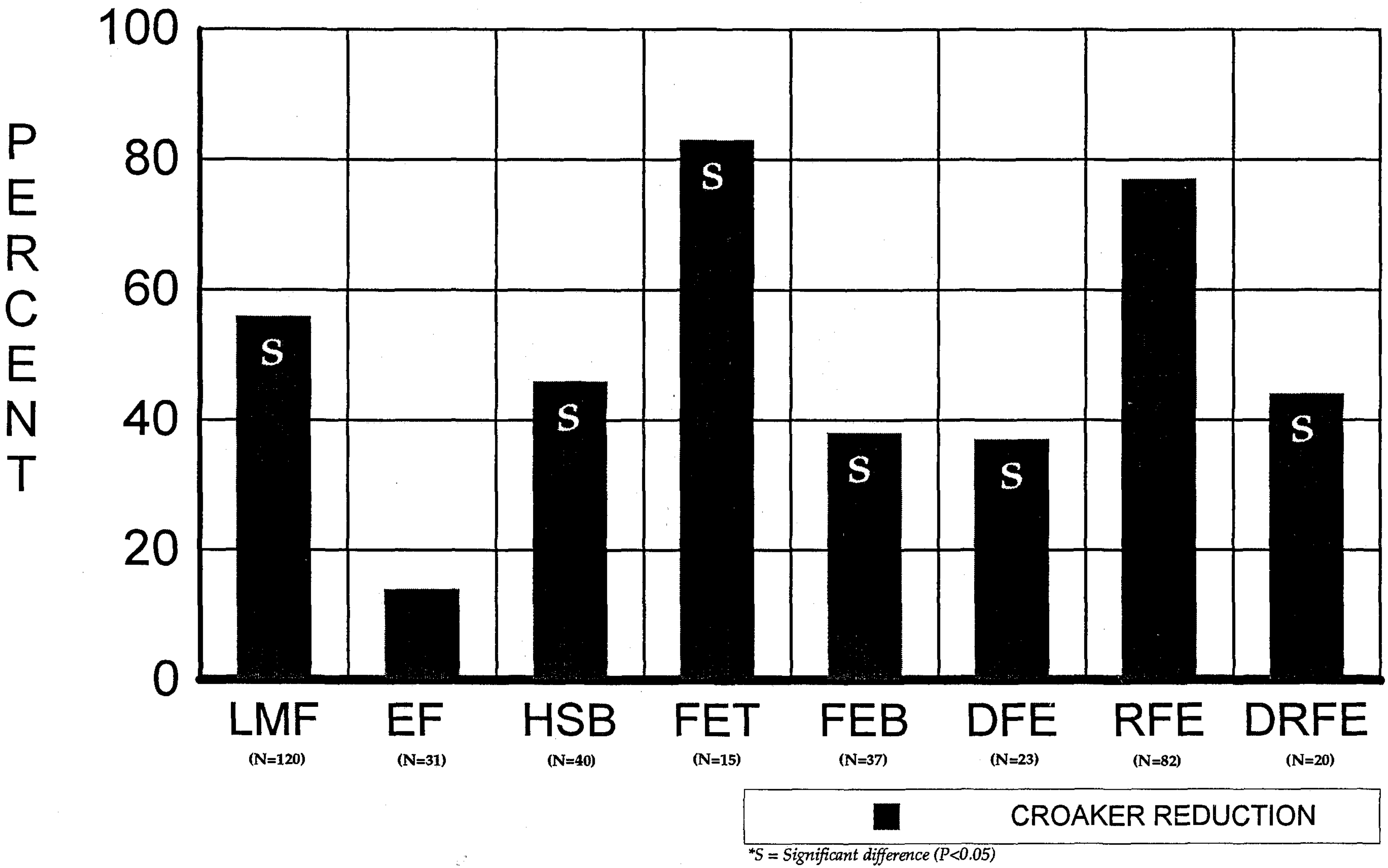



**Figure 6.** **Croaker reduction rates for large mesh funnel excluder (LMF), extended funnel excluder (EF), HSB excluder (HSB), fisheye top position (FET), fisheye bottom position (FEB), double fisheye (DFE), reduced water flow fisheye (RFE), and double reduced water flow fisheye (DRFE).**

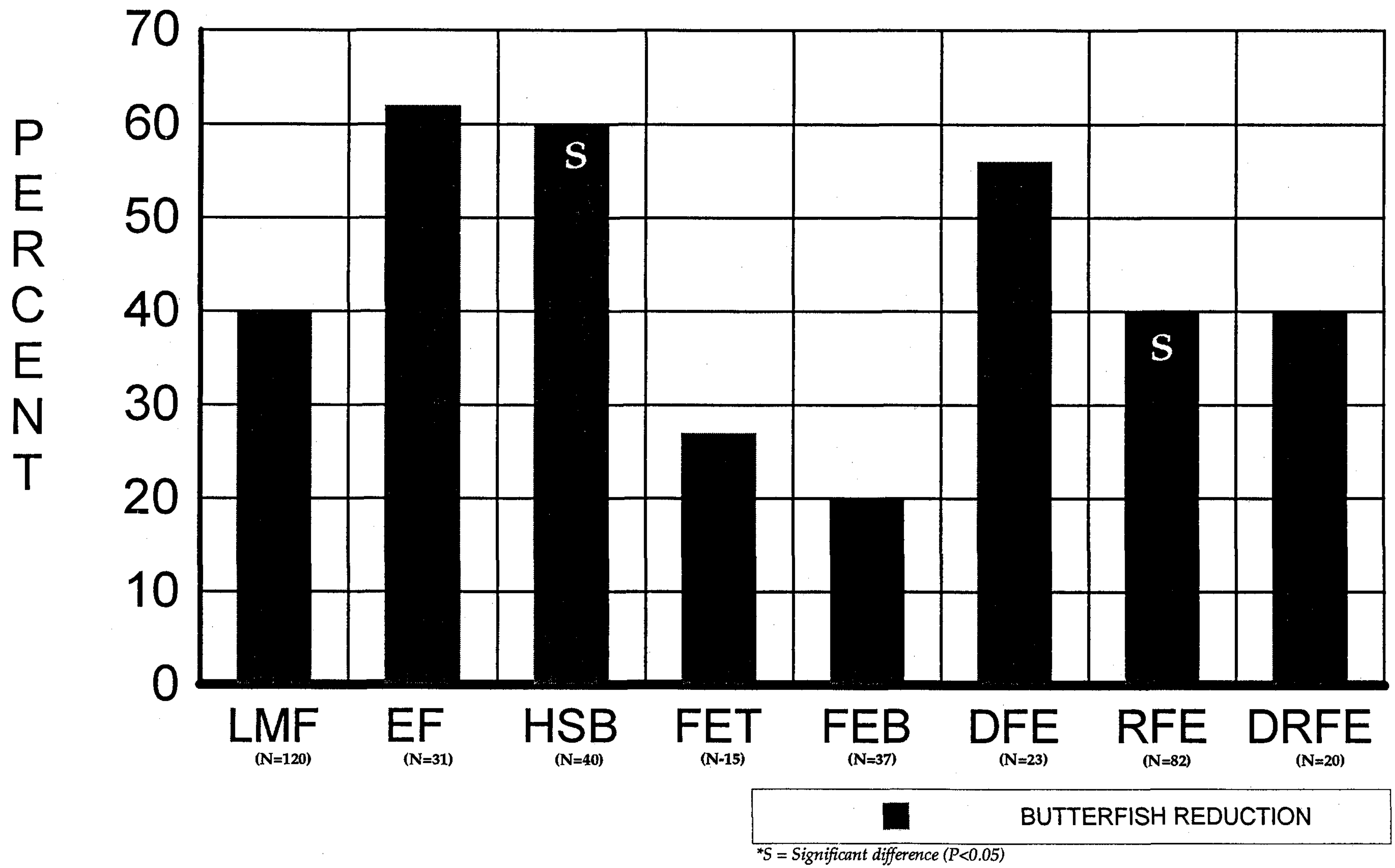



**Figure 7.** **Butterfish reduction rates for large mesh funnel excluder (LMF), extended funnel excluder (EF), HSB excluder (HSB), fisheye top position (FET), fisheye bottom position (FEB), double fisheye (DFE), reduced water flow fisheye (RFE), and double reduced water flow fisheye (DRFE).**

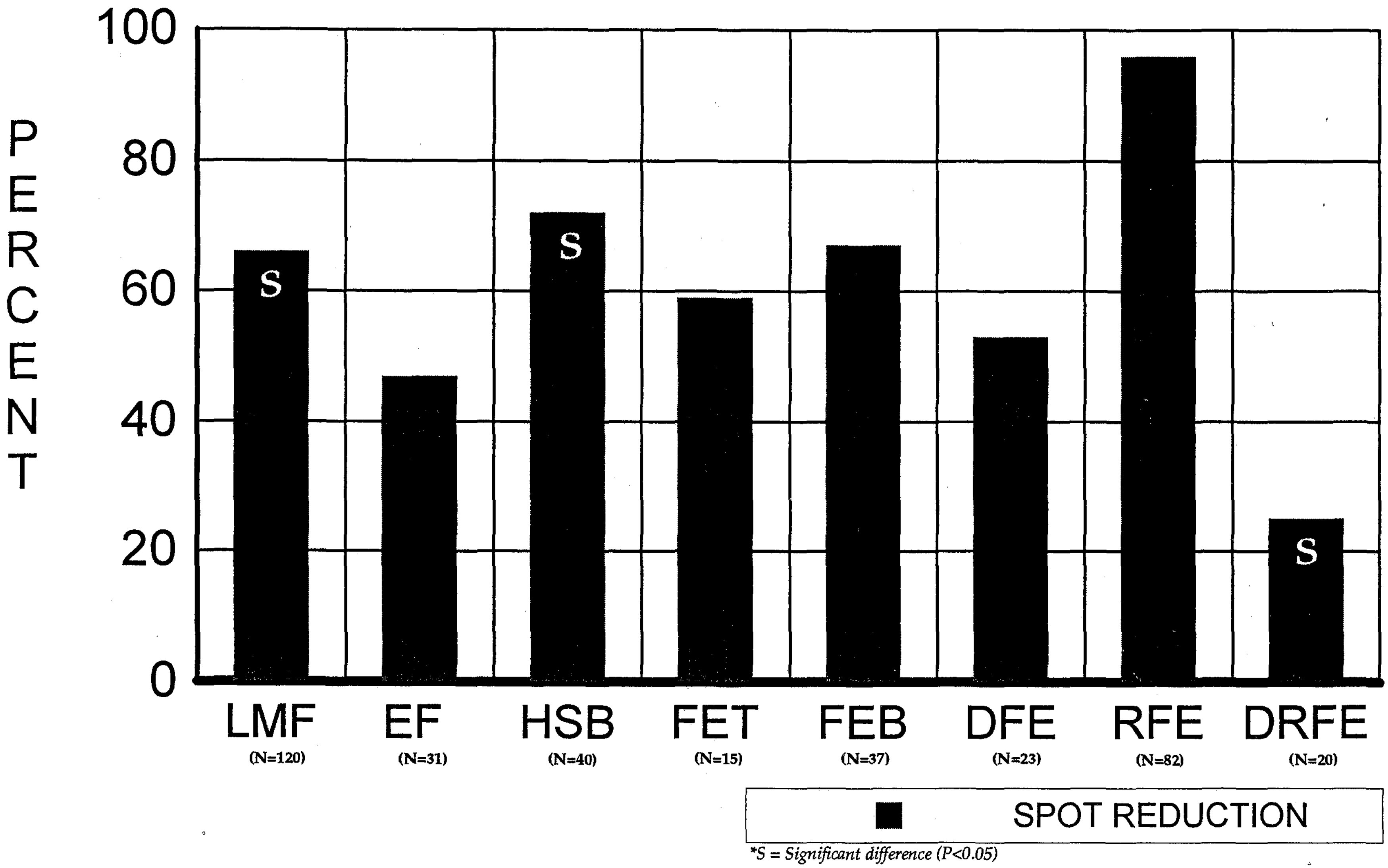



**Figure 8.** **Spot reduction rates for large mesh funnel excluder (LMF), extended funnel excluder (EF), HSB excluder (HSB), fisheye top position (FET), fisheye bottom position (FEB), double fisheye (DFE), reduced water flow fisheye (RFE), and double reduced water flow fisheye (DRFE).**

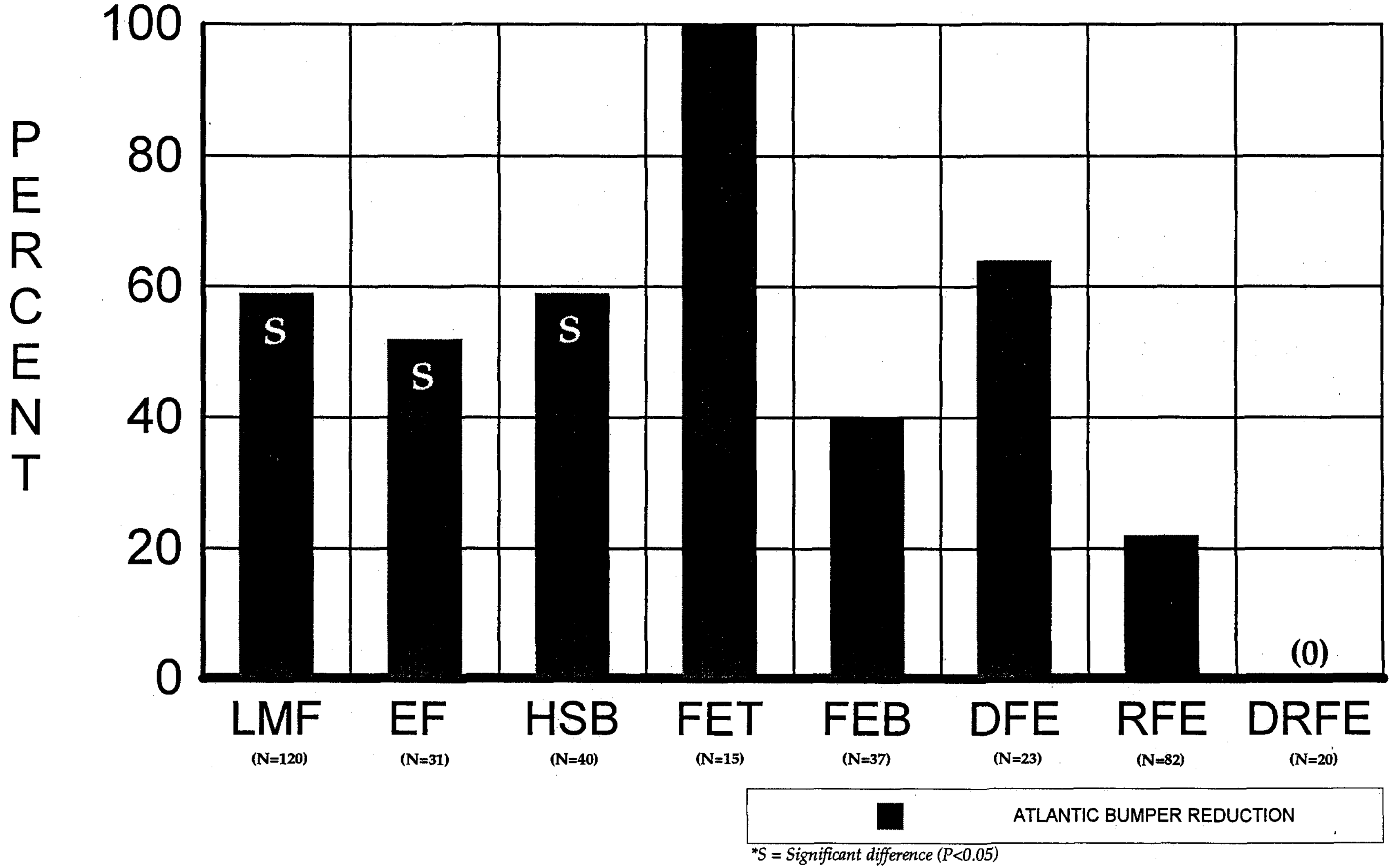
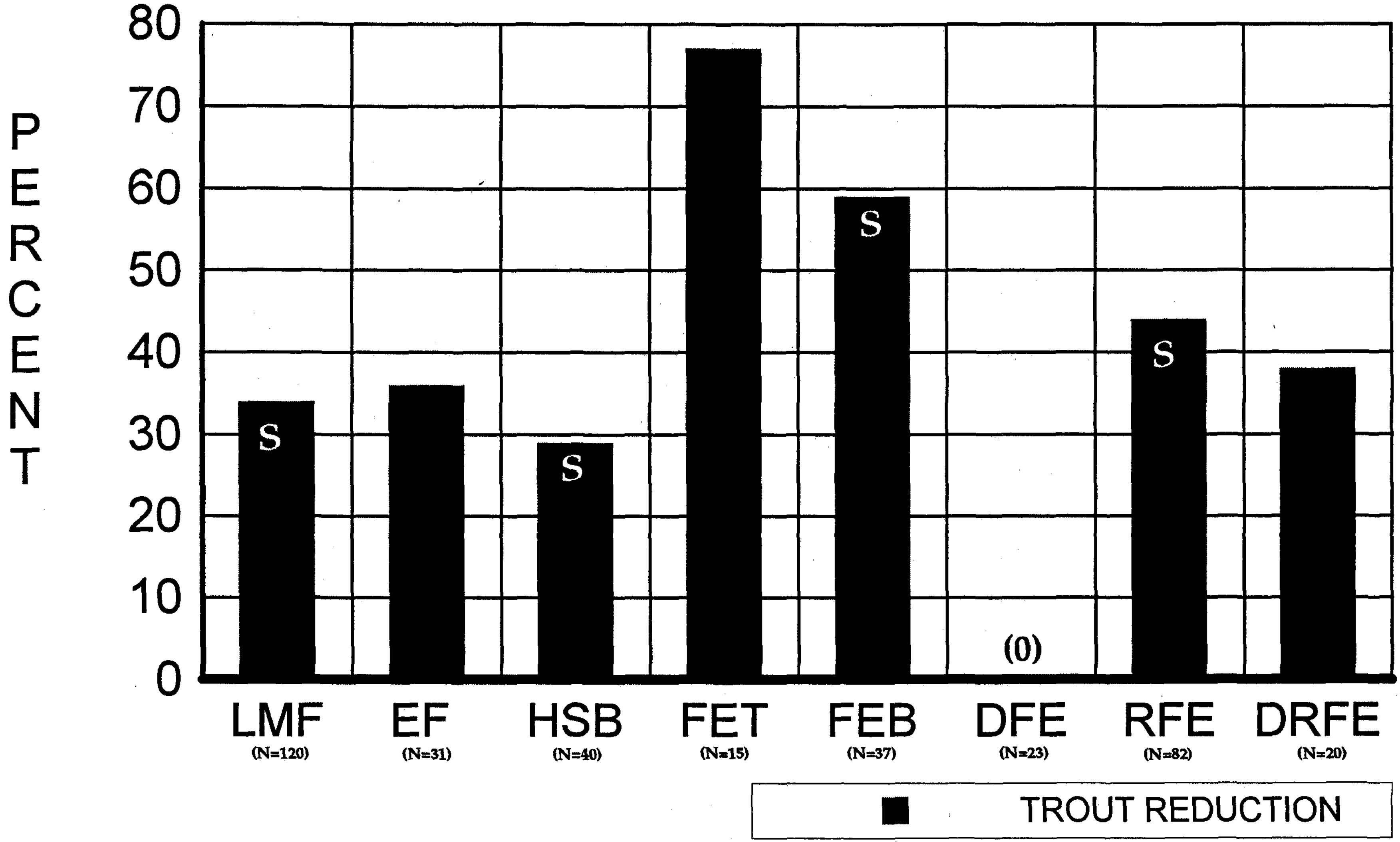



**Figure 9.** **Atlantic Bumper reduction rates for large mesh funnel excluder (LMF), extended funnel excluder (EF), HSB excluder (HSB), fisheye top position (FET), fisheye bottom position (FEB), double fisheye (DFE), reduced water flow fisheye (RFE), and double reduced water flow fisheye (DRFE).**




**S = Significant difference (P<0.05)*

**Figure 10. Trout reduction rates for large mesh funnel excluder (LMF), extended funnel excluder (EF), HSB excluder (HSB), fisheye top position (FET), fisheye bottom position (FEB), double fisheye (DFE), reduced water flow fisheye (RFE), and double reduced water flow fisheye (DRFE).**

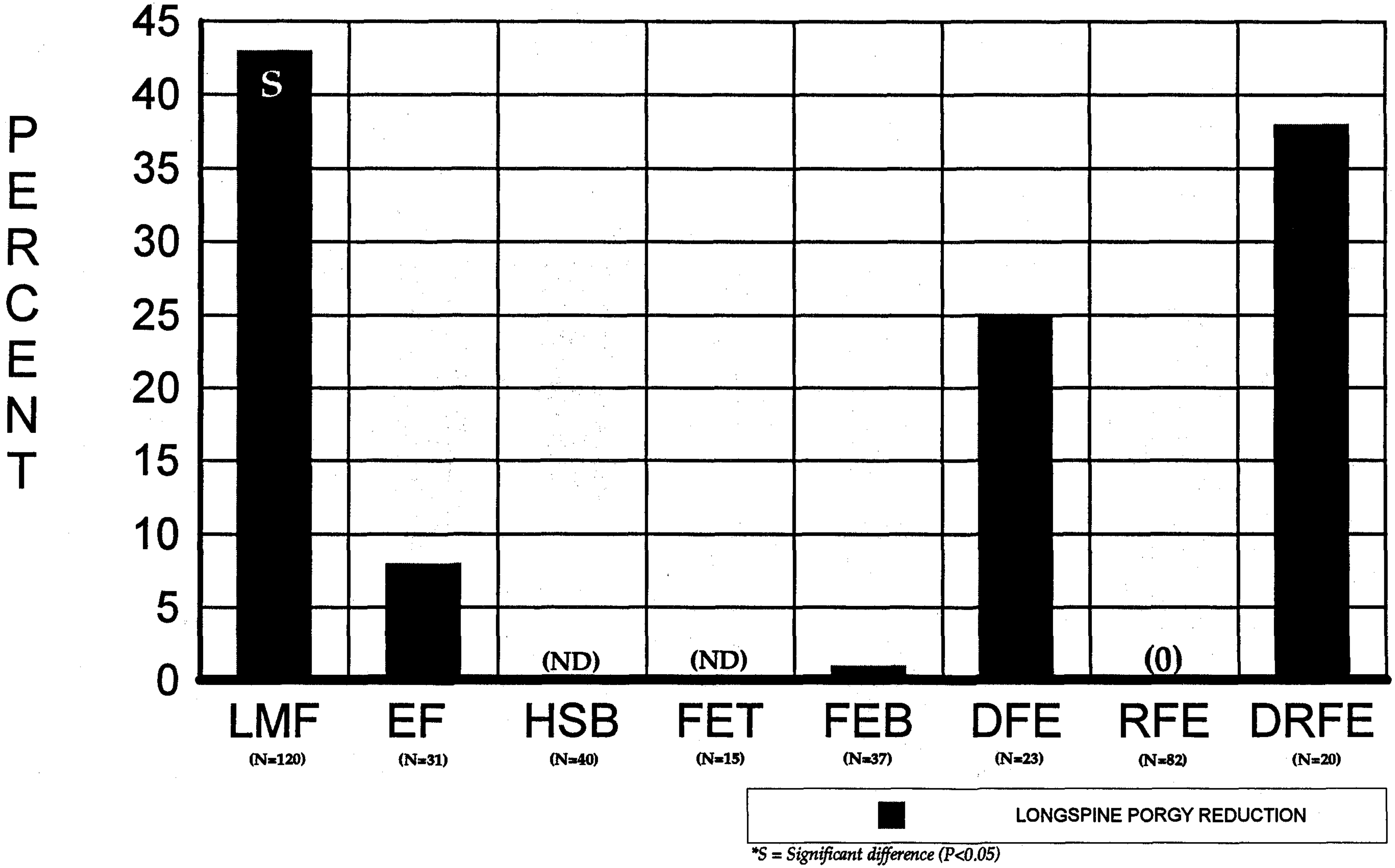



**Figure 11.** **Longspine Porgy reduction rates for large mesh funnel excluder (LMF), extended funnel excluder (EF), HSB excluder (HSB), fisheye top position (FET), fisheye bottom position (FEB), double fisheye (DFE), reduced water flow fisheye (RFE), and double reduced water flow fisheye (DRFE).**

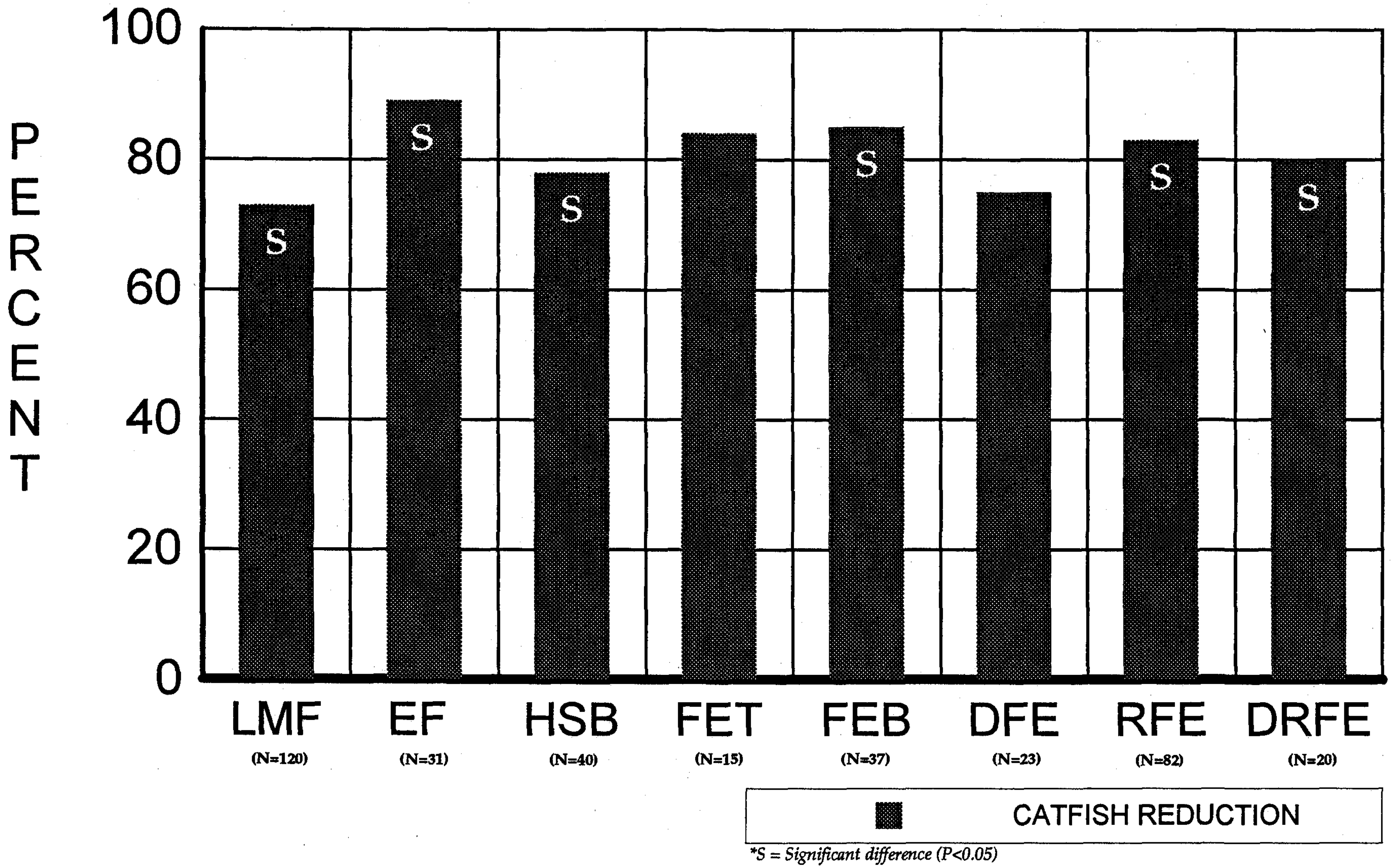
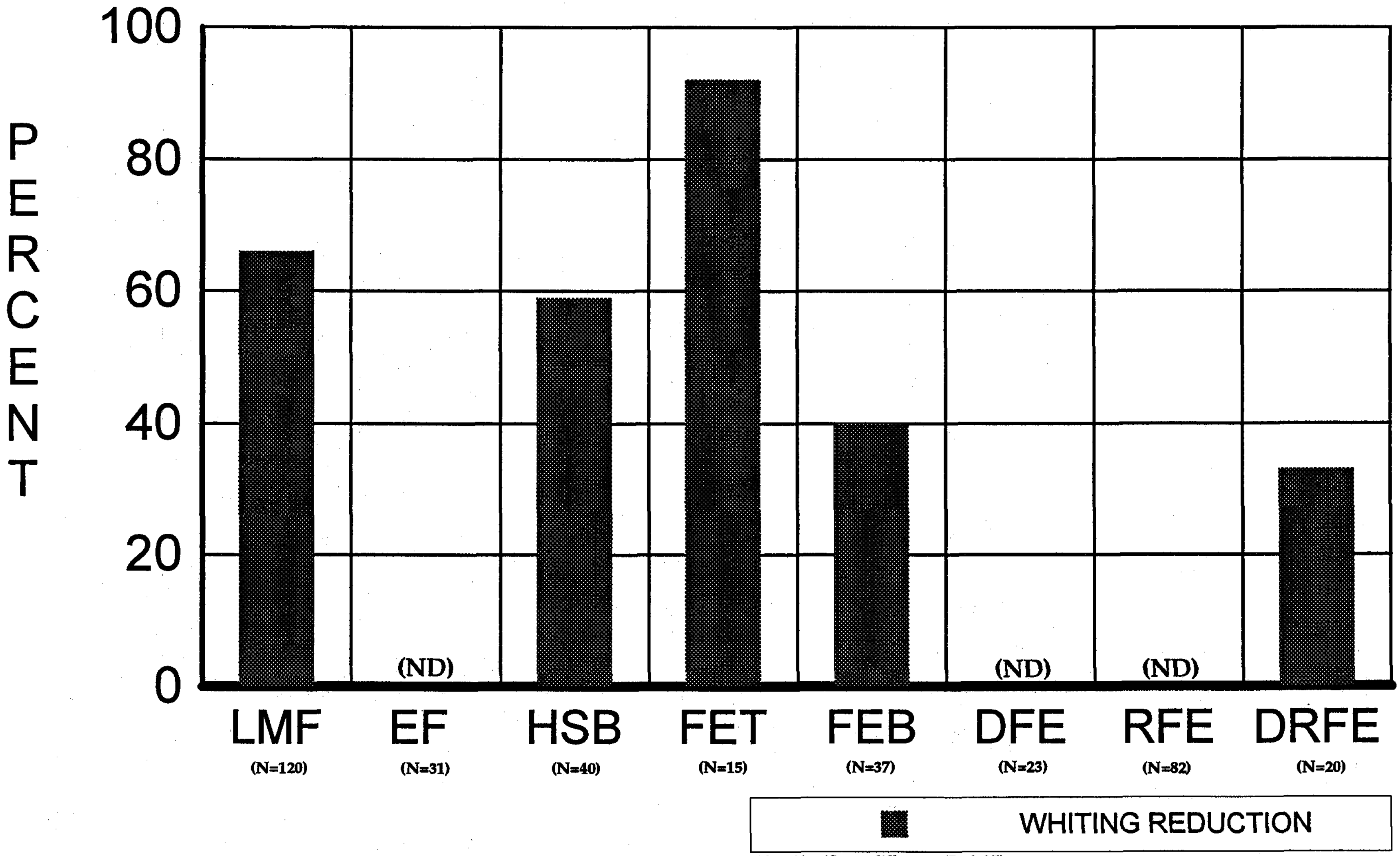



**Figure 12. Catfish reduction rates for large mesh funnel excluder (LMF), extended funnel excluder (EF), HSB excluder (HSB), fisheye top position (FET), fisheye bottom position (FEB), double fisheye (DFE), reduced water flow fisheye (RFE), and double reduced water flow fisheye (DRFE).**




**S = Significant difference (P<0.05)*

**Figure 13.** **Whiting reduction rates for large mesh funnel excluder (LMF), extended funnel excluder (EF), HSB excluder (HSB), fisheye top position (FET), fisheye bottom position (FEB), double fisheye (DFE), reduced water flow fisheye (RFE), and double reduced water flow fisheye (DRFE).**

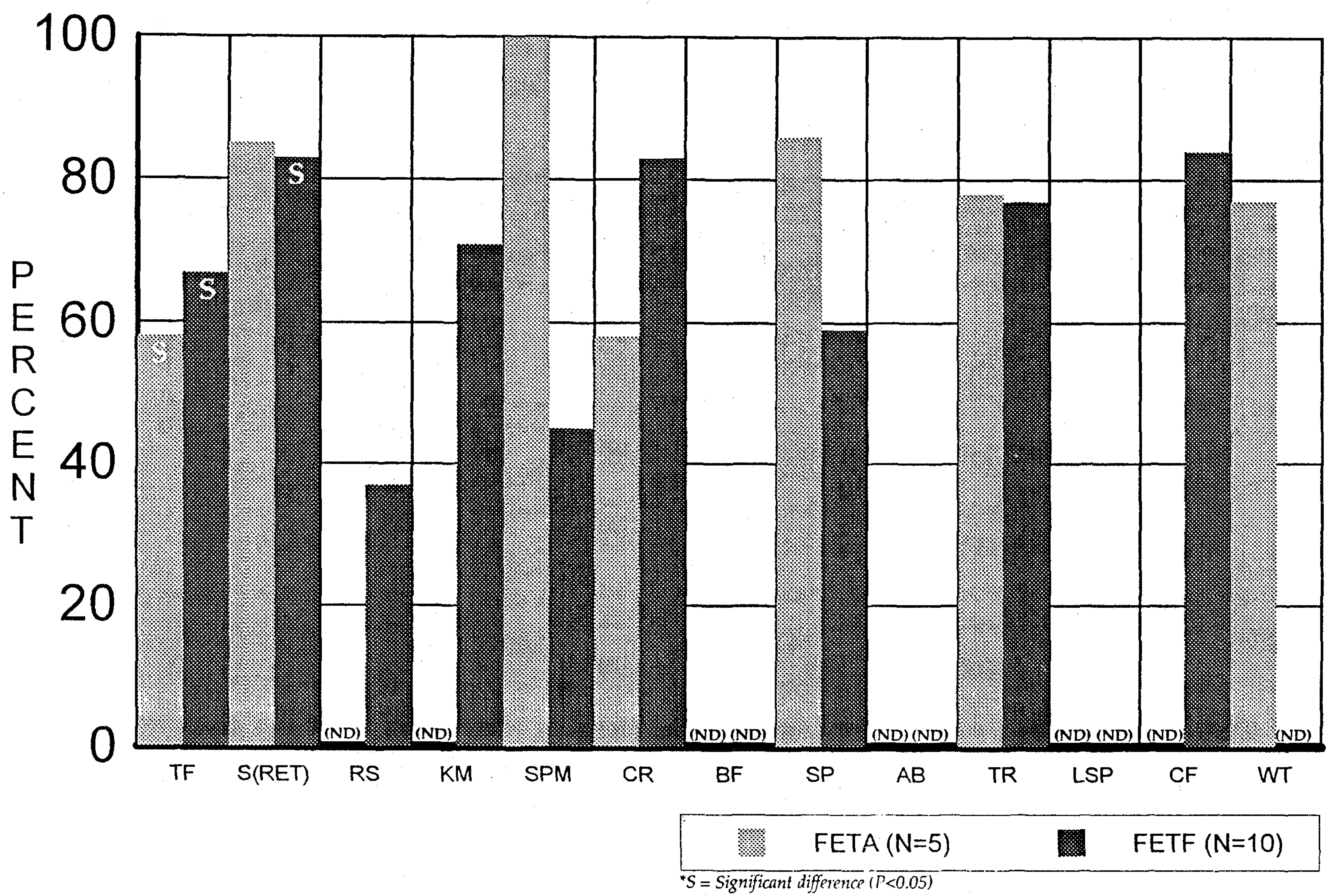



**Figure 14.** **Fish reduction and shrimp retention rates for fisheye top position facing aft (FETA) and fisheye top position facing forward (FETF).**

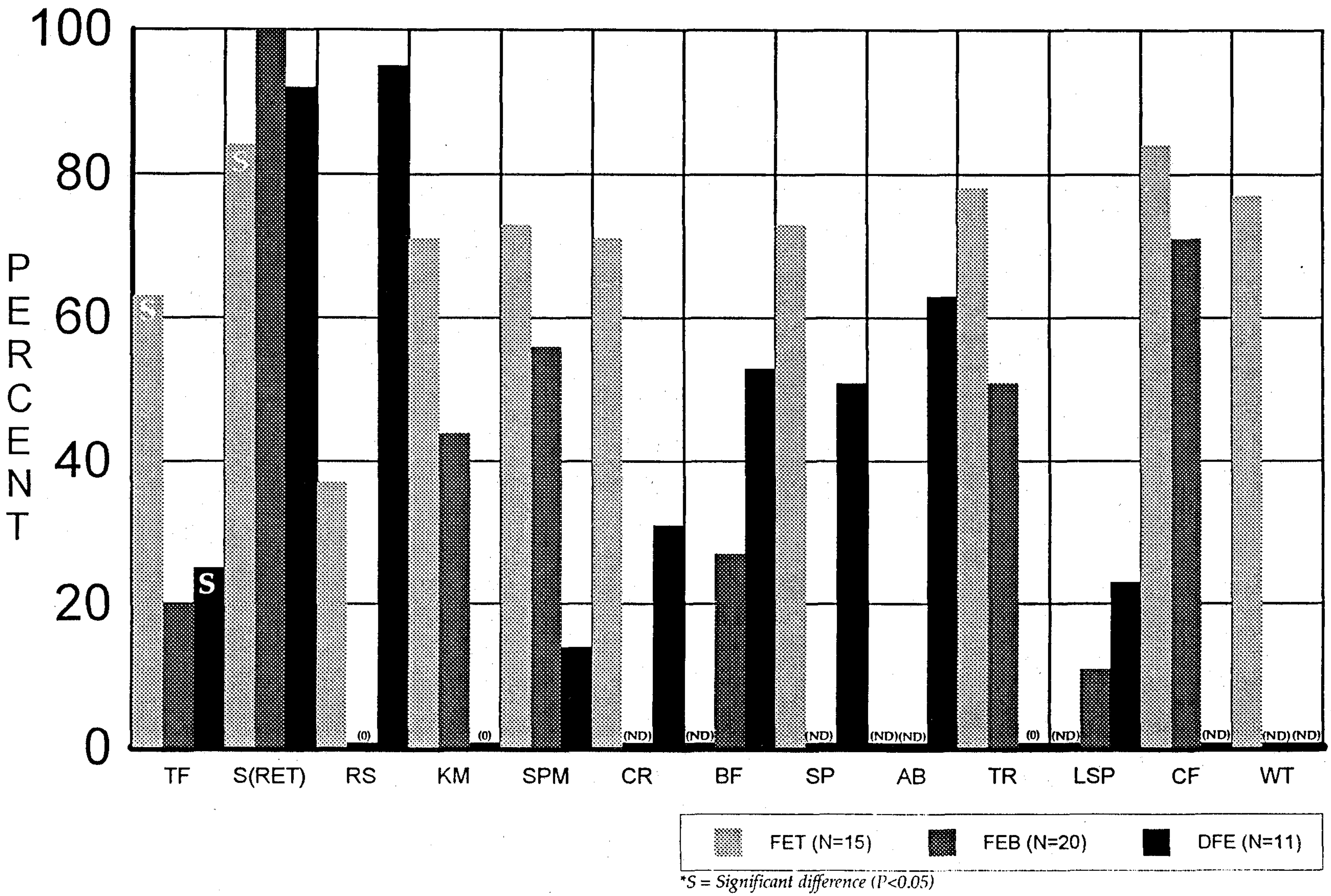



Figure 15. Fish reduction and shrimp retention rates for fisheye top position facing aft (FET), fisheye bottom position (FEB), and double fisheye (DFE).

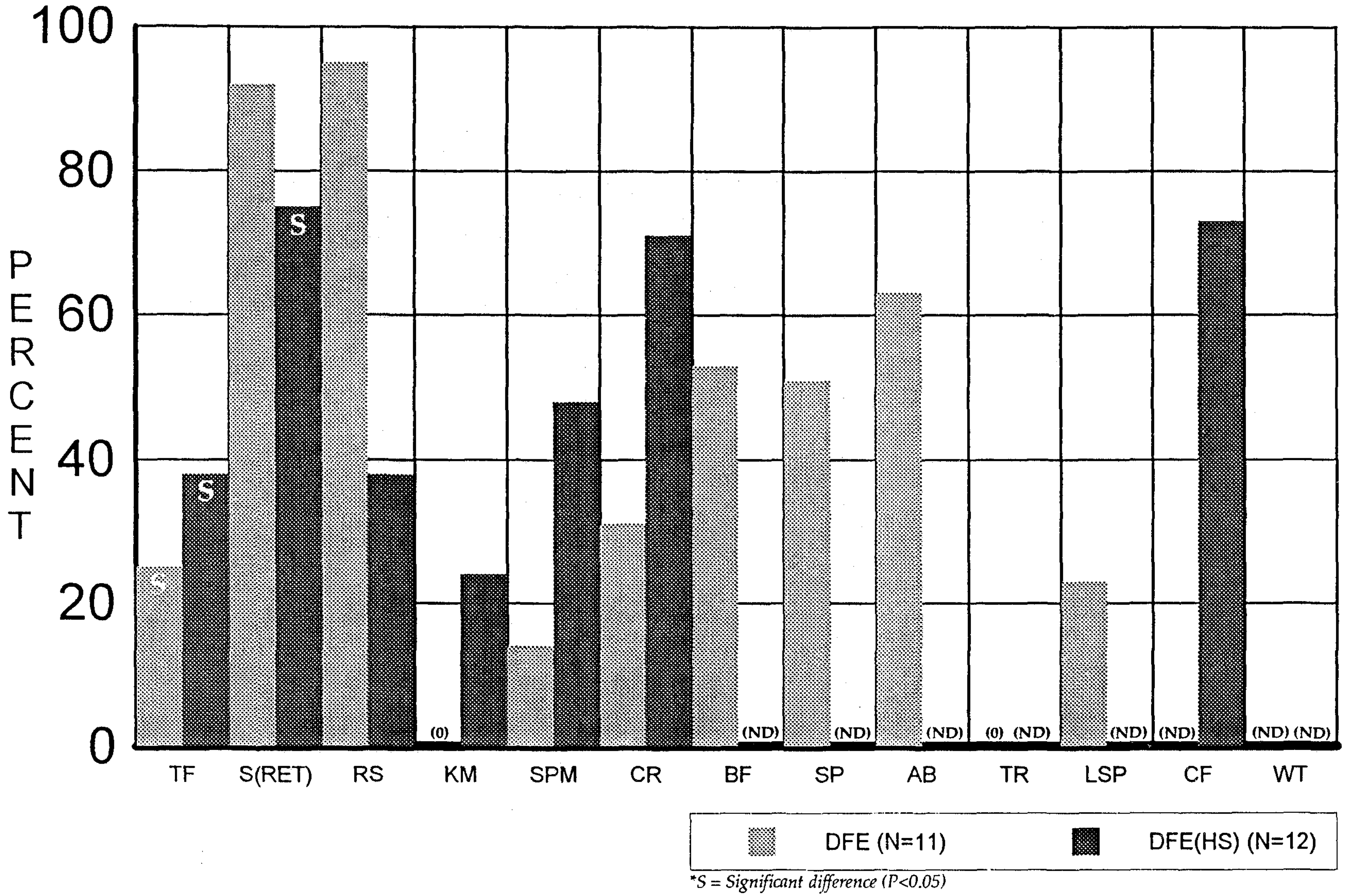



**Figure 16.** **Fish reduction and shrimp retention rates for double fisheye excluder (DFE) and double fisheye excluder with hummer stimulator (DFE(HS)).**

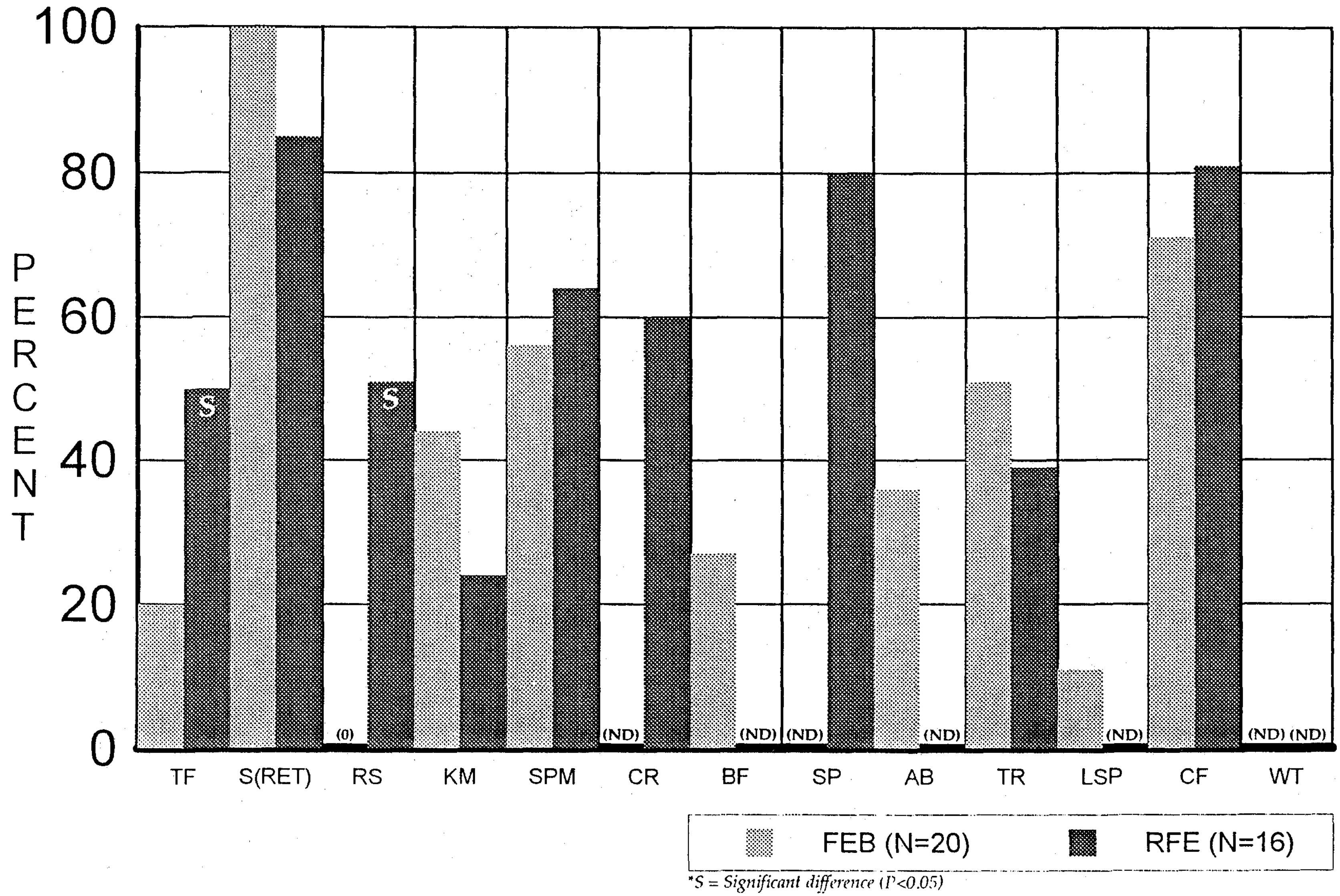



**Figure 17. Fish reduction and shrimp retention rates for fisheye bottom position (FEB) and reduced water flow fisheye (RFE).**

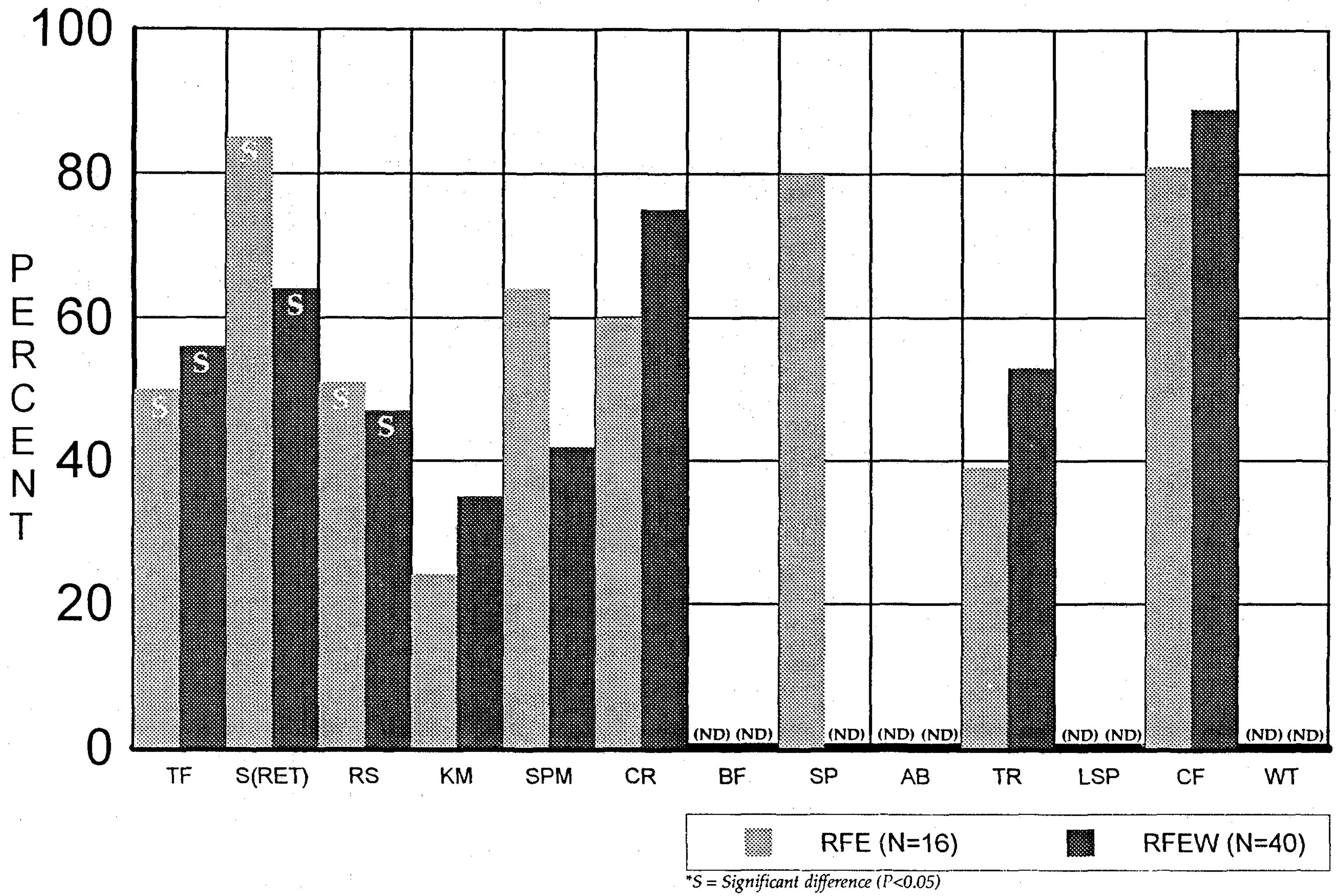



**Figure 18.** **Fish reduction and shrimp retention rates for reduced water flow fisheye (RFE) and reduced water flow fisheye with webbing lead panel (RFEW).**

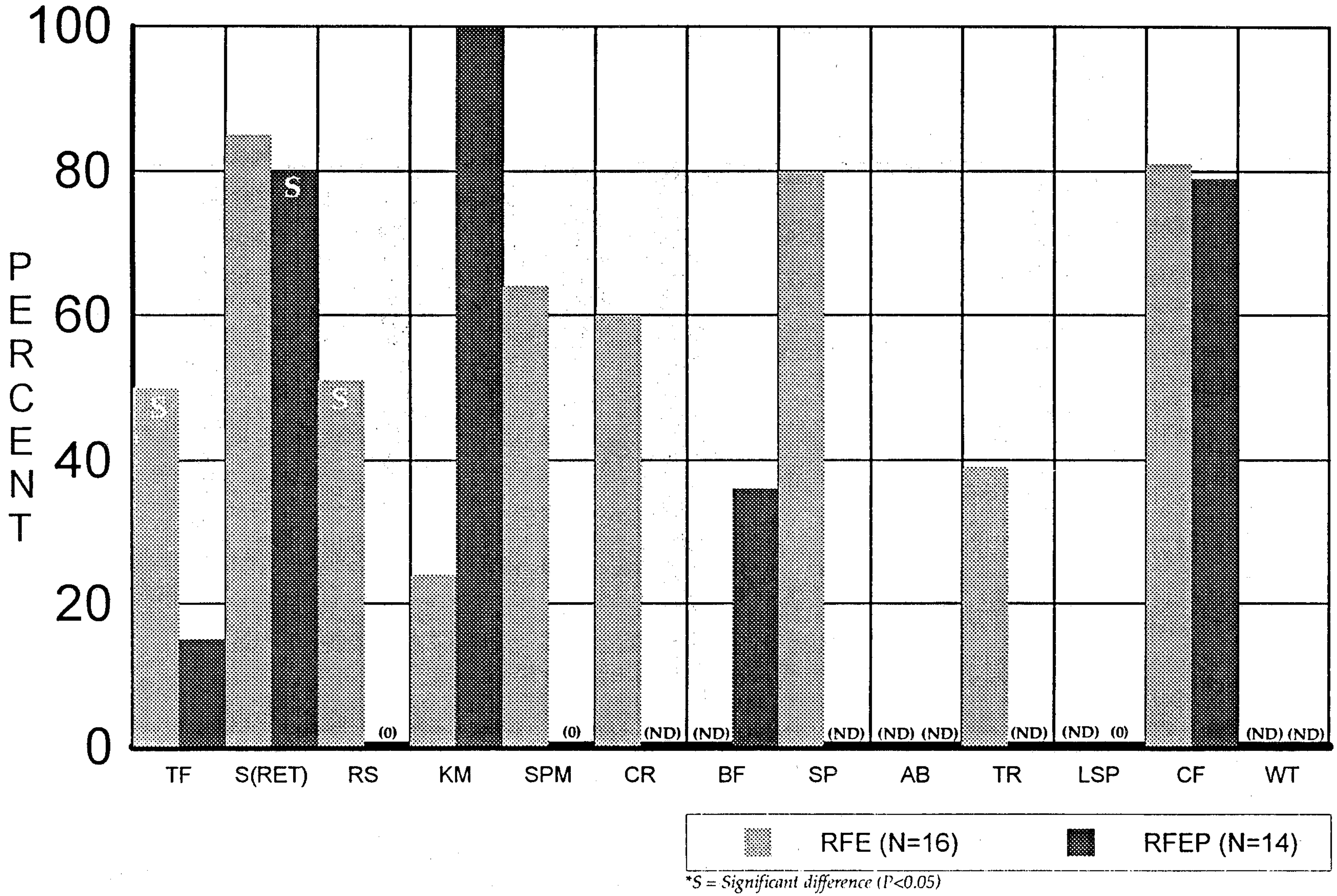



**Figure 19. Fish reduction and shrimp retention rates for reduced water flow fisheye (RFE) and reduced water flow fisheye with plastic panel (RFEP).**

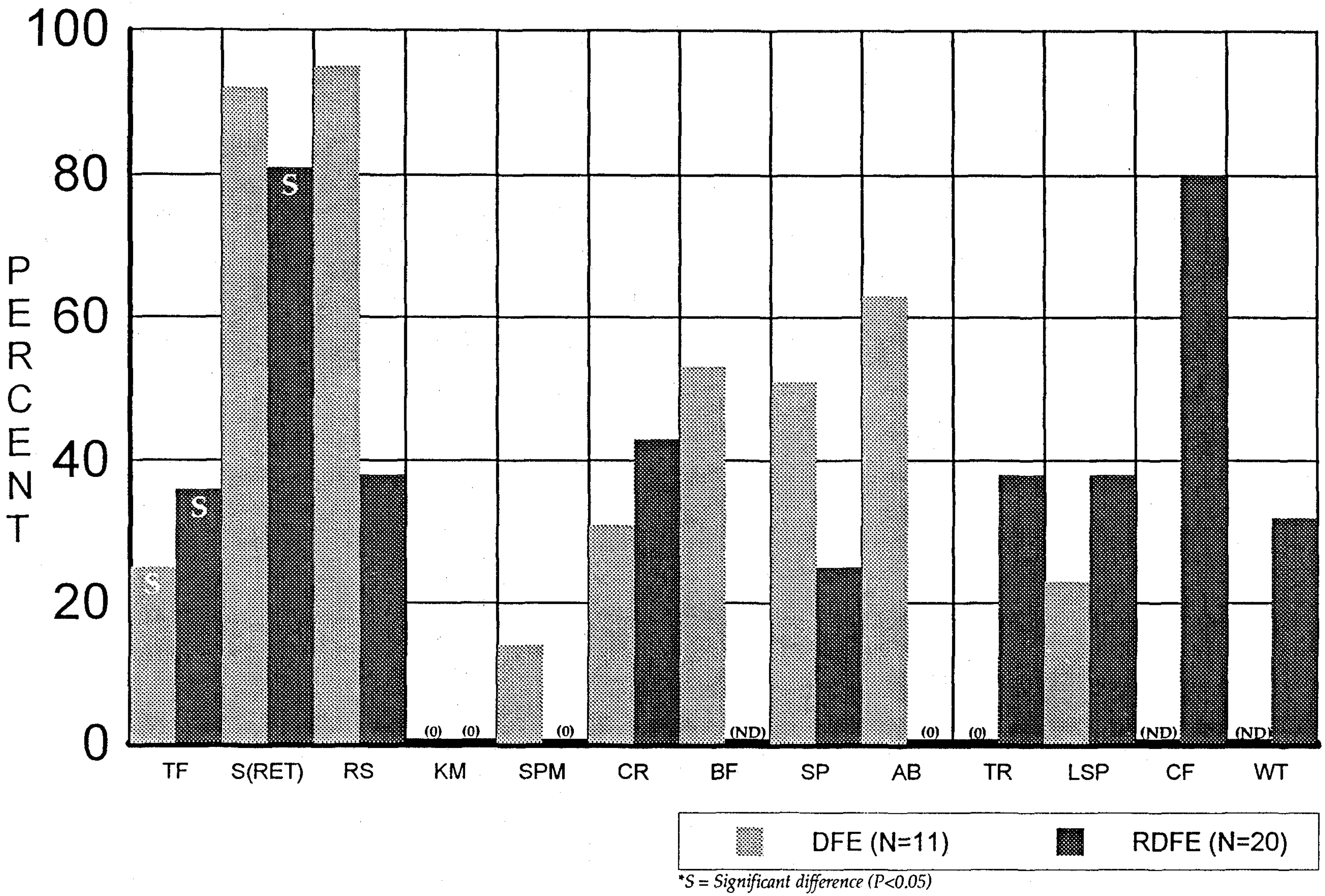



**Figure 20.** **Fish reduction and shrimp retention rates for double fisheye excluder (DFE) and double reduced water flow fisheye excluder (DRFE).**

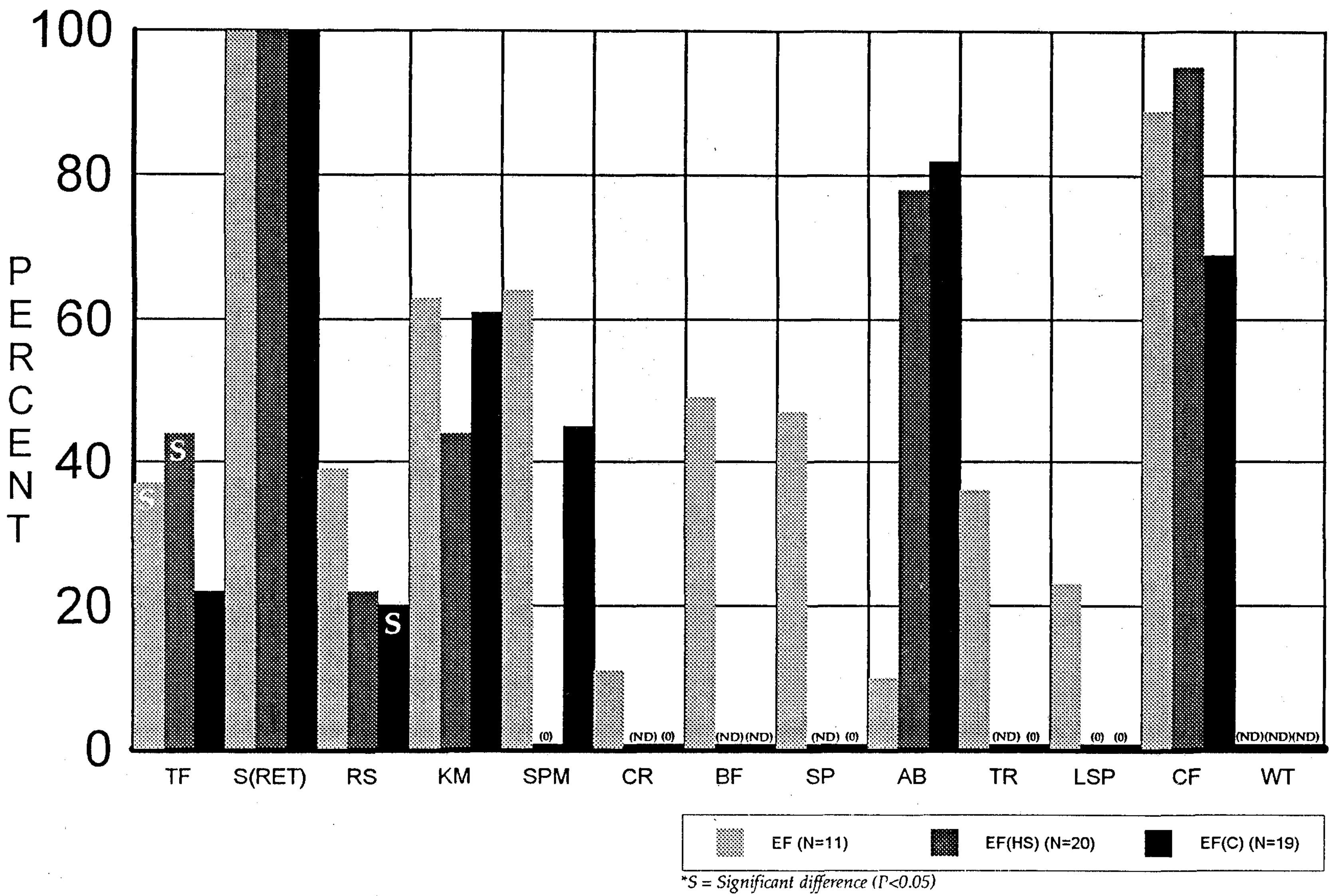



**Figure 21. Fish reduction and shrimp retention rates for extended funnel excluder (EF), extended funnel excluder with hummer stimulator (EF(HS), and extended funnel excluder with chain stimulator (EF(C).**

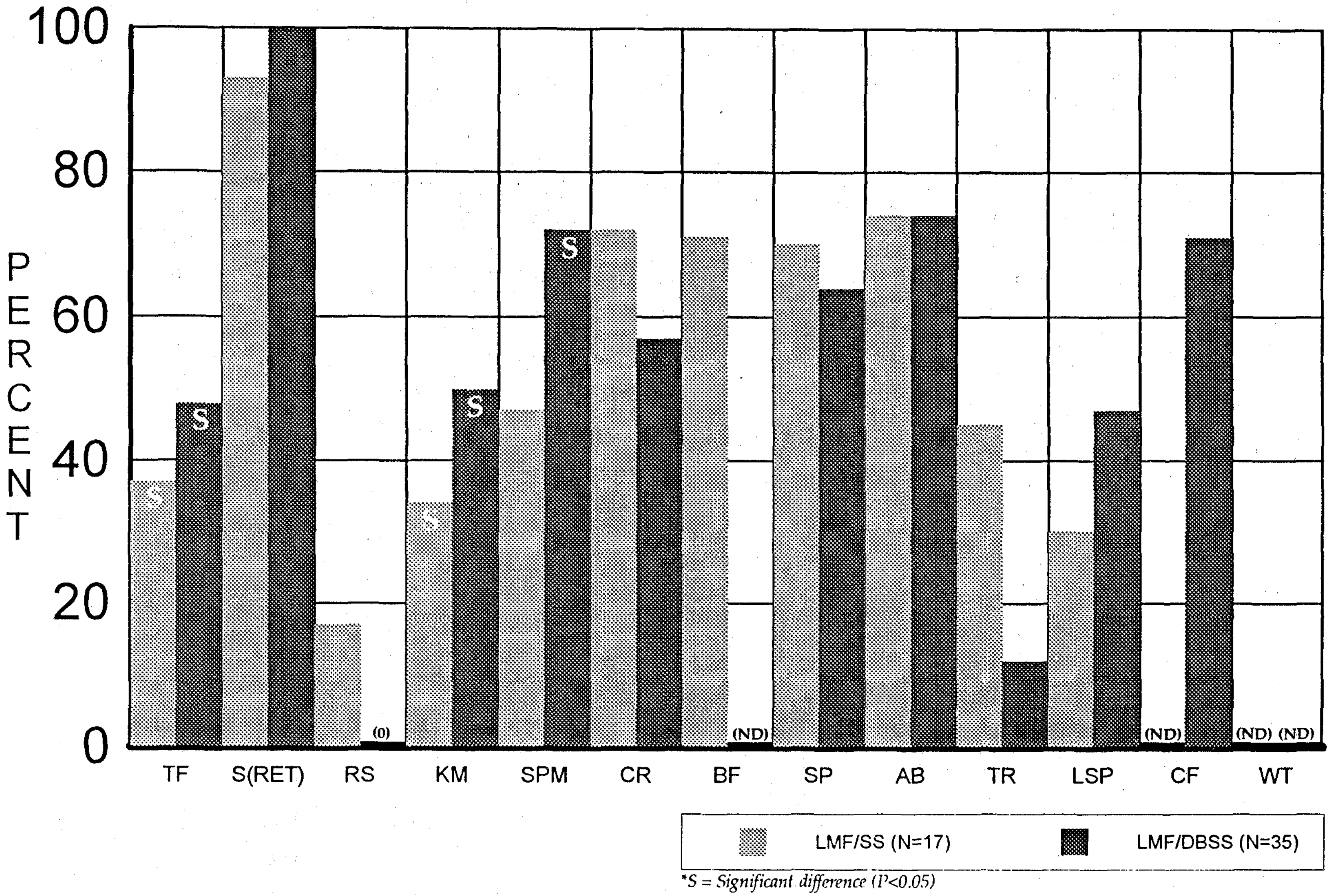



Figure 22. **Fish reduction and shrimp retention rates for large mesh funnel excluder with standard Super Shooter TED (LMF/SS) and large mesh funnel excluder with double bar Super Shooter TED (LMF/DBSS).**

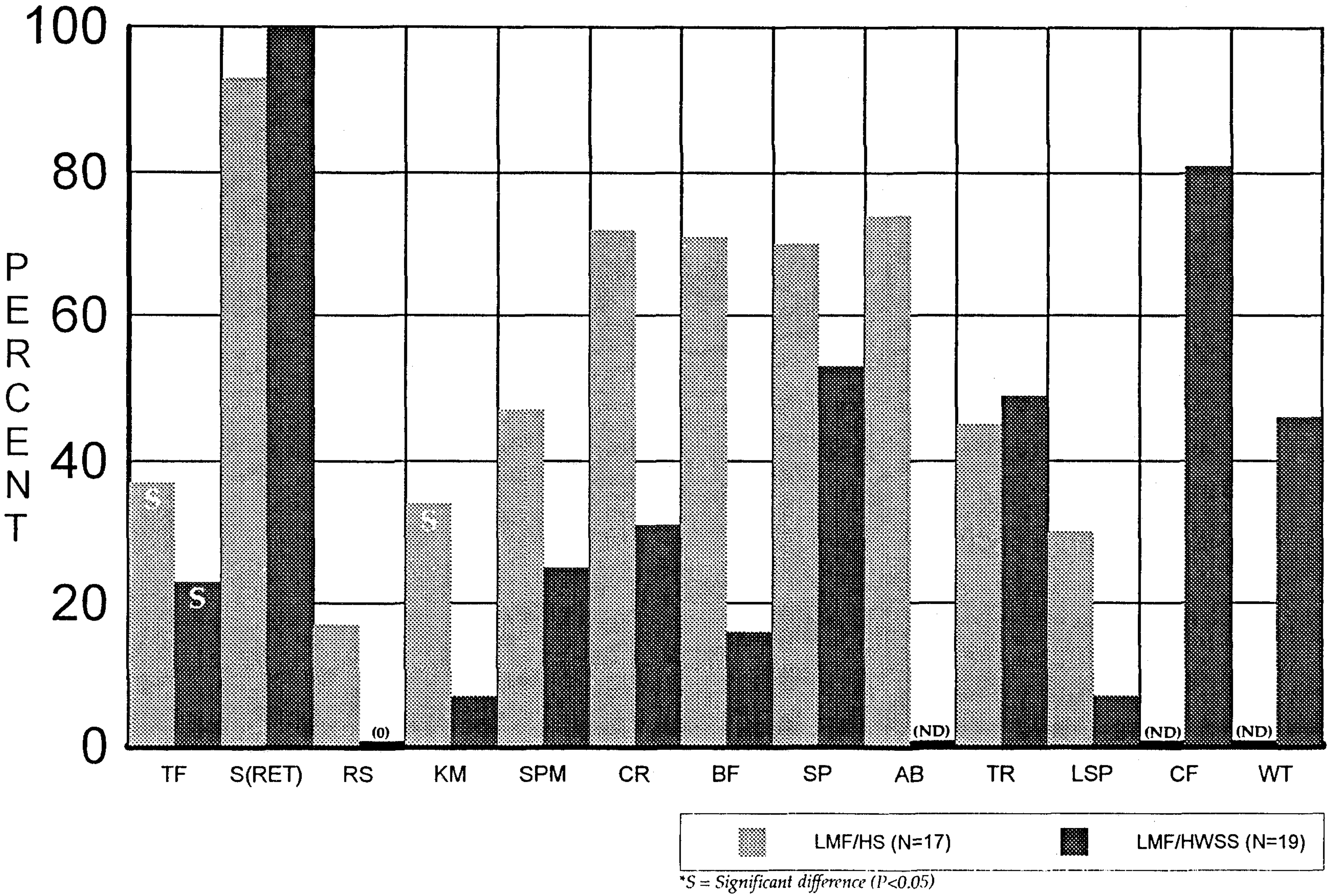



Figure 23. Fish reduction and shrimp retention rates for large mesh funnel excluder with hummer stimulator (LMF/HS) and large mesh funnel excluder with hummer wire Super Shooter TED (LMF/HWSS).

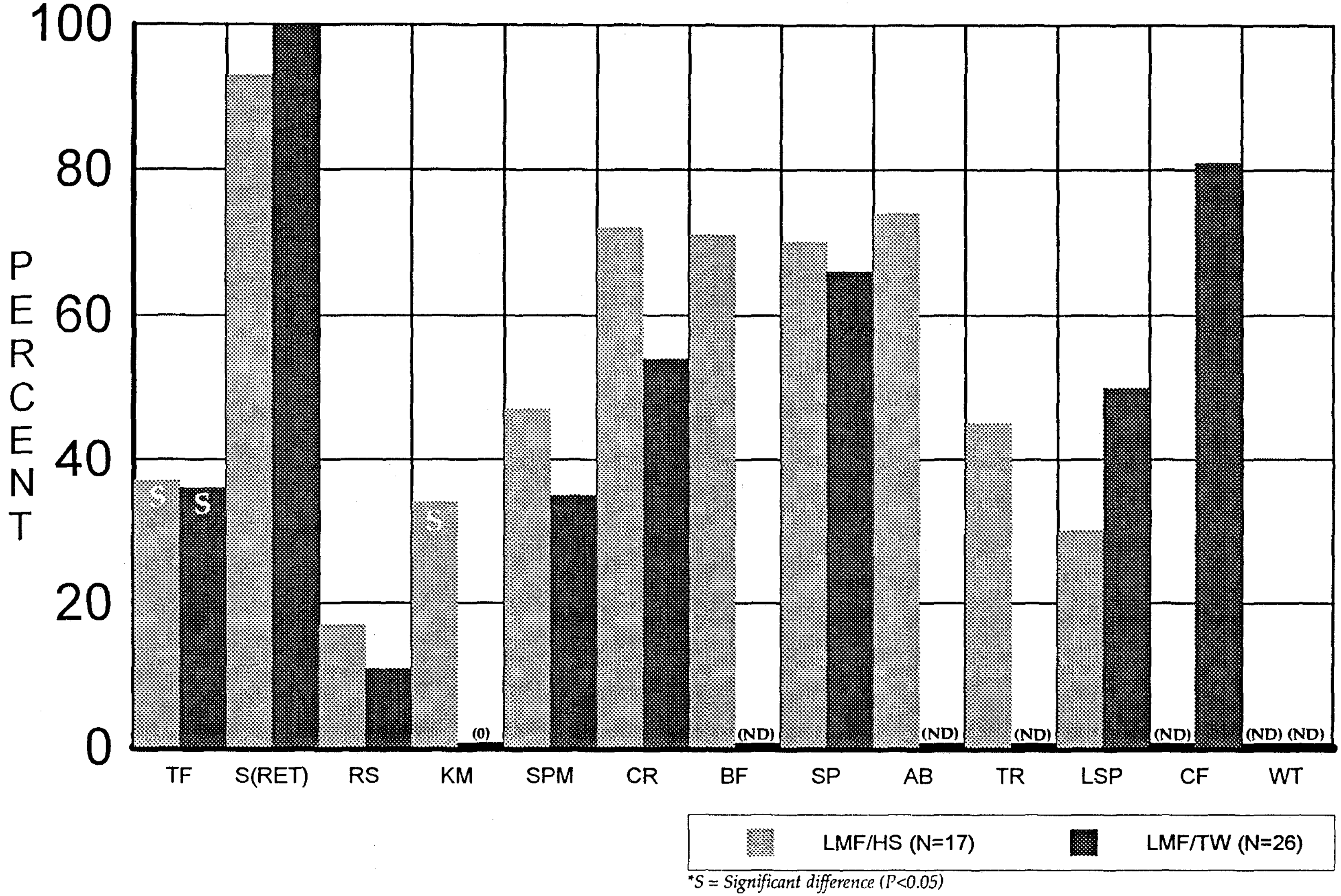



**Figure 24.** **Fish reduction and shrimp retention rates for large mesh funnel excluder with hummer stimulator (LMF/HS) and large mesh funnel excluder with Ty-wrap stimulator (LMF/TW).**

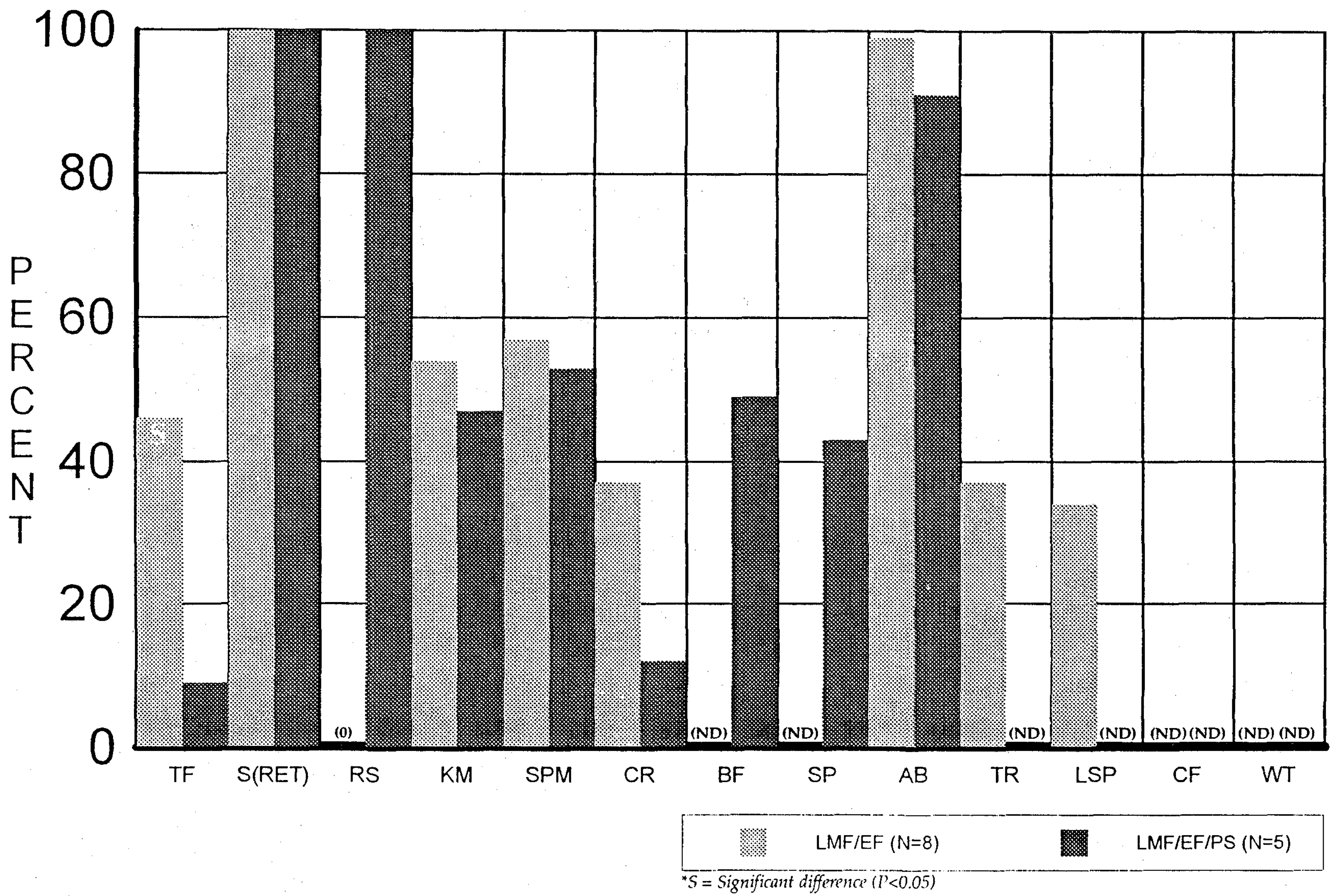



Figure 25. **Fish reduction and shrimp retention rates for large mesh funnel excluder, extended funnel combination (LMF/EF), and large mesh funnel, double fisheye combination (LMF/DFE).**

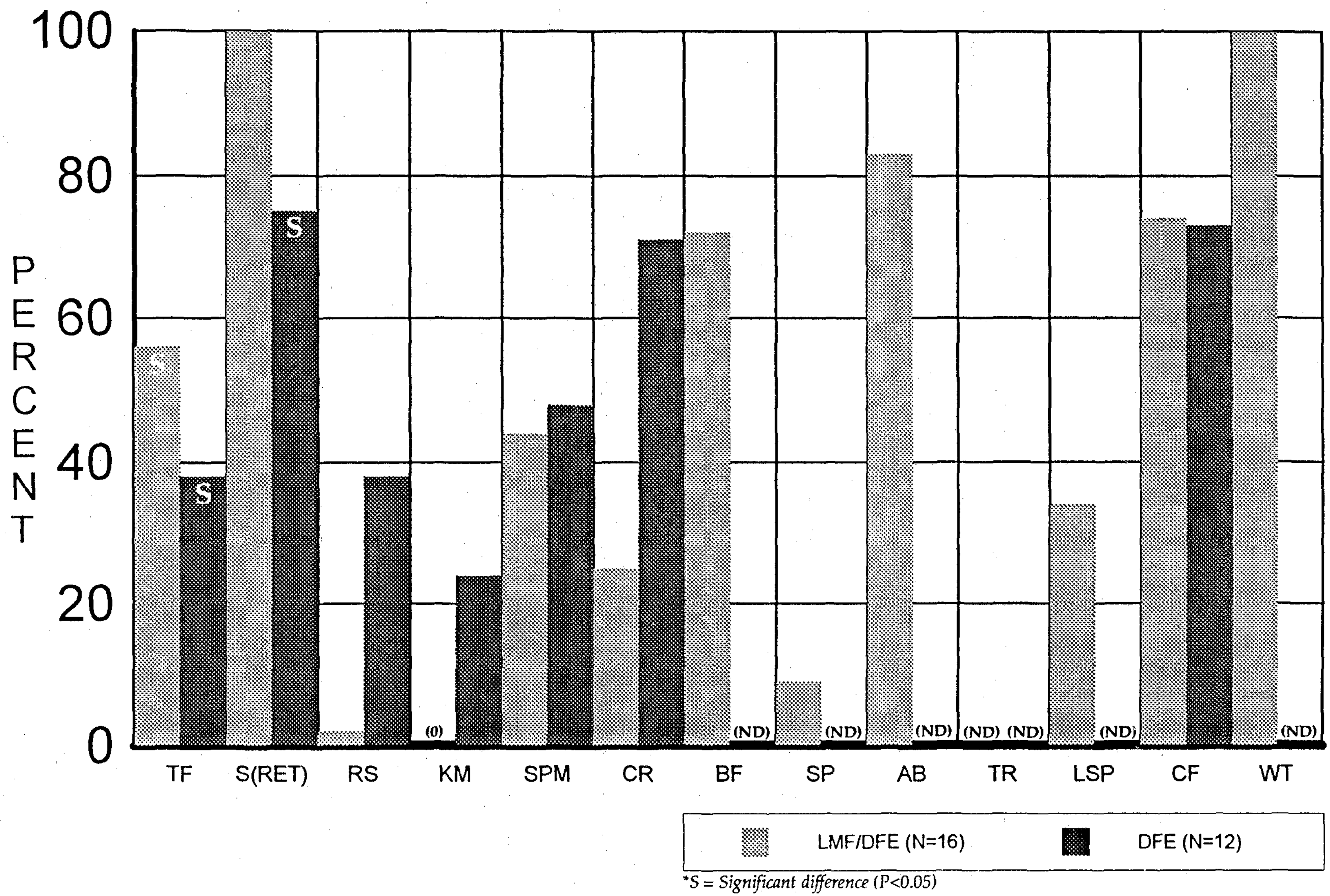



**Figure 26. Fish reduction and shrimp retention rates for large mesh funnel excluder and double fisheye excluder combination (LMF/DFE) and double fisheye excluder (DFE).**

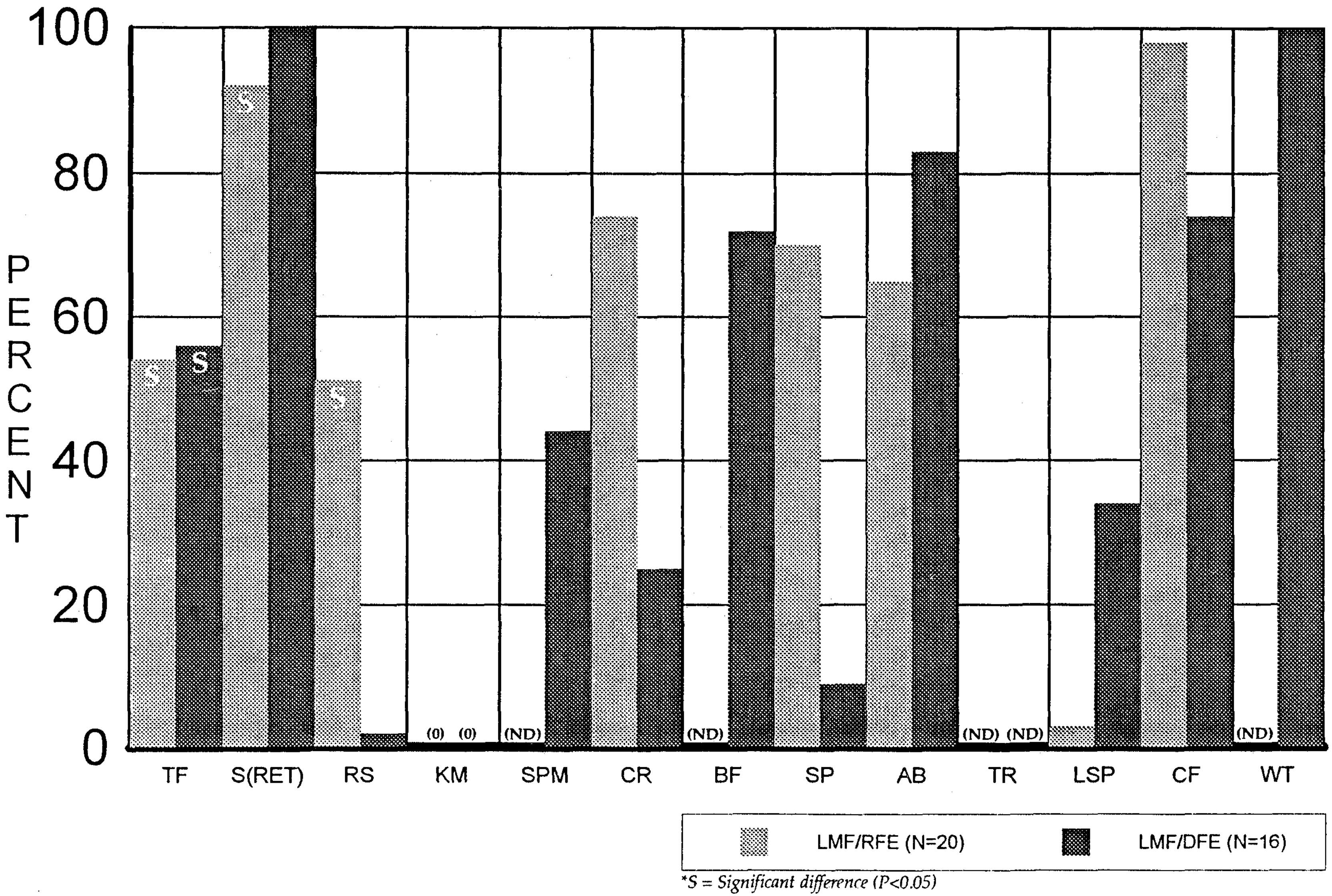
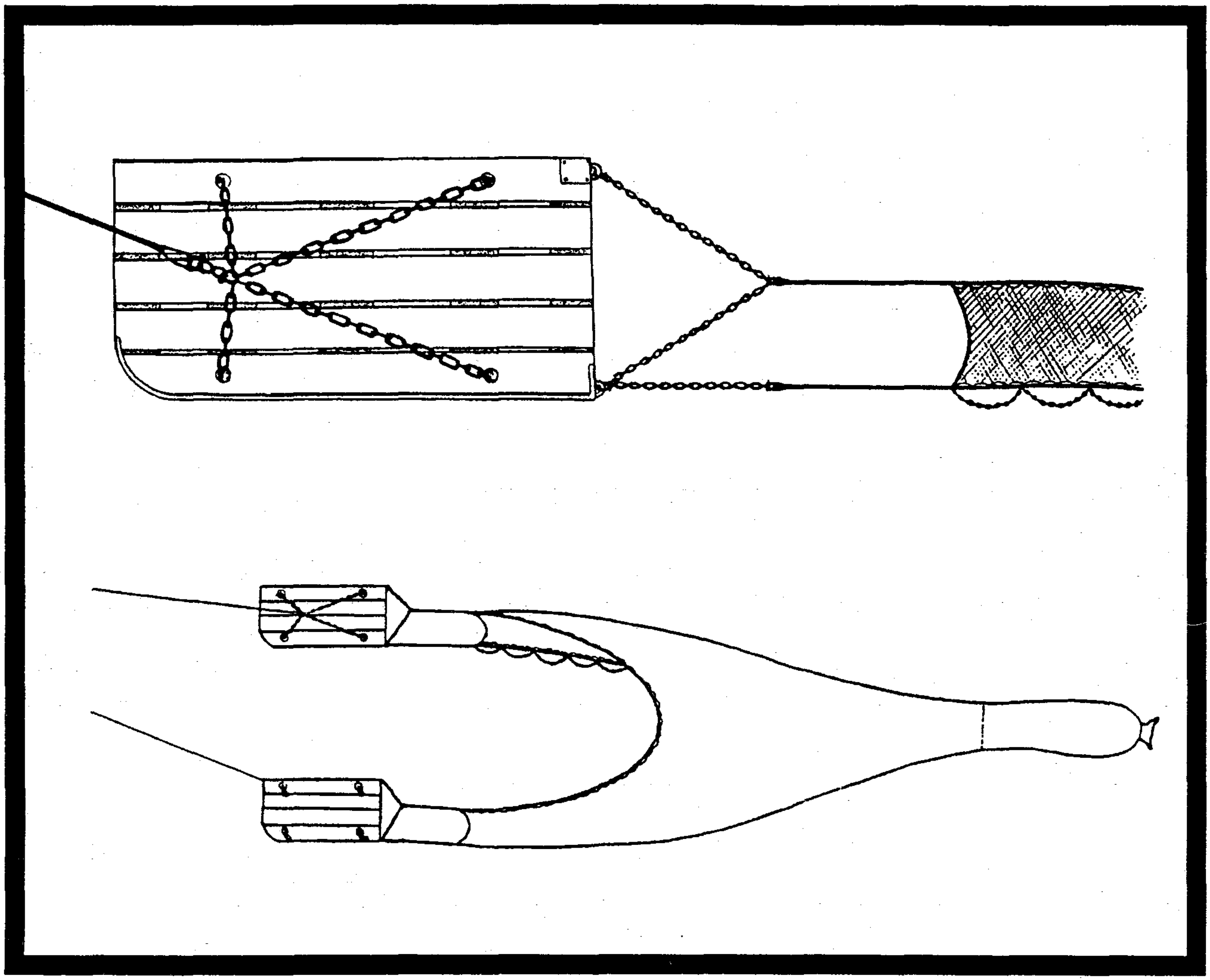



Figure 27. **Fish reduction and shrimp retention rates for large mesh funnel excluder, reduced water flow fisheye combination (LMF/RFE) and large mesh funnel excluder, double fisheye combination (LMF/DFE).**

# APPENDIX I

# BRD DIAGRAMS, DESCRIPTIONS, AND DIVER EVALUATIONS

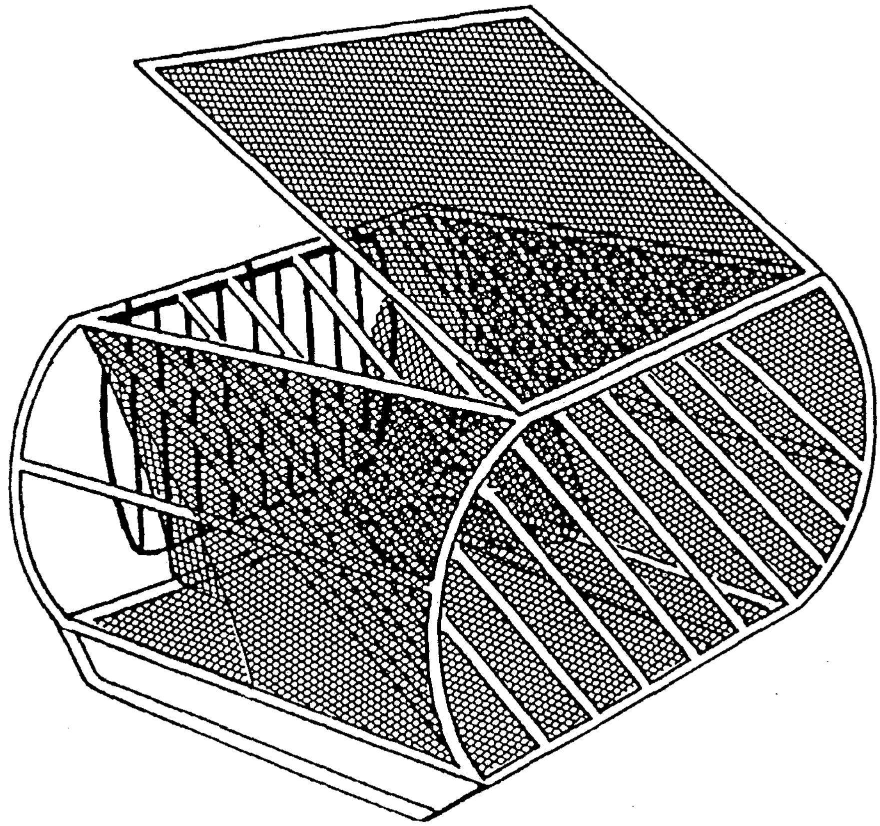
# LOW PROFILE TRAWL



- o This is a shallow wing semiballoon trawl design rigged to fish beneath schools of fish.
- o Diver evaluations determined that the trawl design and rigging was operationally feasible, but was restrictive in adjusting trawl dimensions for optimum shrimp production. As a result, the design would have only limited application.

Appendix I, Figure 1

# NMFS TED

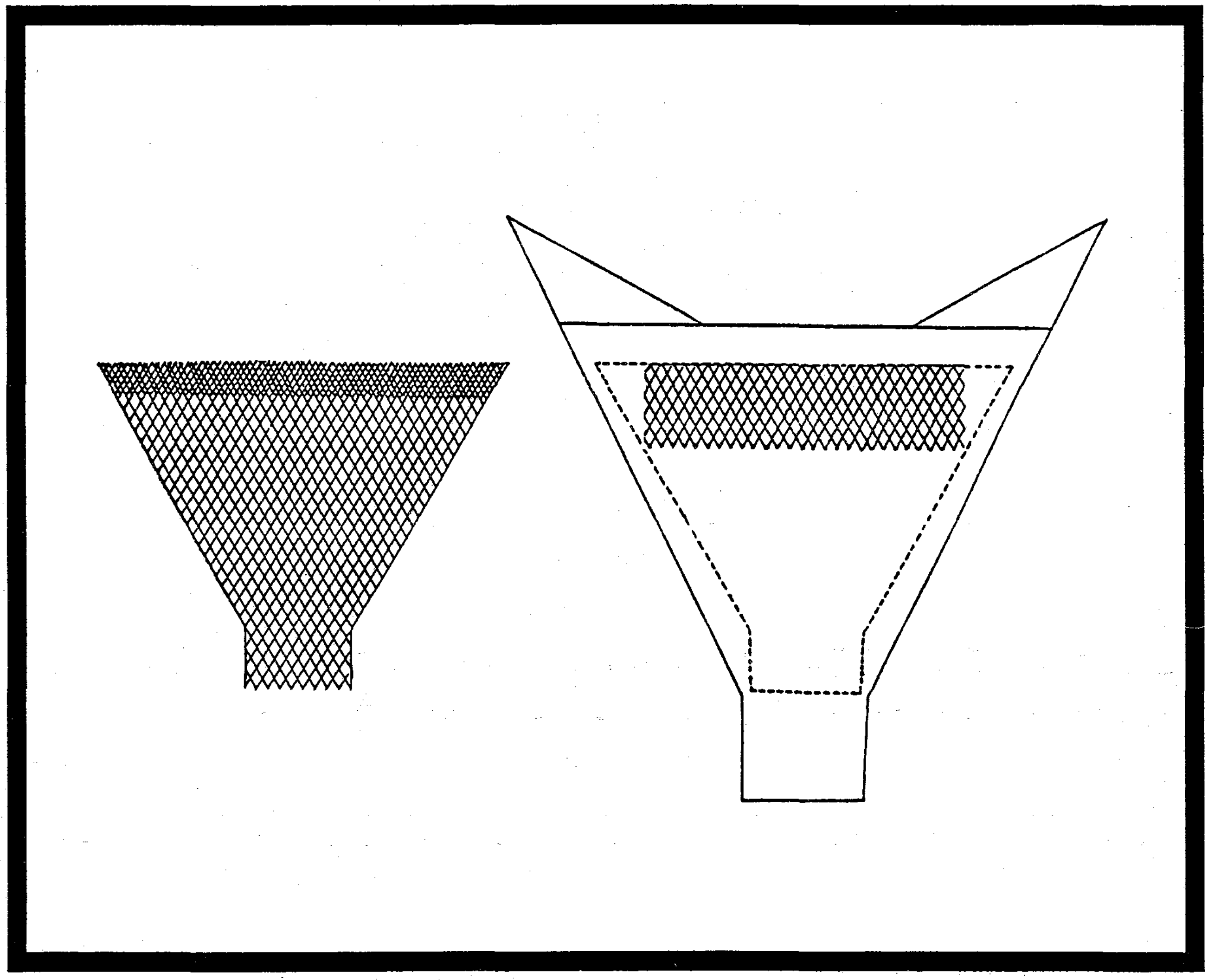


- The original TED design developed in 1980 was modified in 1982 to include lead panels and fish escape openings on the sides of the TED.

- The NMFS TED performed well but has limitations which include size, weight, and complexity. It is only effective in a top opening configuration which limits its use under some shrimping conditions.

Appendix I, Figure 2

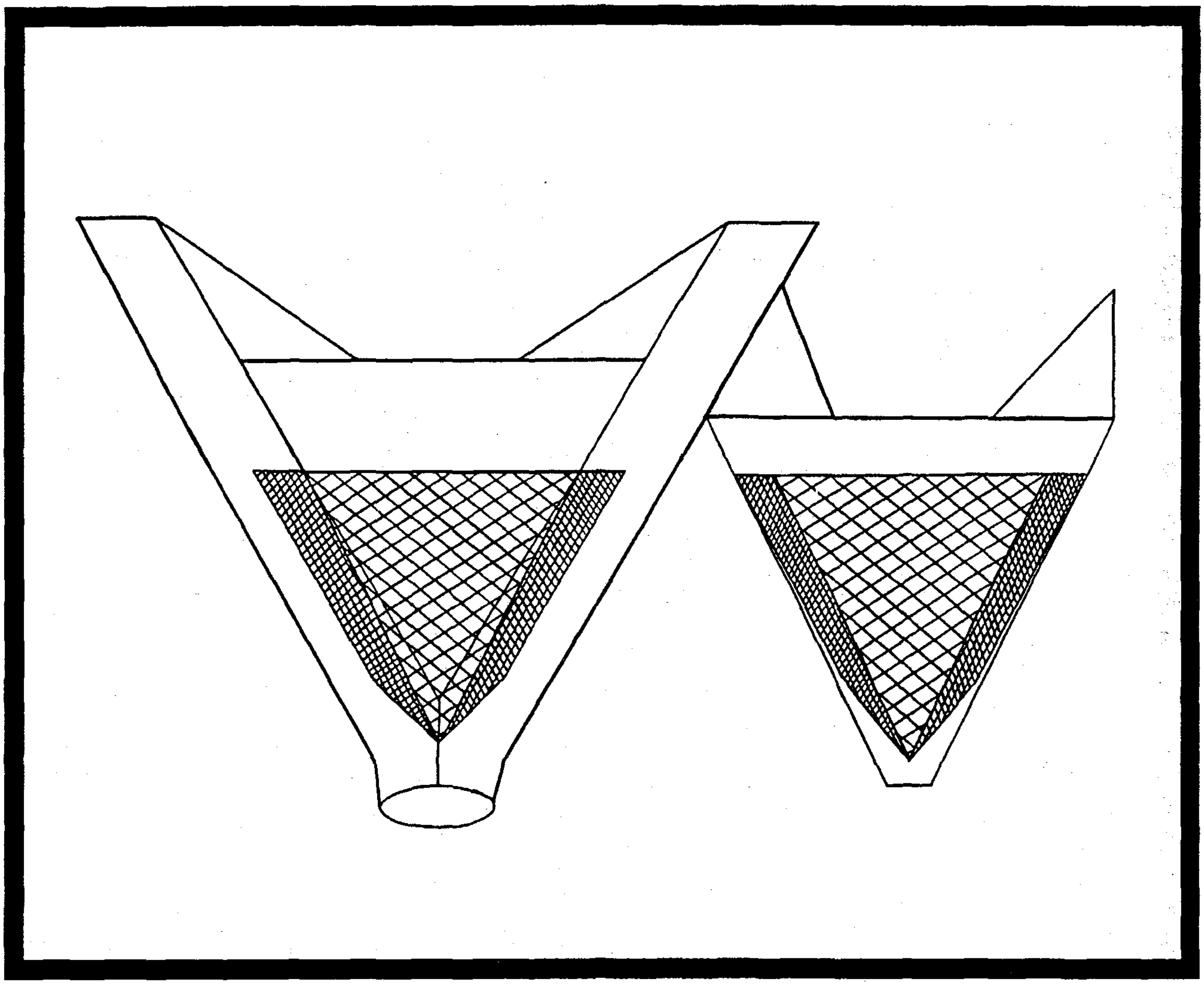
# MODIFIED MORRISON TED



- A standard Morrison Soft TED was modified in an attempt to increase fish exclusion. This was done by replacing the leading edge of the excluder panel with small mesh webbing and installing an 8 inch panel in the bottom of the trawl below the small mesh section.
- Diver evaluation of the design indicated there was little clearance between the small mesh section of the TED and the bottom of the trawl. This would make fish escapement difficult.

Appendix I, Figure 3

# MODIFIED ANDREWS TED

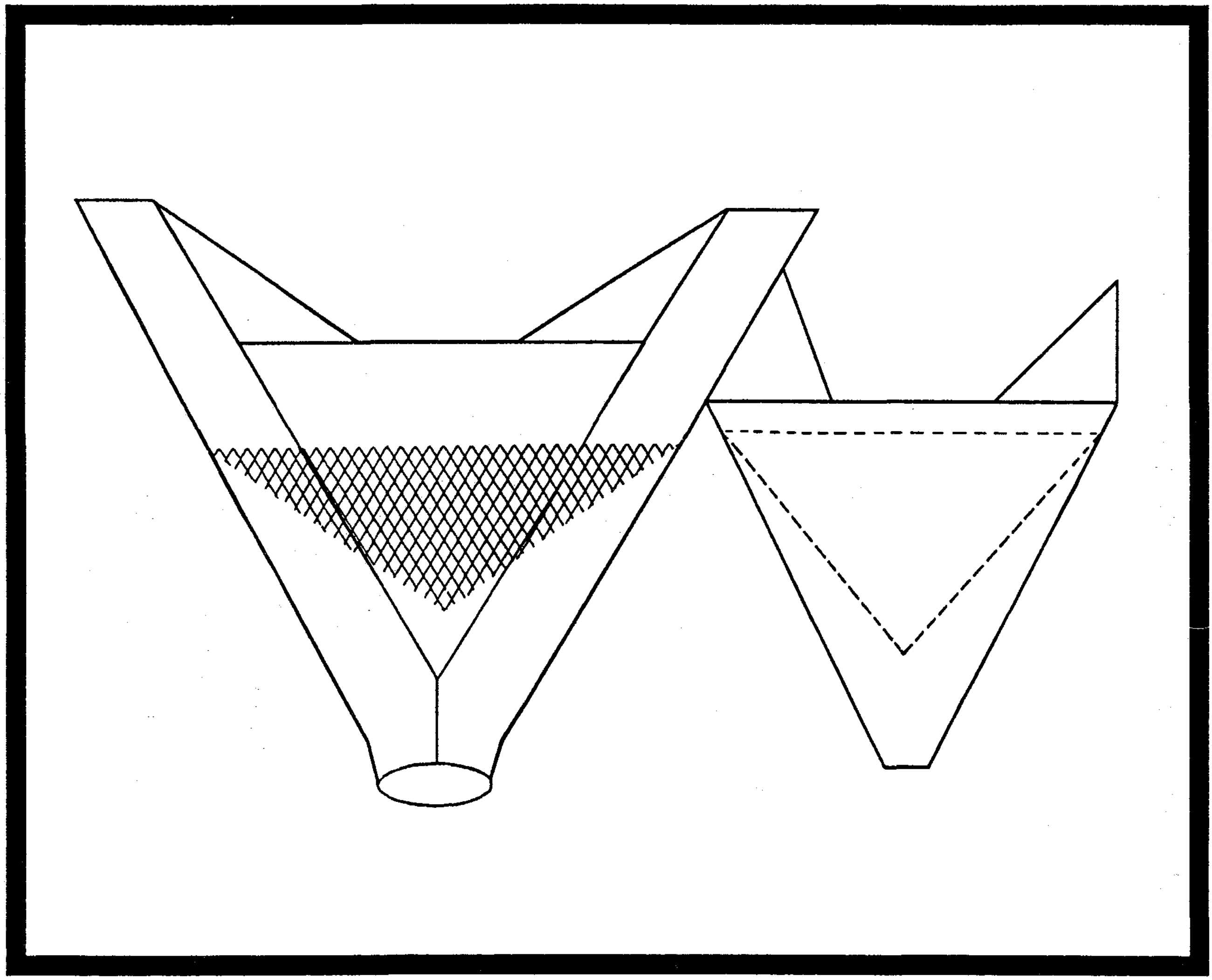


- This design consists of a four panel Andrews Soft TED design. The top and bottom panels are constructed of 8 inch webbing. The side panels are 5 inch webbing.

- Diver evaluations indicated that the webbing panel had a good configuration The panel was tight, and the meshes were opening square. The 5 inch side panels covered the curve in the sides, leaving the top and bottom panels relatively flat and parallel.

Appendix I, Figure 4

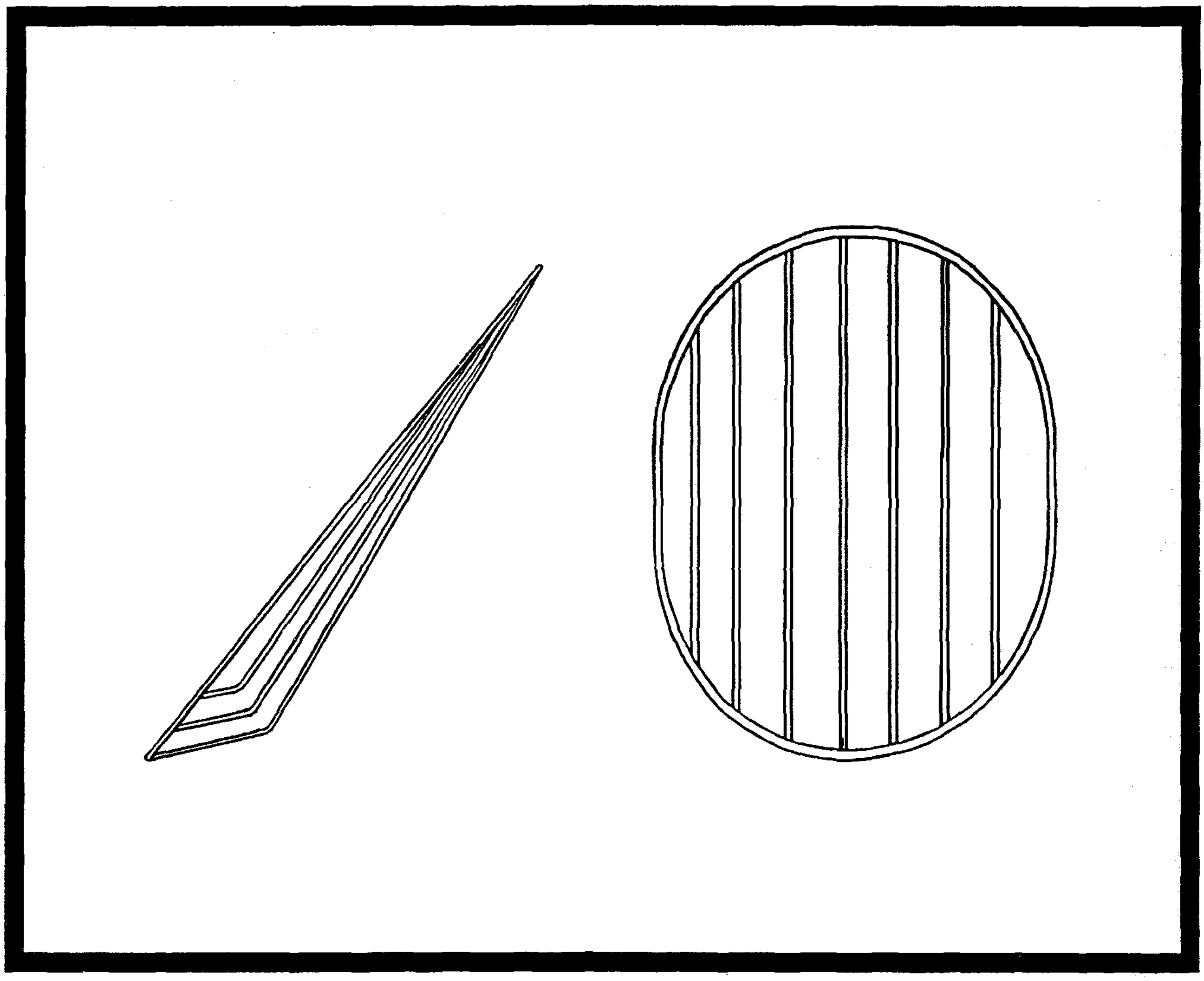
# GOLDEN TED



o The Golden TED is a soft TED design constructed of 6 inch mesh polyethylene webbing. This TED has not been approved for use under the endangered species regulations , but was tested for its finfish reduction potential under a research permit.

Appendix I, Figure 5

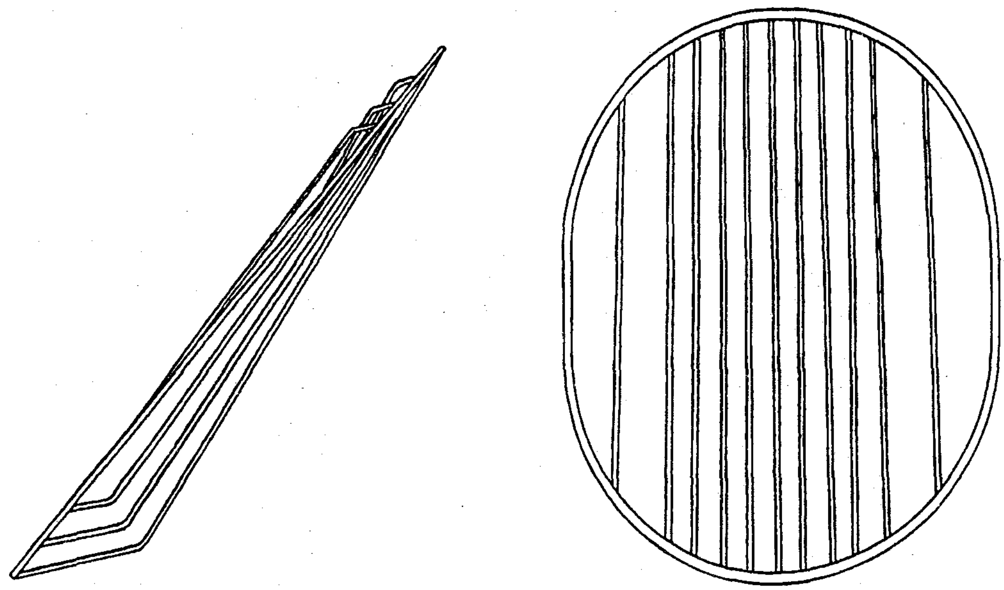
# SUPER SHOOTER TED



- The Super Shooter is a grid type TED that consists of several bars set at 45 degree angles to direct turtles toward an escape opening.

- This was the standard TED used for evaluating the BRD designs that were not incorporated into other TEDs.

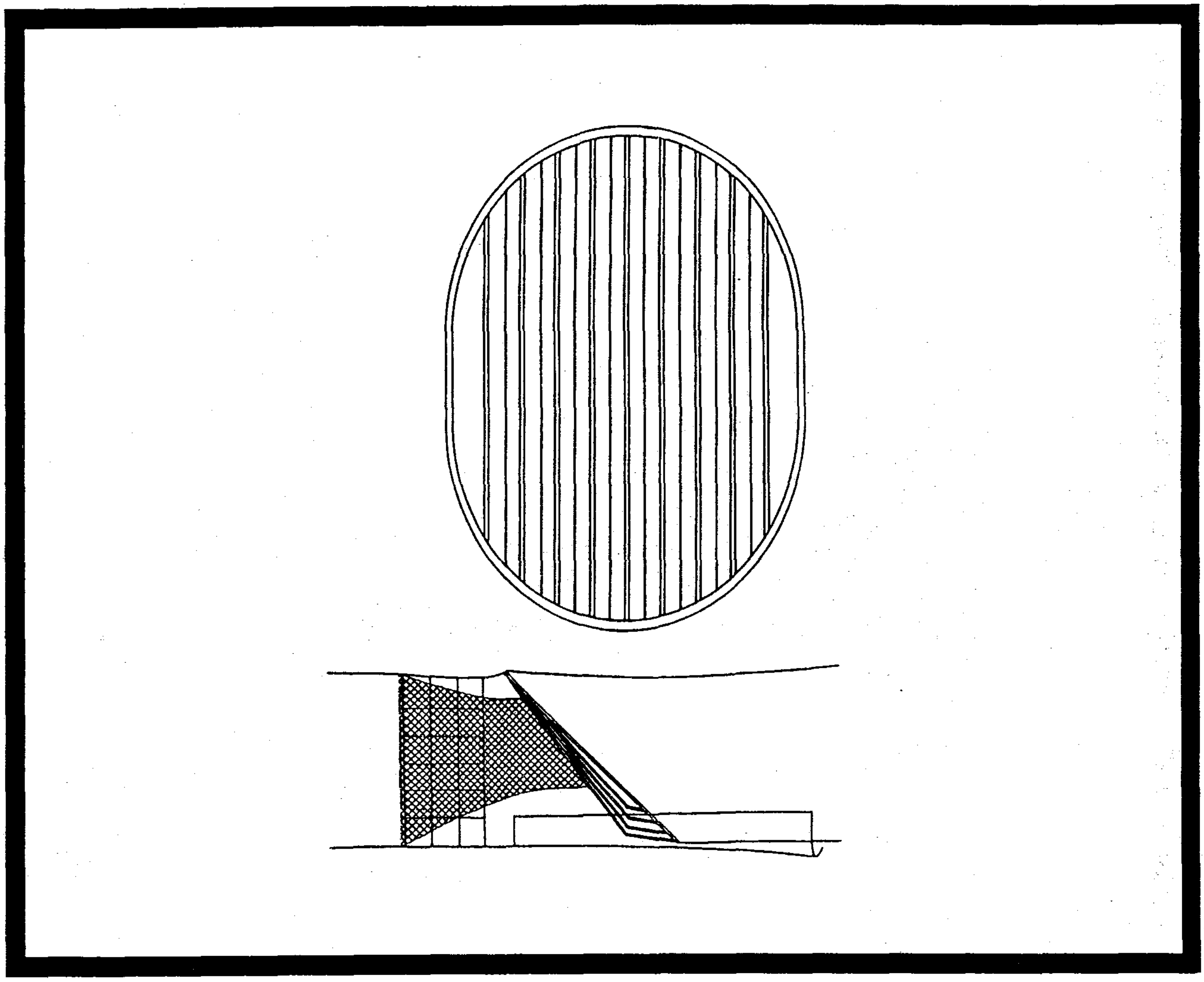
# SUPER SHOOTER WITH DOUBLE BARS



- This design incorporates a standard TED with additional grid bars offset 2-1/2 inches behind and in between the original grid bars.

- The additional bars are designed to restrict fish from passing through the bars while not restricting shrimp. The design was tested in combination with a large mesh funnel excluder ahead of the TED.

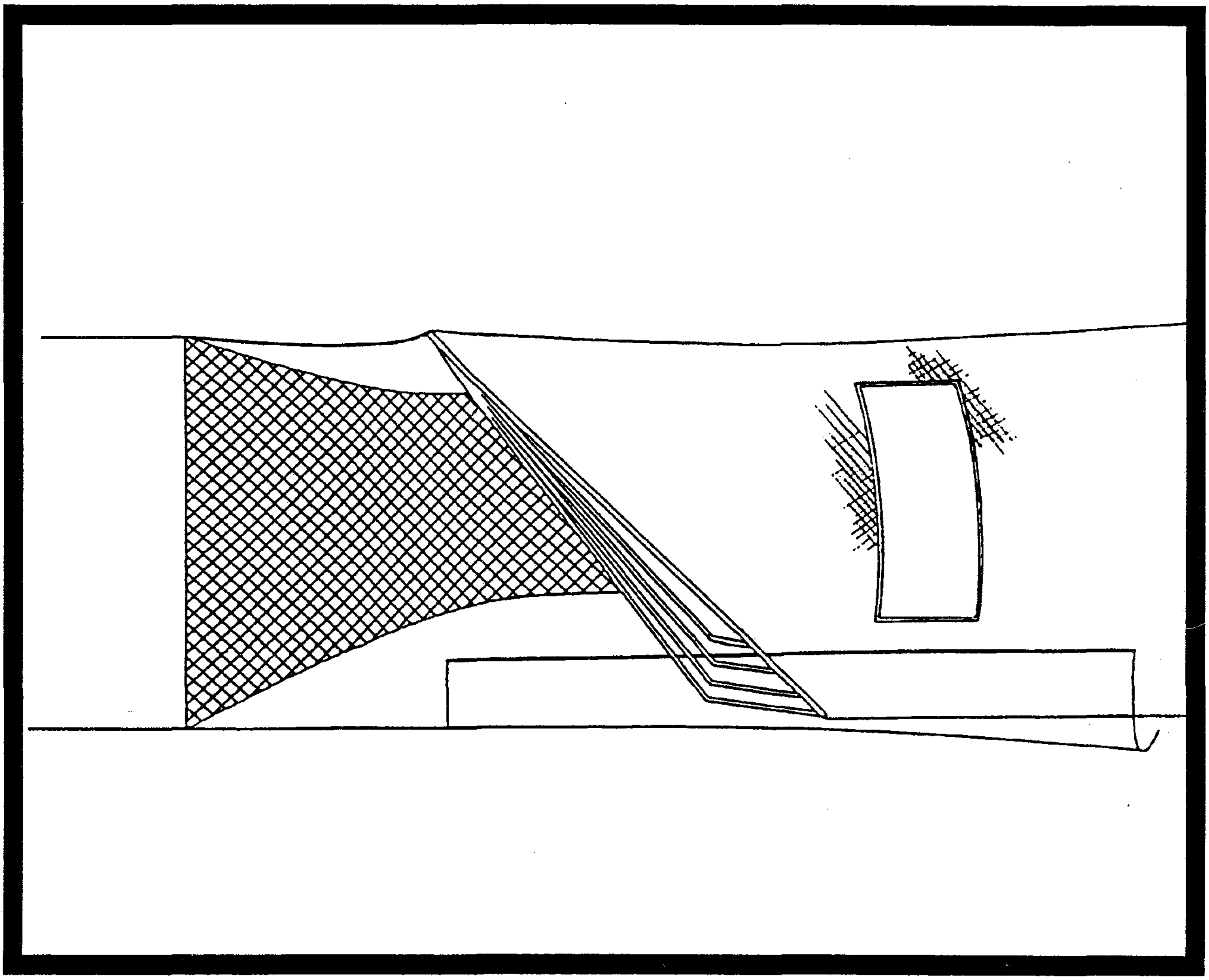
# SUPER SHOOTER WITH HUMMER WIRES



- This design is a Super Shooter style TED that has been modified by installing small diameter wires between the grid bars. The wires vibrate and discourage fish from passing through the grid. The modified TED was designed to be used in combination with a large mesh funnel excluder ahead of the TED.

Appendix I, Figure 8

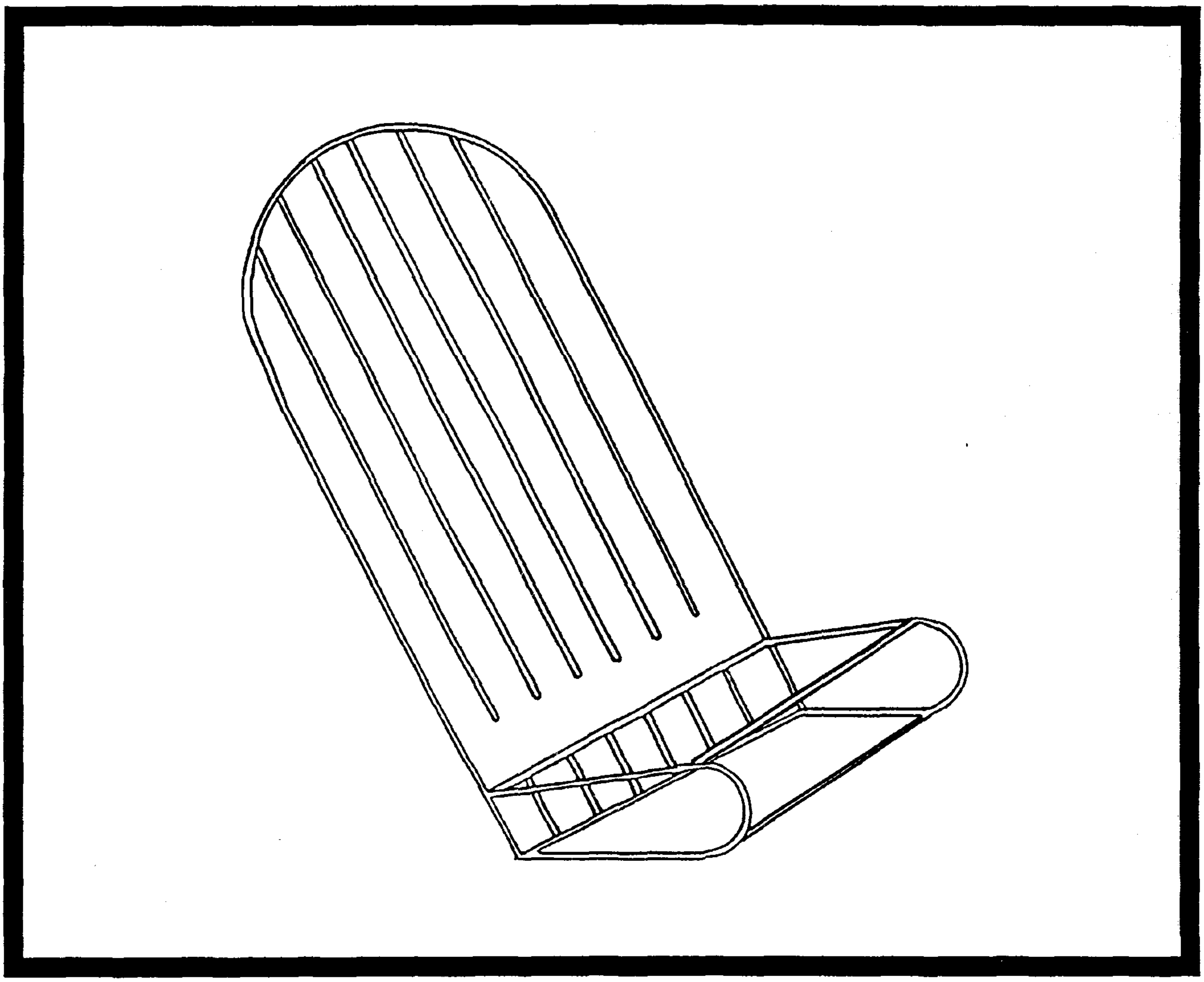
# SUPER SHOOTER WITH SIDE PANELS



- This design consists of panels of polyethylene webbing which are installed directly behind a super shooter style TED. Openings are cut in the trawl extension behind the panels to allow for fish escapement.

- Diver evaluations determined that without support frames the panels did not allow sufficient clearance between the side panels and the TED extension webbing.

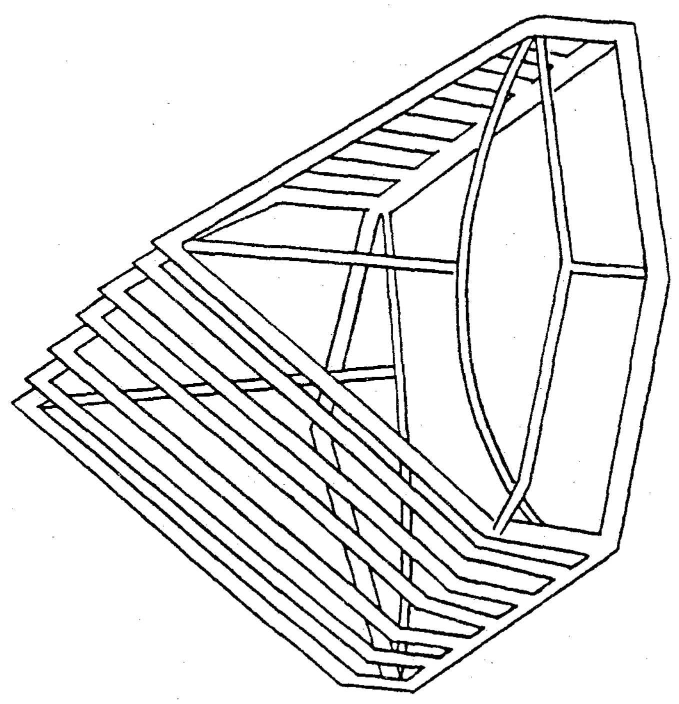
# HSB EXCLUDER



- This design consists of a frame which is added to the bottom of a grid style TED. Webbing panels are sewn inside the frame to lead fish to openings in the side of the frame. The initial design was used with an Anthony Weedless style TED that was shortened to allow for the extra length of the excluder frame.

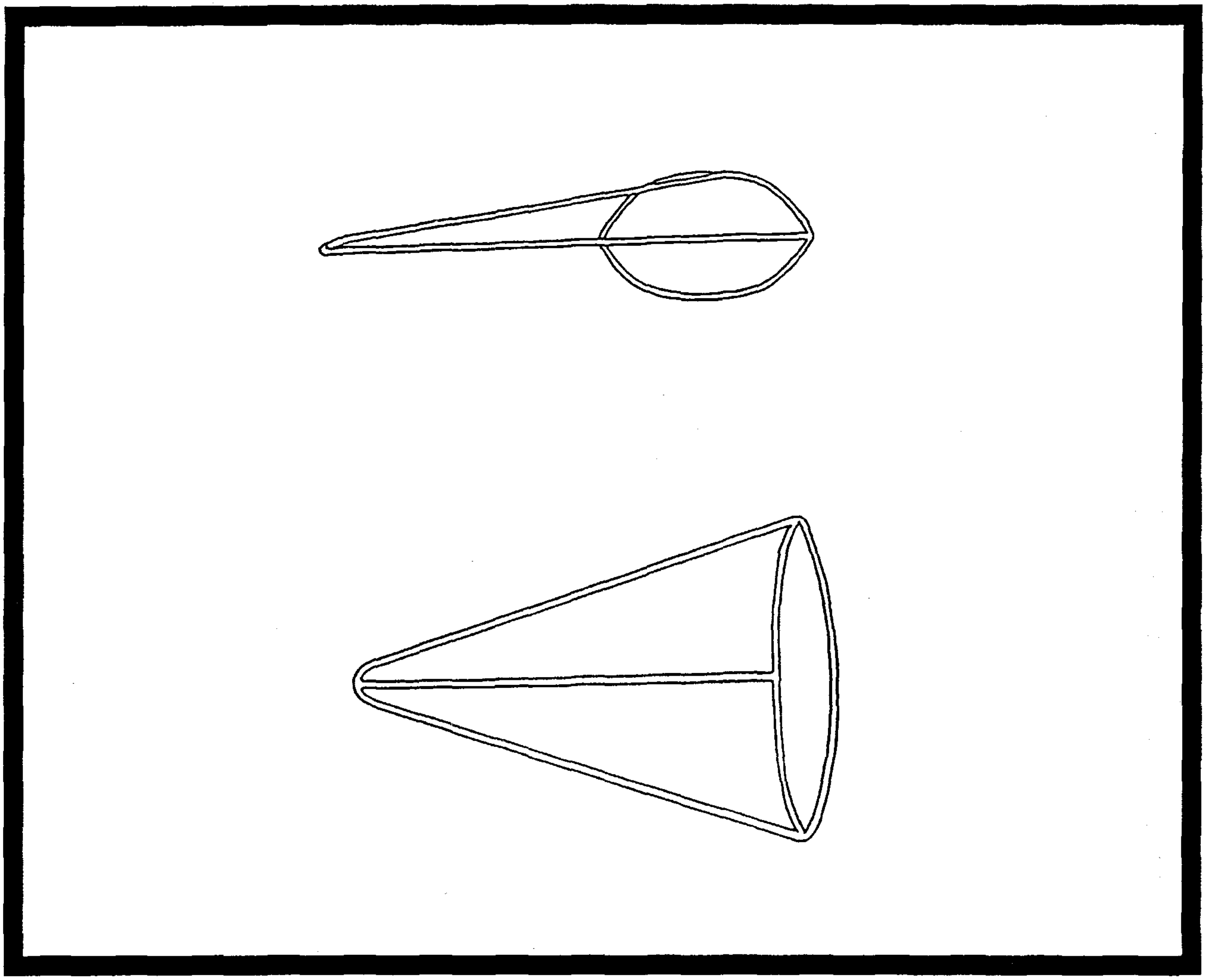
Appendix I, Figure 10

# TOP AND BOTTOM OPENING TED



- The top and bottom opening TED allows turtles to escape through the top or bottom of the trawl. It has grid bars set on 45 degree angles that come together to form points. Side openings are cut in the trawl extension behind the TED to form lead panels for fish escapement.

# FISHEYE



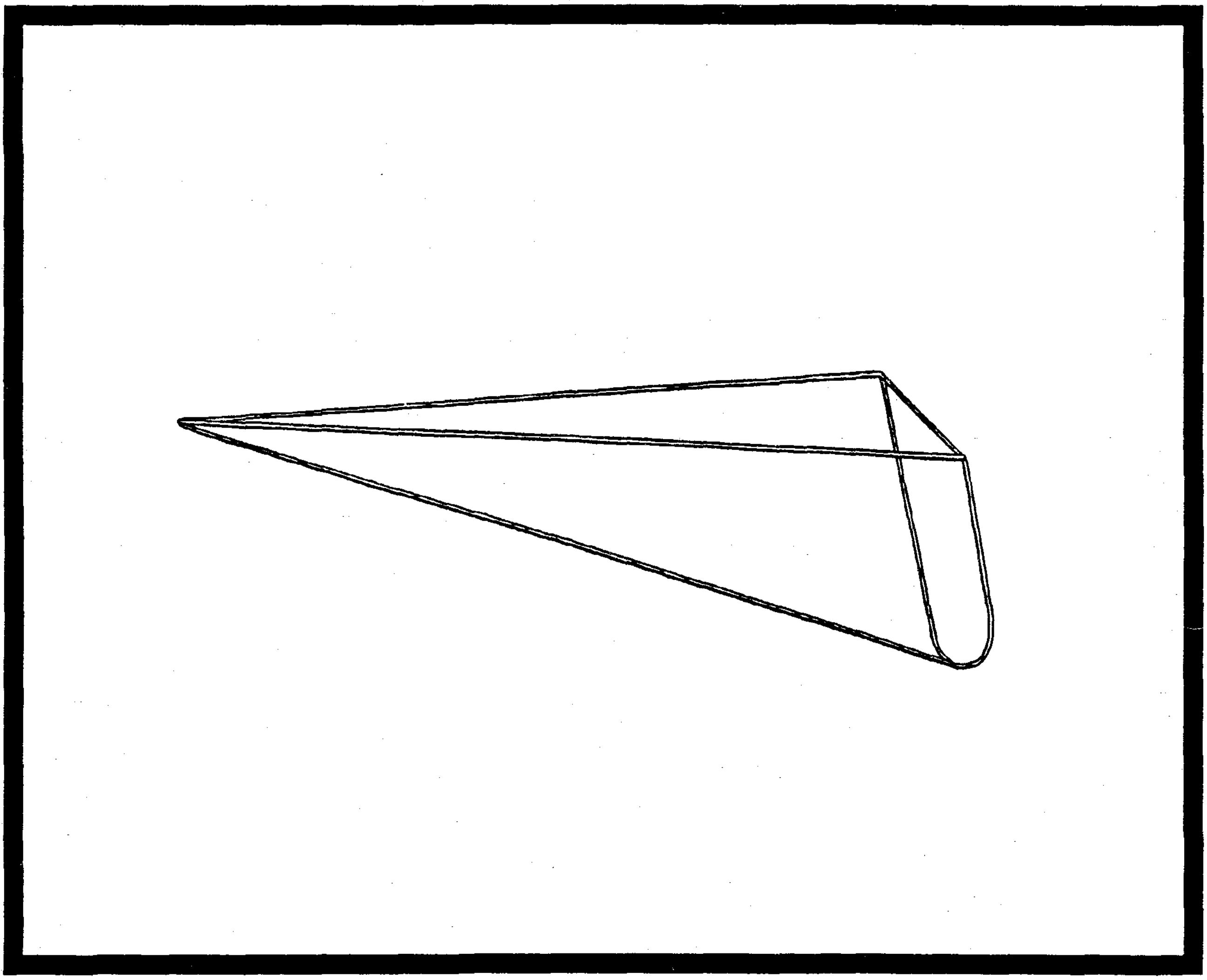
- The fisheye is an industry developed design which consists of a football or round shaped frame inserted into a trawl extension or codend to provide an opening for fish to escape.

- Dye flow tests indicated the water flow entering the opening of the device was reduced providing a stimulus for fish escapement.

- The fisheye was tested in three different positions, in the top of the codend, bottom of the extension, and on the sides of the extension behind a grid style TED.

Appendix I, Figure 12

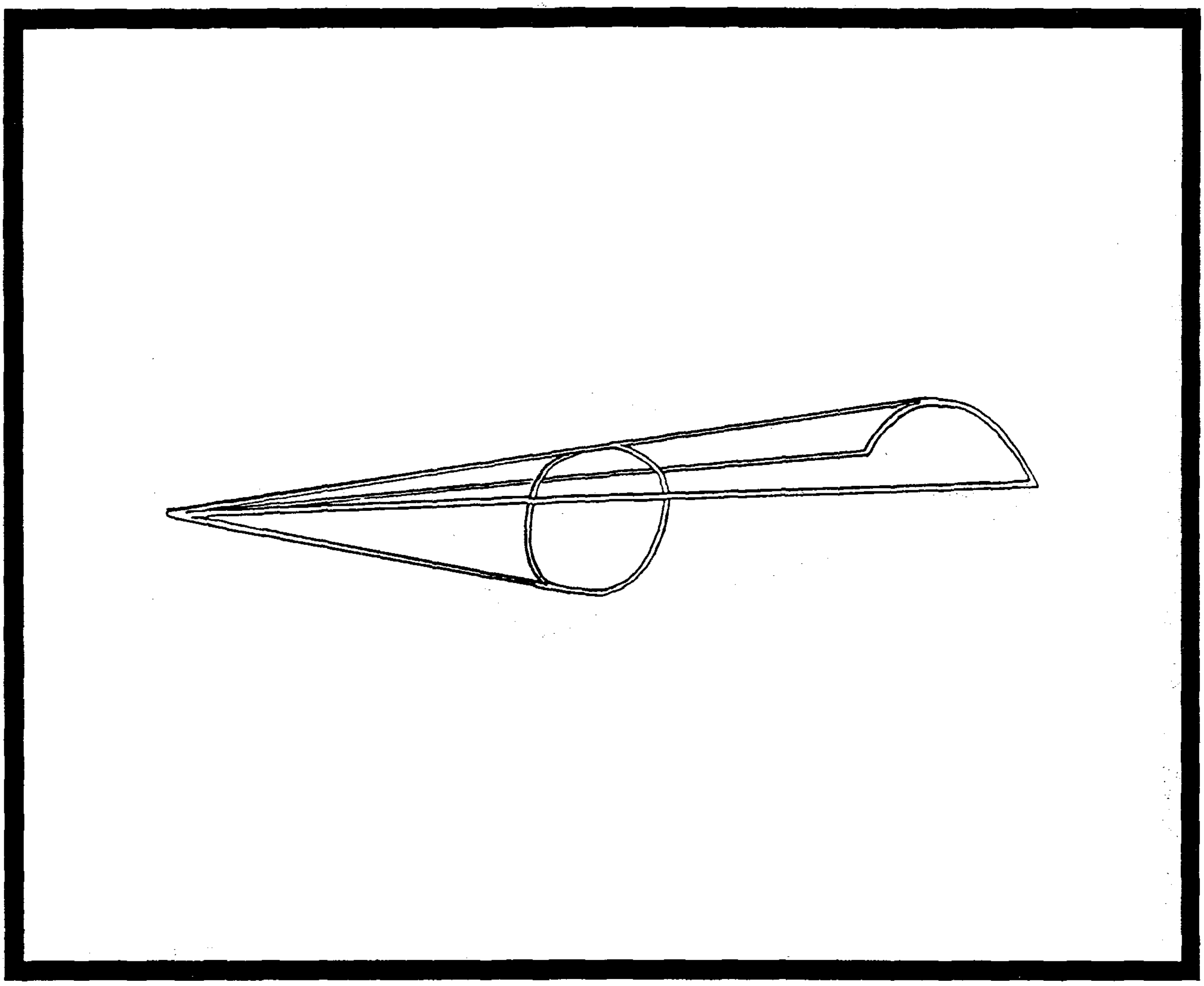
# LIONEL FISHEYE



- This industry developed device consists of a metal frame which creates a fish escape opening in the top of the codend two feet behind the leading edge.

Appendix I, Figure 13

# BARBOUR FISHEYE

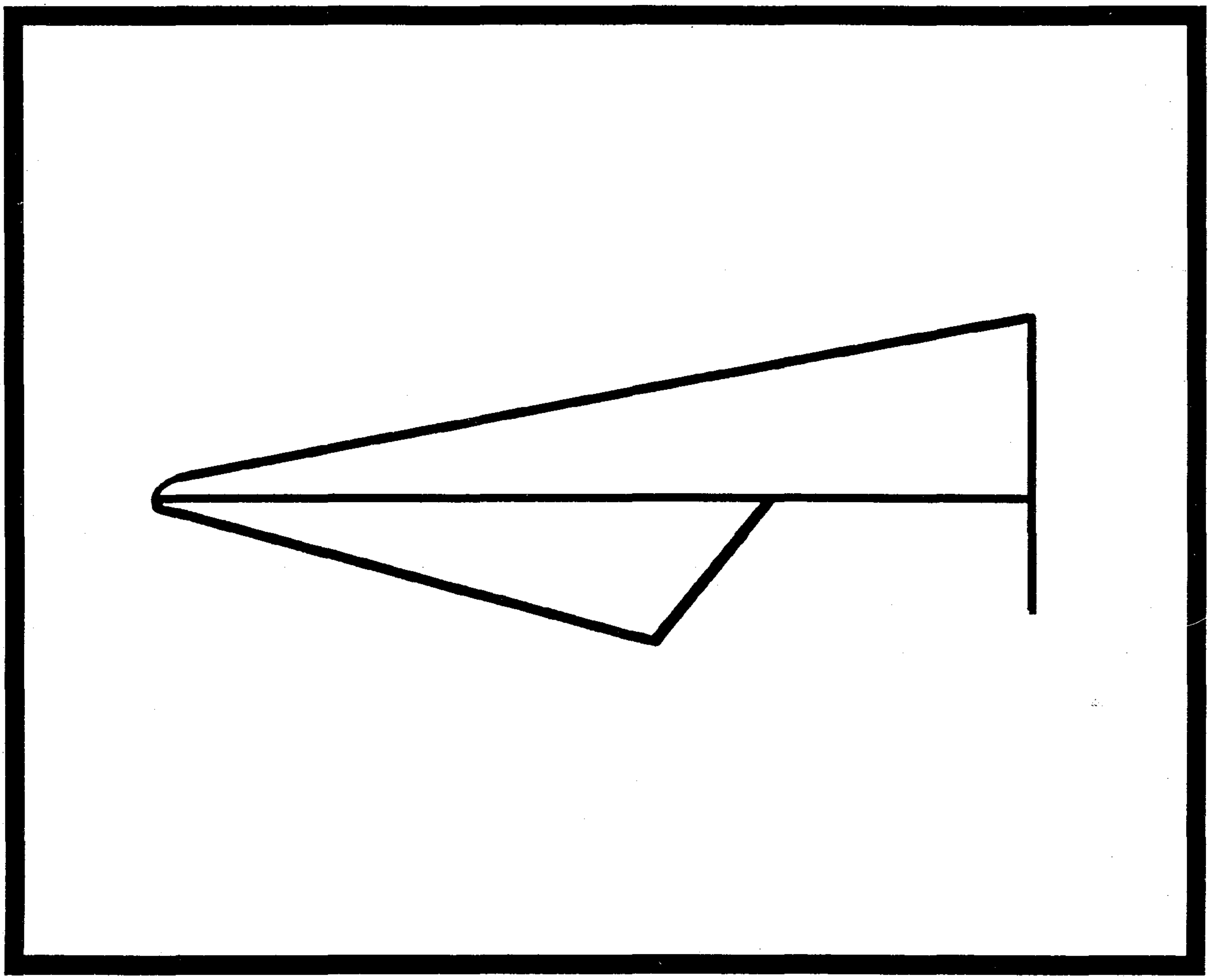


- This design consists of a triangular frame. The top inside of the frame overlaps the escape opening by 12 inches. The overlap was designed to reduce shrimp escapement through the fisheye.

- This design was difficult to install. The round shape of the webbing extension caused stress points at the wide corners which could, under tow, result in damage to the extension webbing.

Appendix I, Figure 14

# RWF FISHEYE

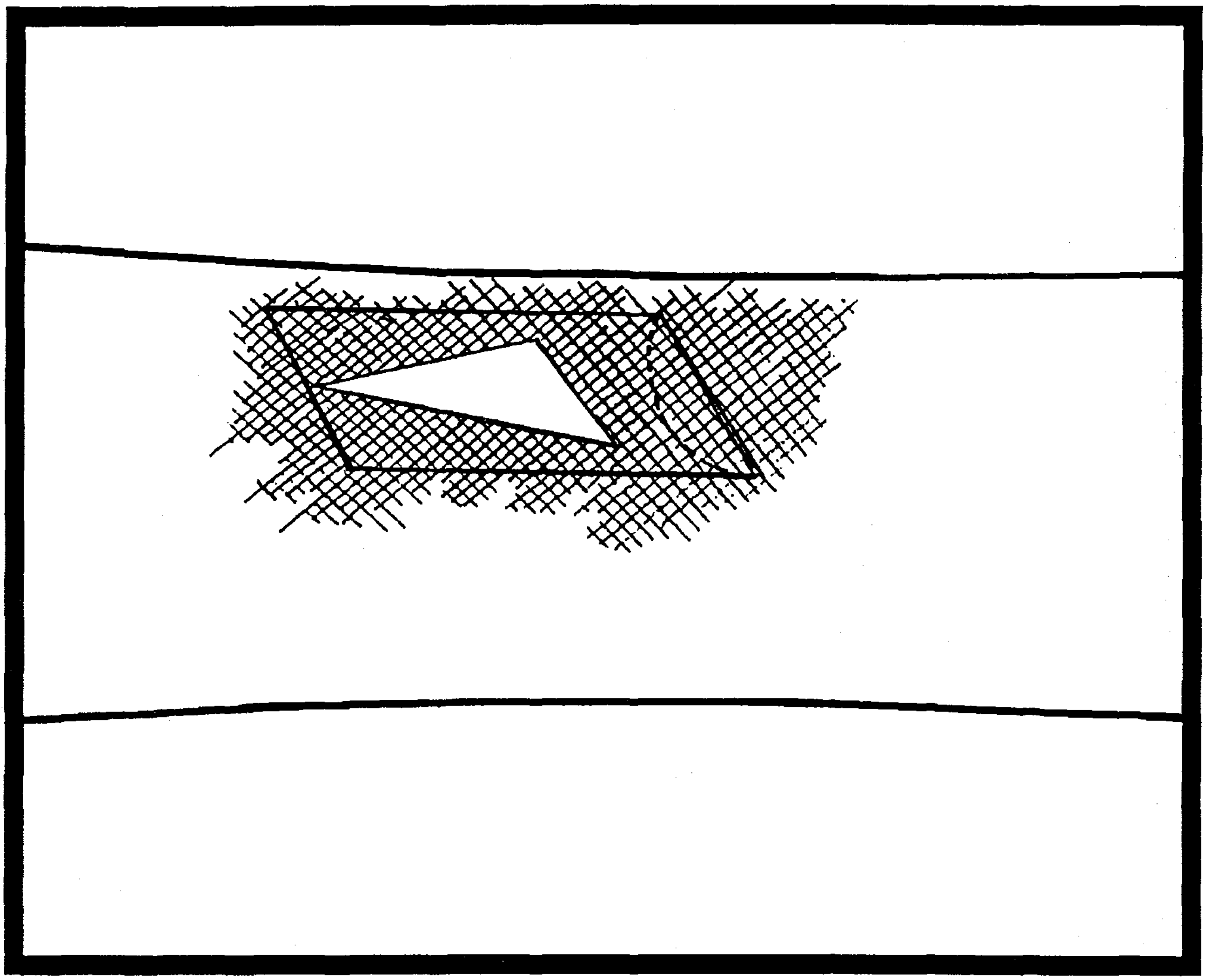


- This design is a modification of the commercially designed fisheye. The standard design was modified by adding a webbing covered frame on the front section of the fisheye to reduce water flow coming into the device from outside of the trawl.

- The reduced water flow allowed juvenile fish to escape. However, the placement of the device resulted in shrimp escapement, particularly when the frame webbing became blocked by grass or debris. An attempt was made to reduce shrimp loss by attaching a webbing panel to the upper edge of the escape opening and a plastic panel to the bottom.

Appendix I, Figure 15

# SOFT FISHEYE

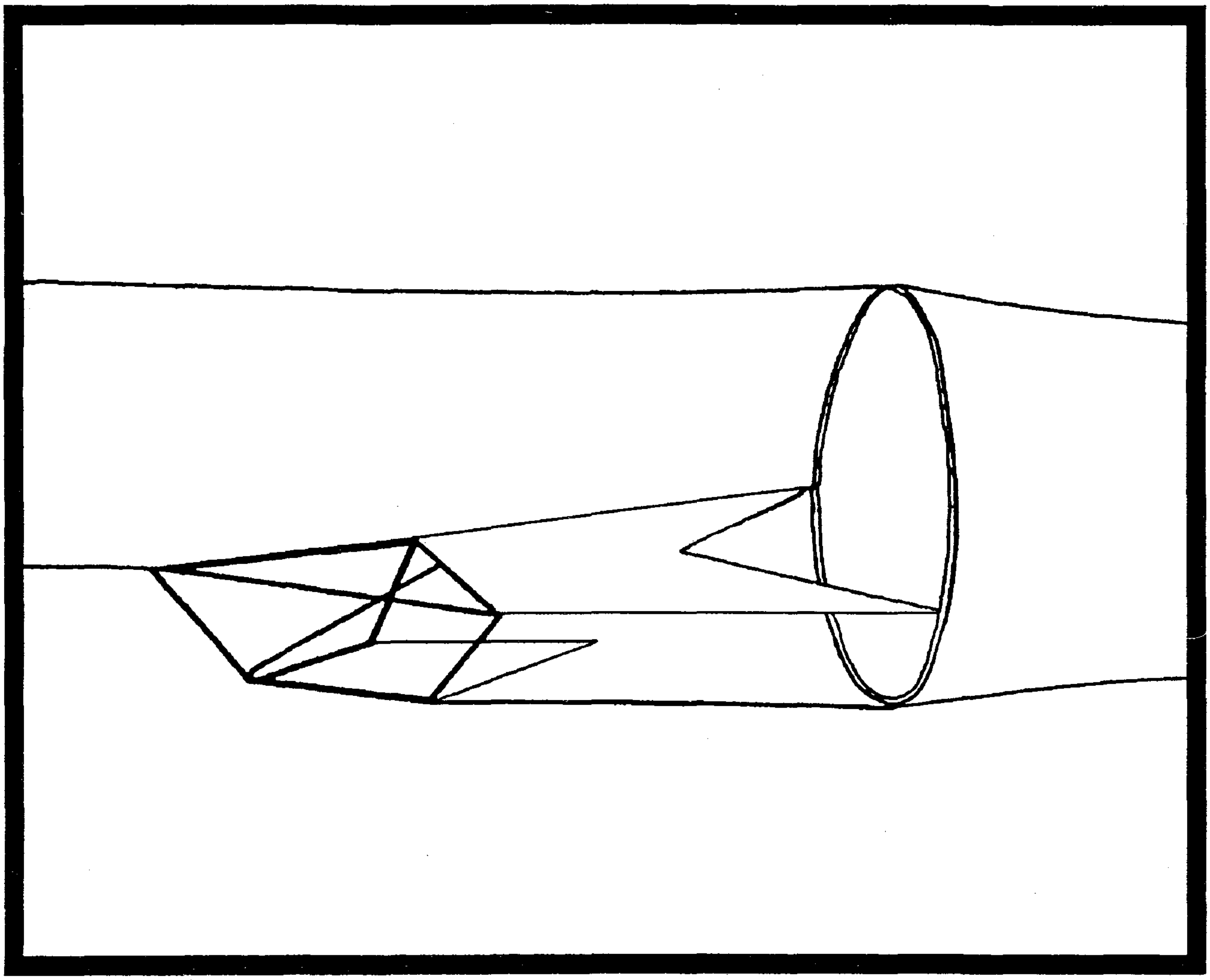


- o This design consists of a triangular hole cut in the top of the trawl codend six feet up from the bag rings. A polyethylene webbing flap was sewn over the hole on the inside of the codend.

- o Diver evaluations determined that water flow kept the flap closed. When weight was added to the flap to keep it open, the codend collapsed.

Appendix I, Figure 16

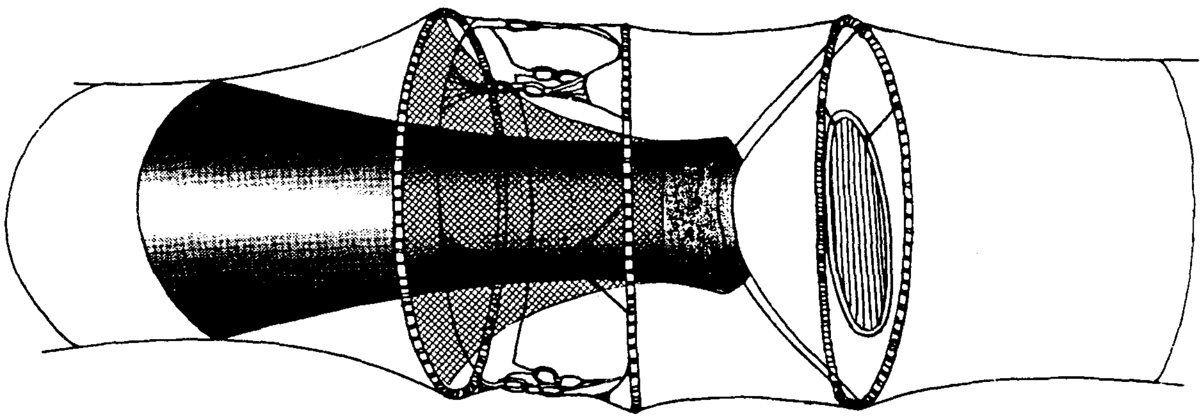
# DOUBLE V EXCLUDER



- o This device is a modification of the fisheye design. It consists of a metal frame covered by small mesh webbing designed to reduce water flow. It was installed under the trawl where a V shaped exit opening was cut in the extension webbing. This created panels leading to the escape openings.

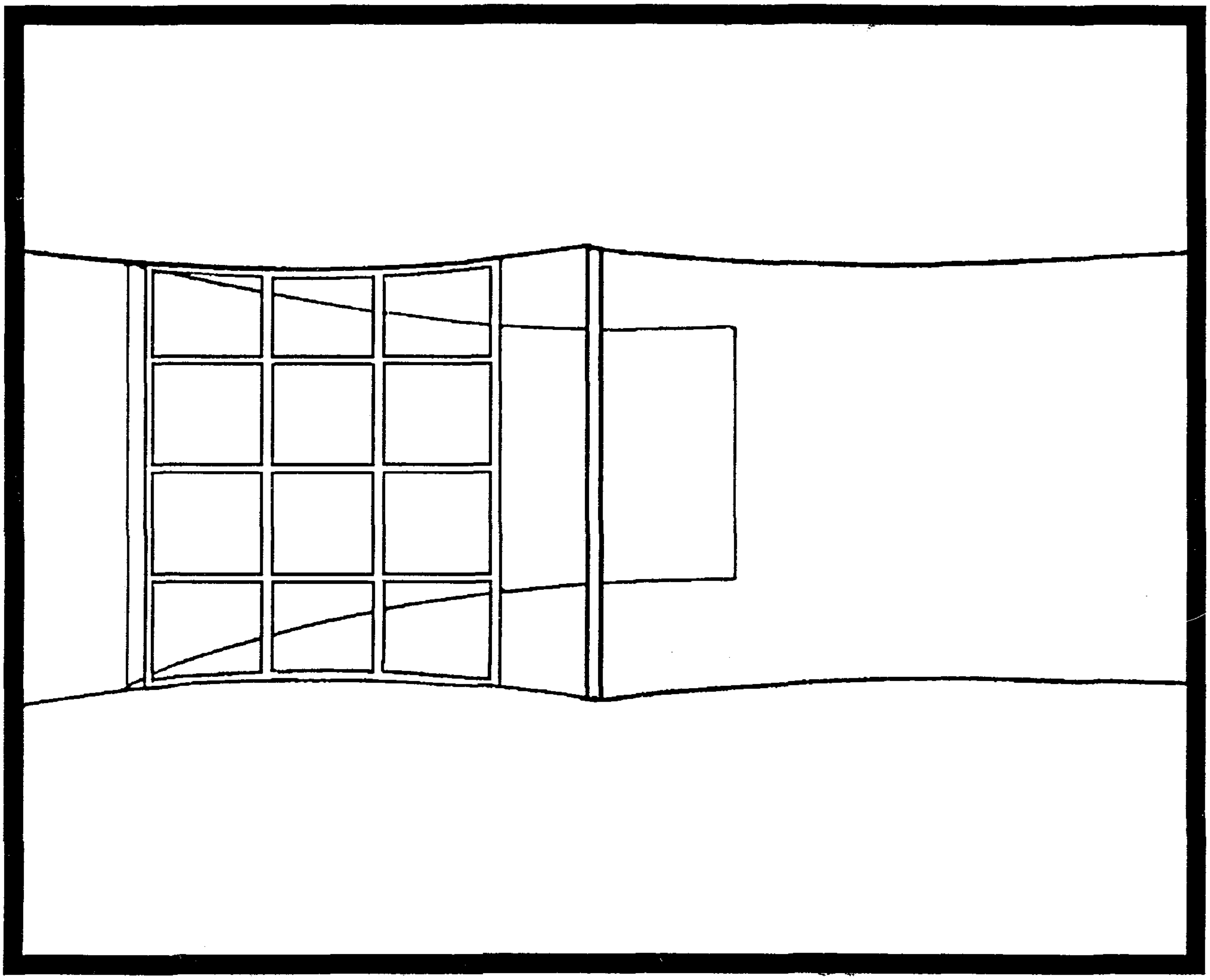
Appendix I, Figure 17

# FSD



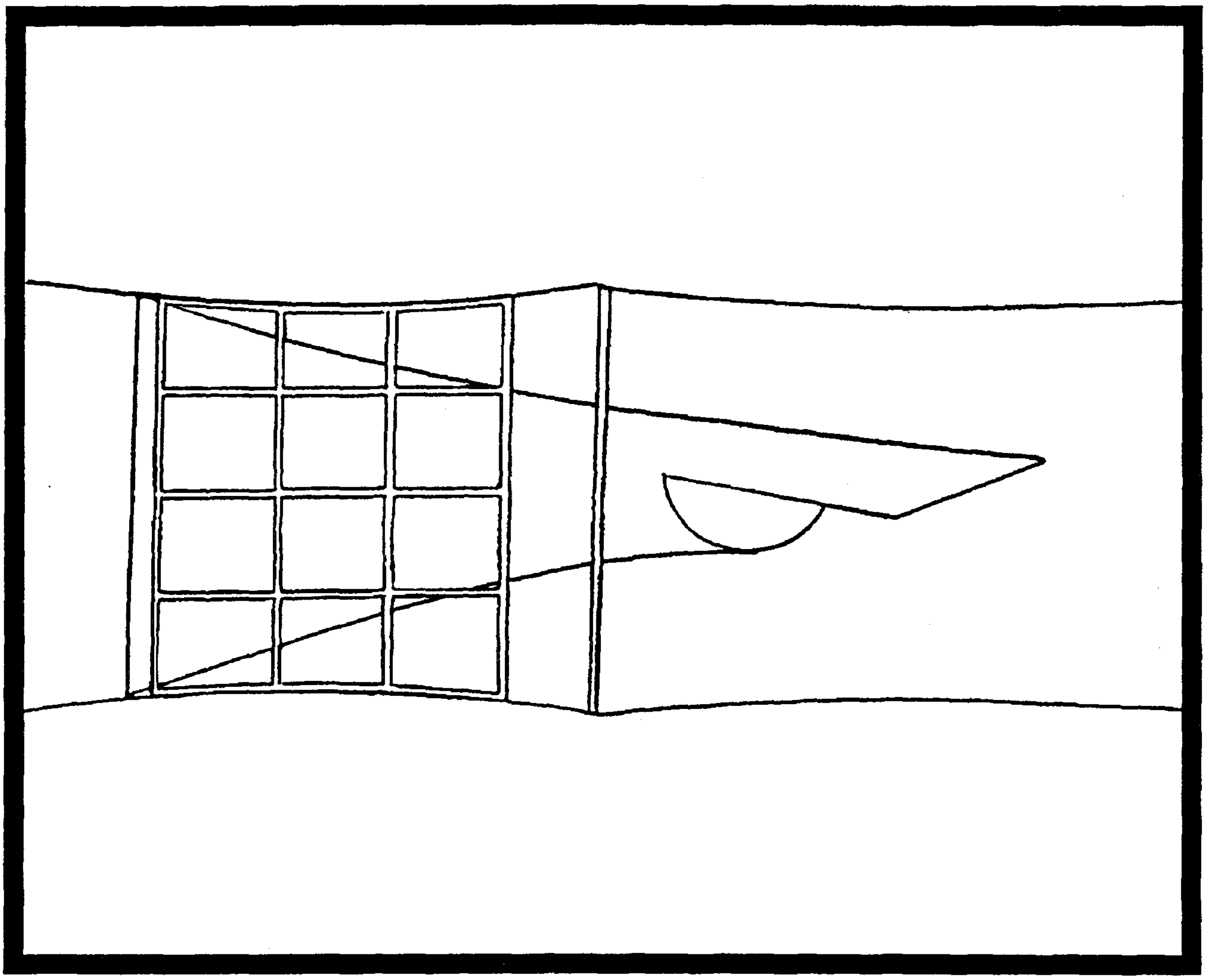
- This design is a finfish separator device developed by NMFS in the late 1970s. It incorporates a webbing funnel and hoops patterned after a catfish trap used on the east coast. Webbing is removed between the hoops to allow fish escapement.

# LARGE MESH/FUNNEL EXCLUDER



- o This design consists of a small mesh webbing funnel surrounded by a large mesh section for fish escapement.
- o It was tested in two positions, ahead and behind a grid style TED.

# EXTENDED FUNNEL DESIGN

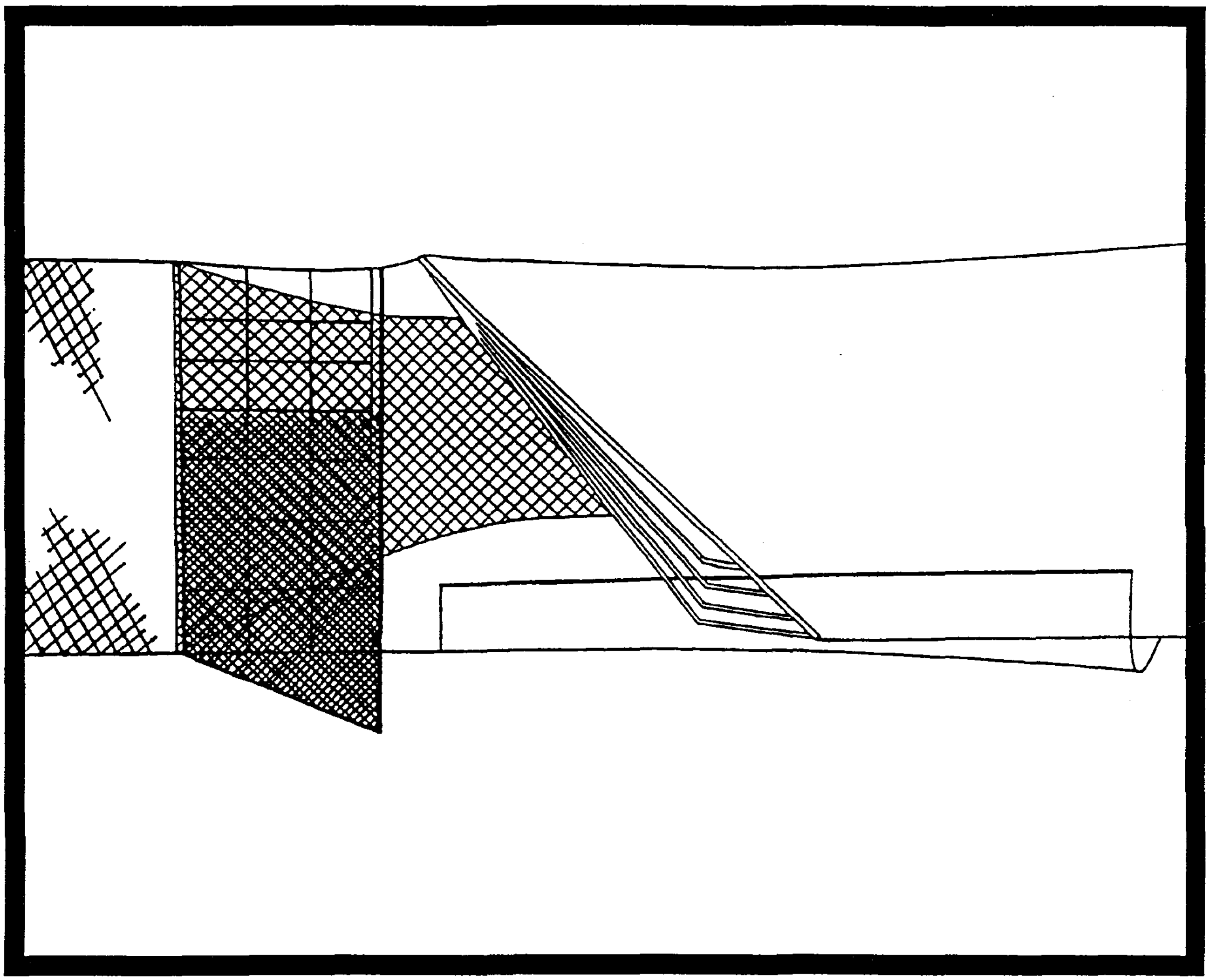


- This design consists of a small mesh webbing funnel surrounded by a large mesh escape section held open by two plastic coated cable hoops.

- One side of the funnel is extended to form a lead panel that creates an area of reduced water flow on the backside of the funnel. It is placed behind a hard grid TED between the TED extension and the trawl.

Appendix I, Figure 20

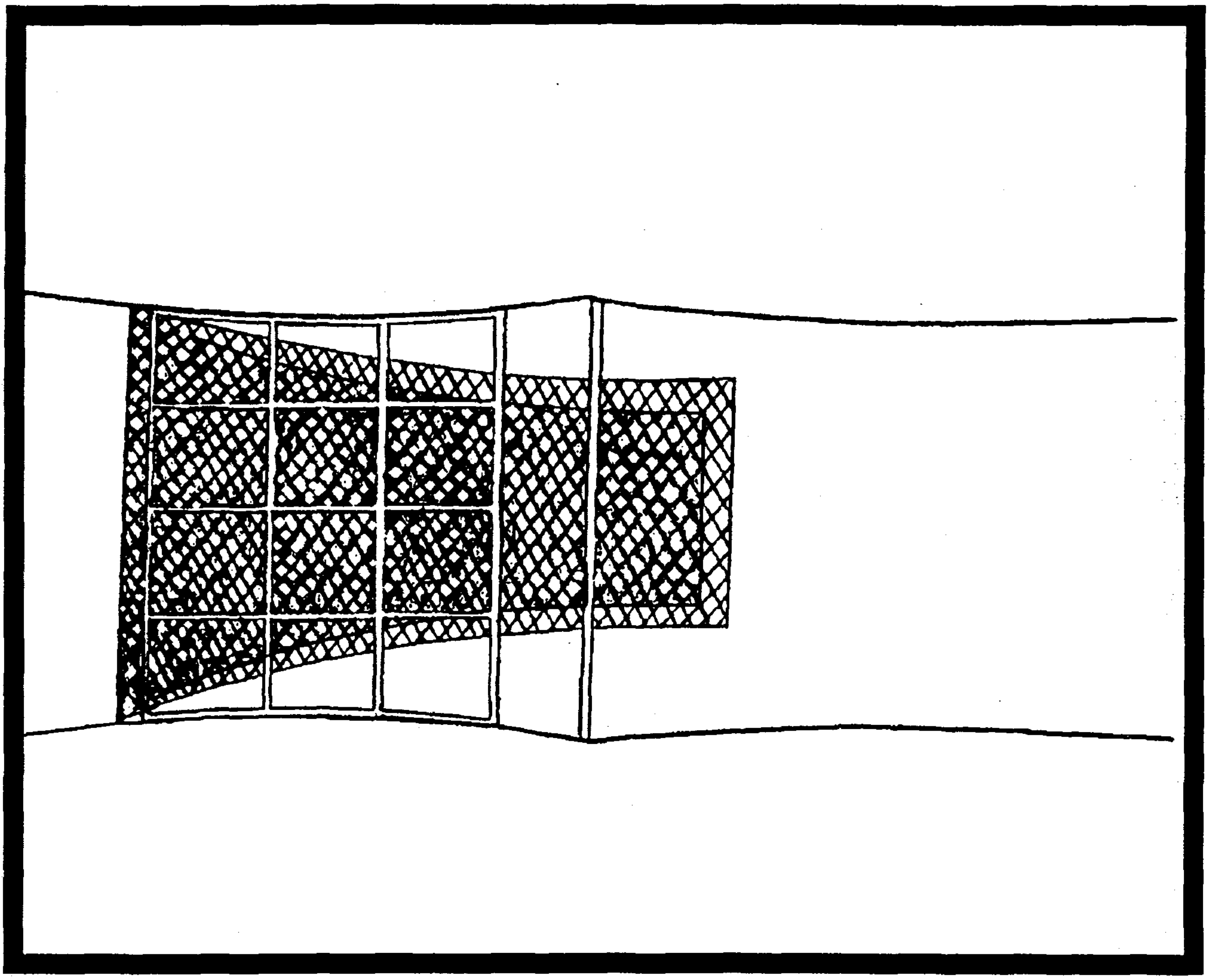
# RWF LARGE MESH FUNNEL EXCLUDER



- This design is a modification of the large mesh excluder design which incorporates a small mesh skirt around the outside of the large mesh section to reduce water flow. The skirt is held open using a plastic coated cable hoop.

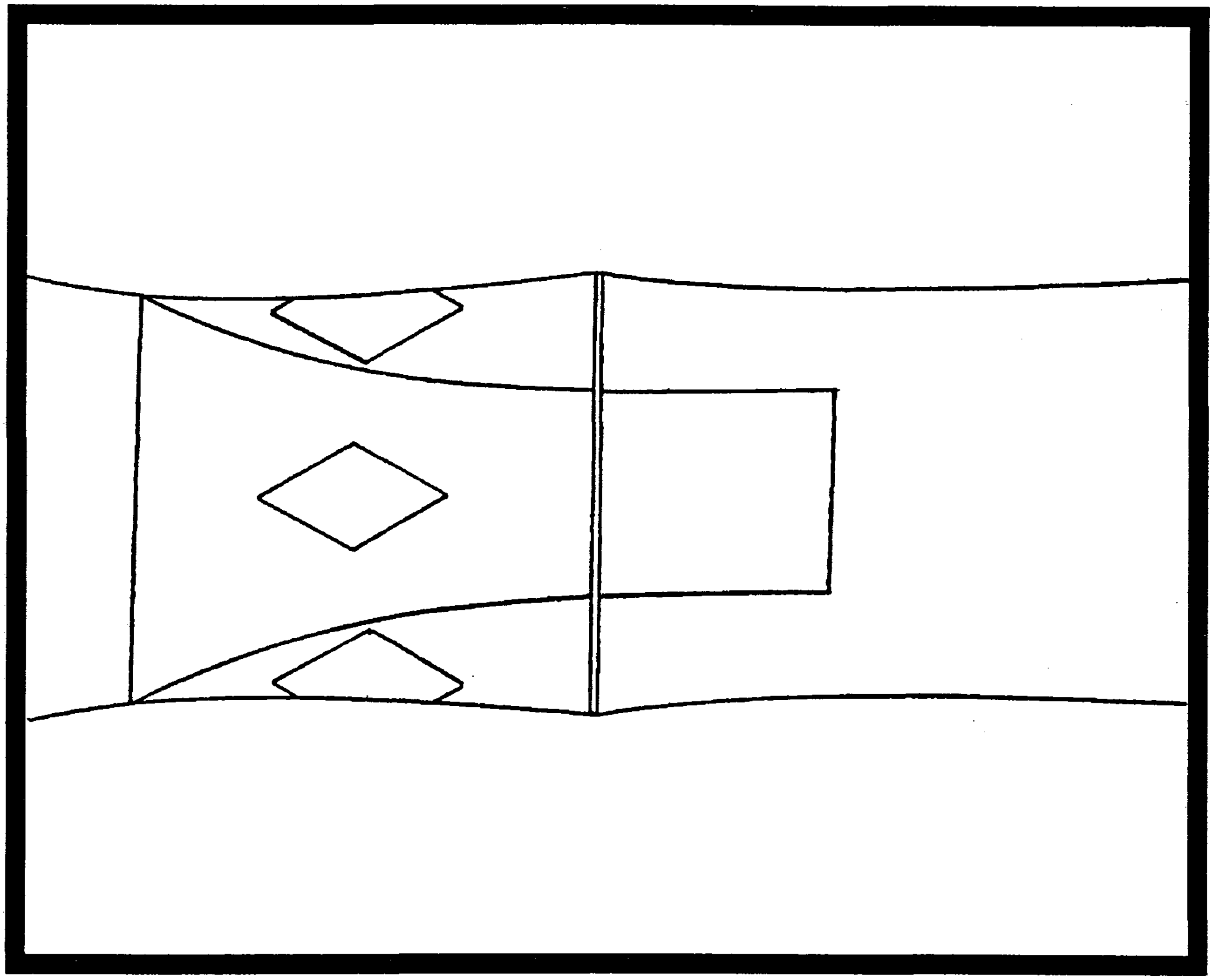
- Diver evaluations indicated the skirt effectively slowed water flow entering the device and juvenile fish were able to escape through the opening.

# LARGE MESH
# DOUBLE FUNNEL EXCLUDER



- This design is a modification of the large mesh funnel design incorporating a second funnel inside the original funnel. The purpose of the second funnel is to reduce the water passing through the funnel and increase fish escapement.

# WWF DESIGN

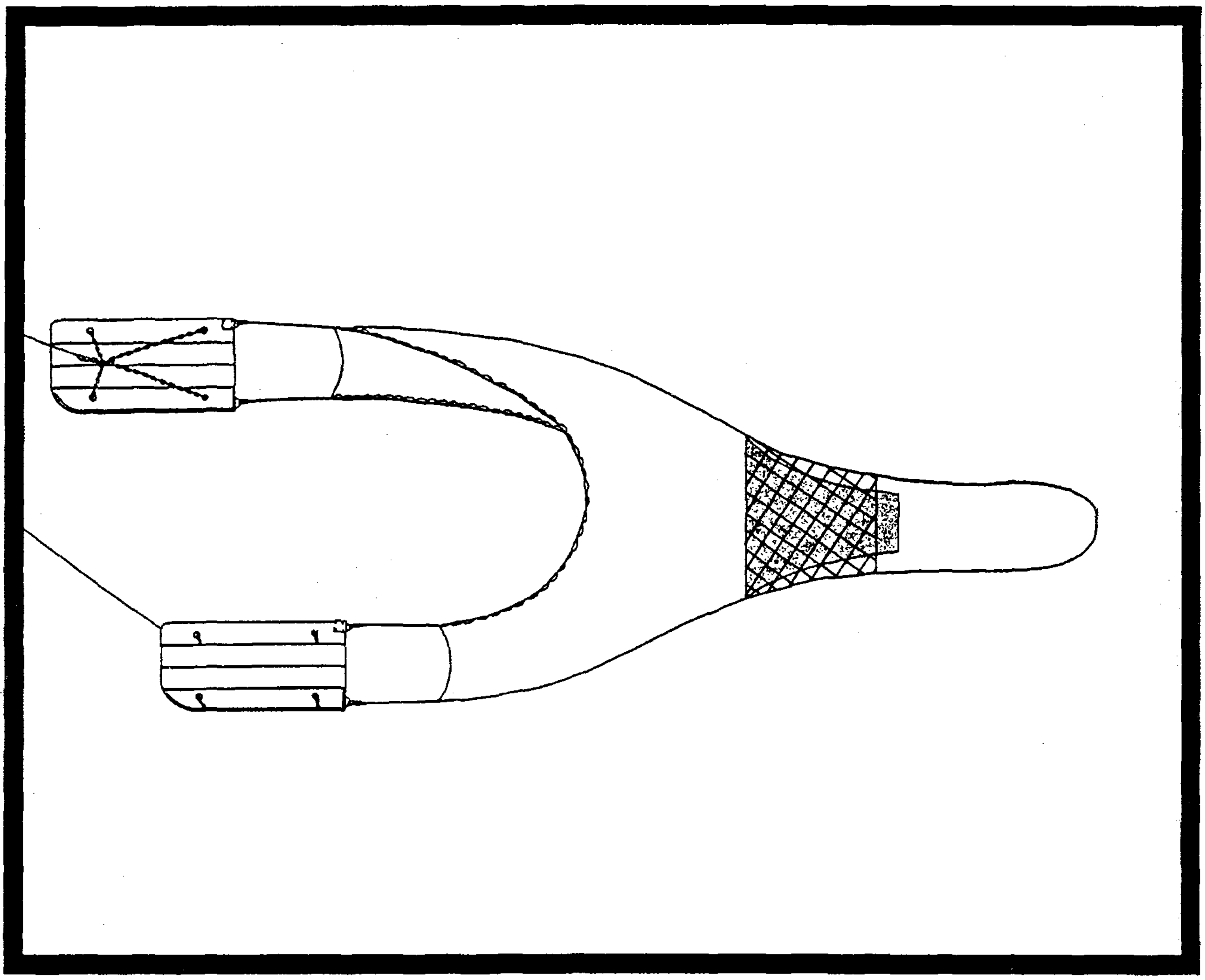


- This design evolved from observations of fish swimming around the accelerator funnels used to reduce shrimp loss with grid style TEDs. Large diamond shaped holes were cut and reinforced in the TED extension around the funnel.

- Diver evaluations showed that fish escaped through the openings more efficiently when the funnel was modified to allow more clearance from the sides of the extension. This design evolved into the more efficient and stronger large mesh/funnel design.

Appendix I, Figure 23

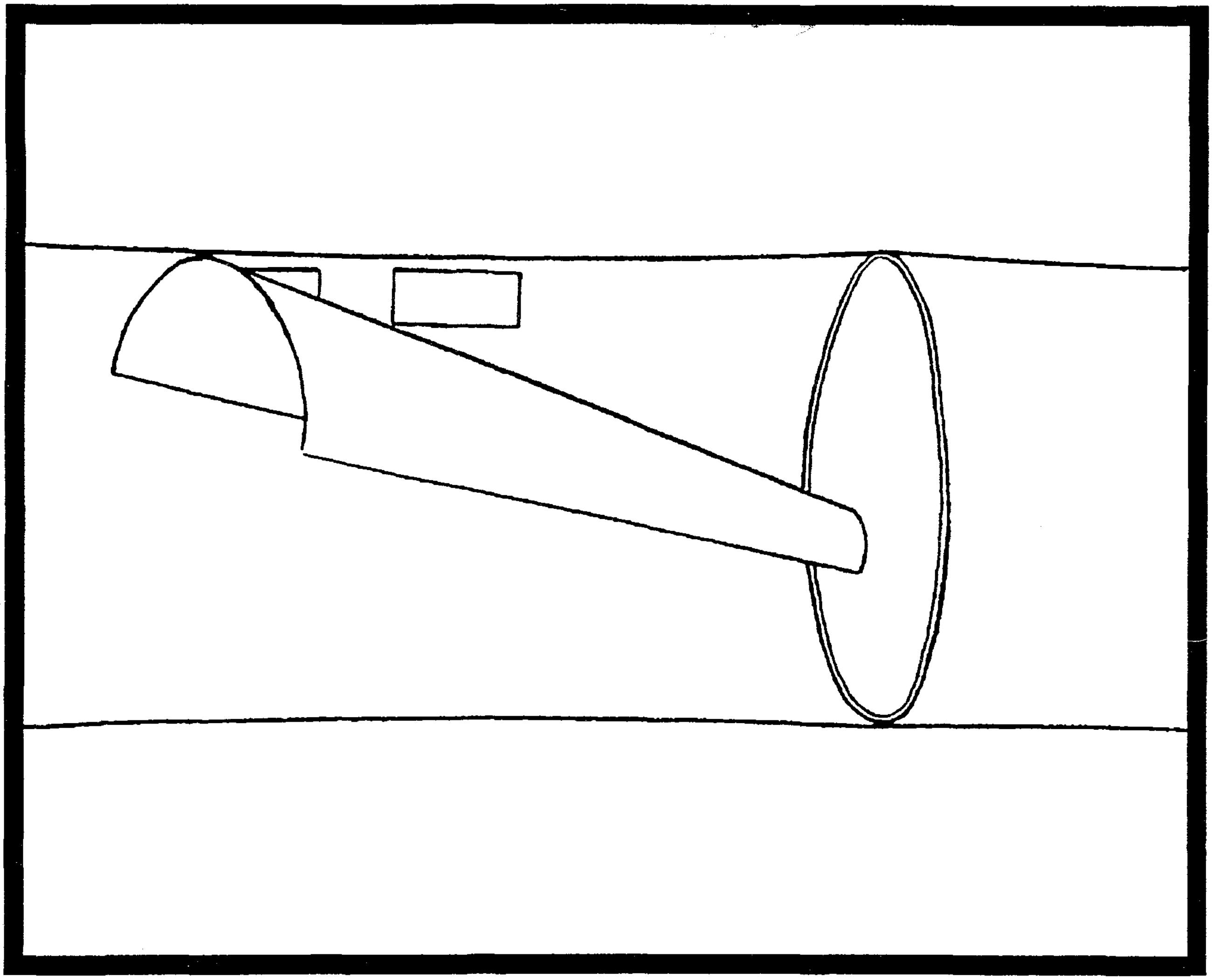
# LARGE FUNNEL EXCLUDER



- This design consists of a large polyethylene funnel which was installed ahead of the intermediate section of a trawl. The trawl webbing over the funnel was replaced with 12 inch mesh webbing to allow for fish escapement.
- Divers observed that the drag forces on the large funnel caused it to balloon, closing off the space between the funnel and the 12 inch webbing.

Appendix I, Figure 24

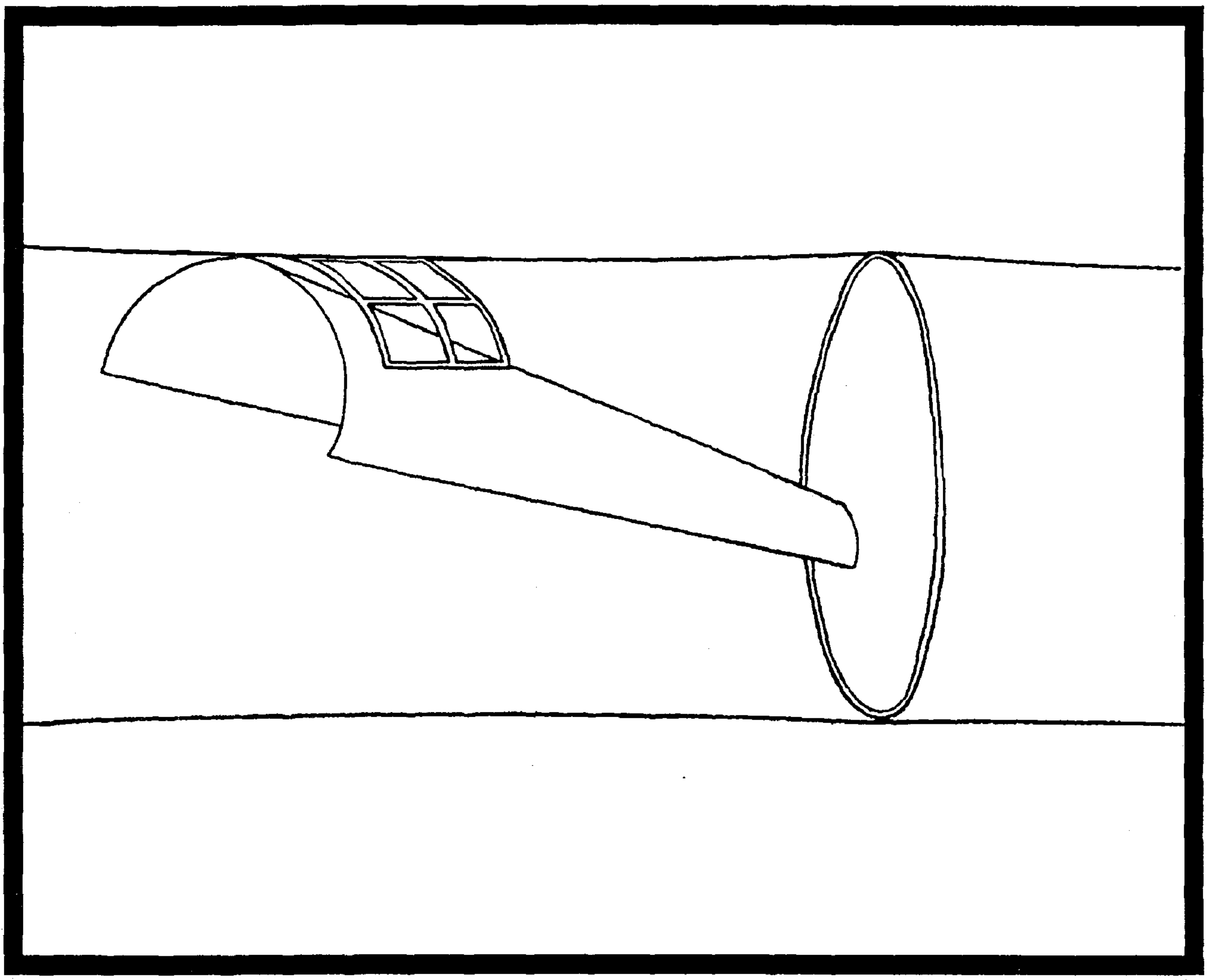
# LEAD PANEL DESIGN



- This design consists of a polyethylene webbing panel placed on a downward angle behind a grid type TED. The panel's trailing edge was attached to an aluminum hoop. Two rectangular frames were installed above the lead panel to allow fish escapement.

- Observations of fish reactions indicated the device was not effective

# LEAD PANEL AND SKYLIGHT

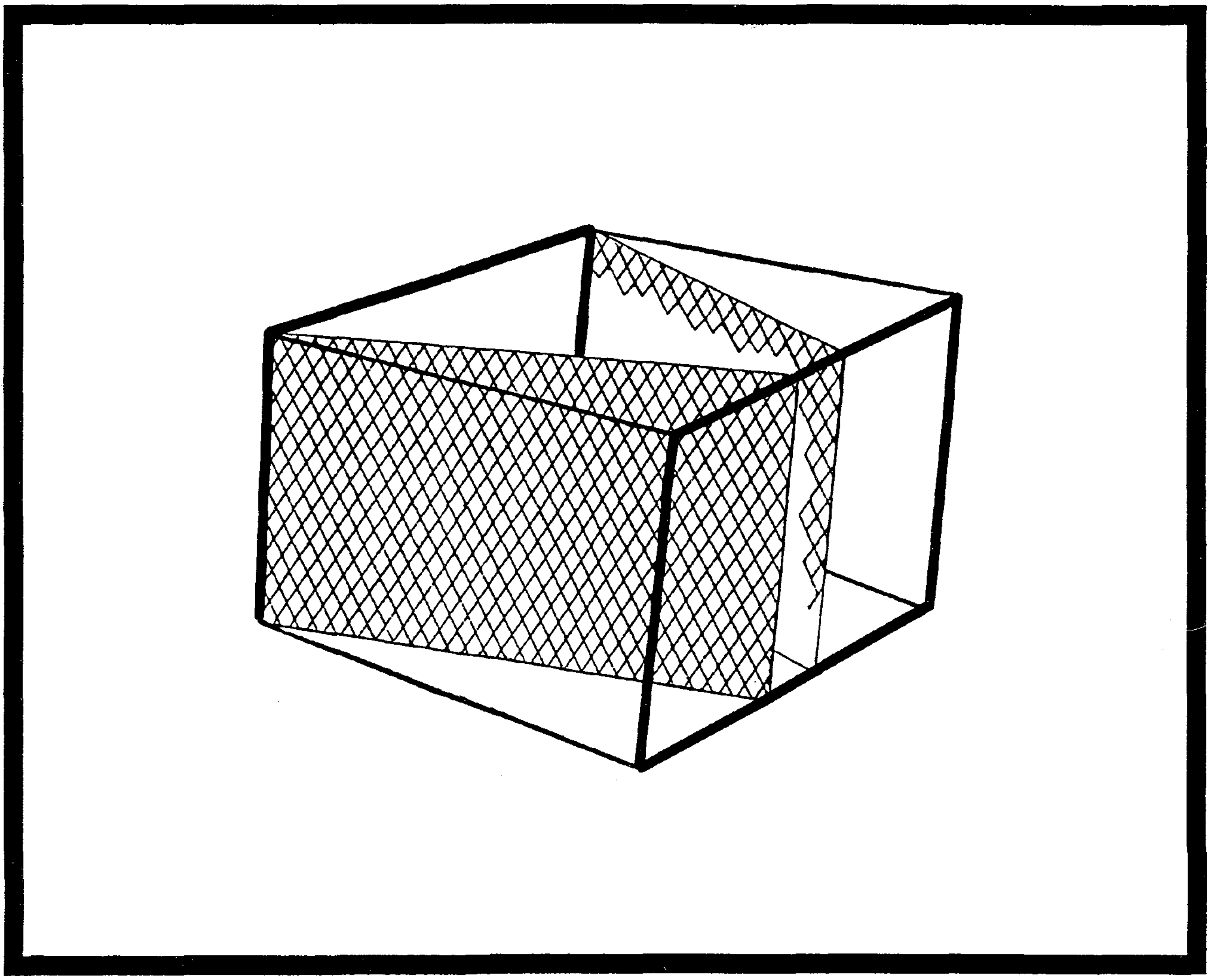


- o This design consists of a webbing lead panel inserted in the codend behind and accelerator funnel. A large mesh skylight was placed above the lead panel. The panel was held taut by plastic coated cable hoops.

- o Diver evaluations determined that the clearance between the skylight and the lead panel was inadequate.

Appendix I, Figure 26

# SIDE OPENING SEPARATOR

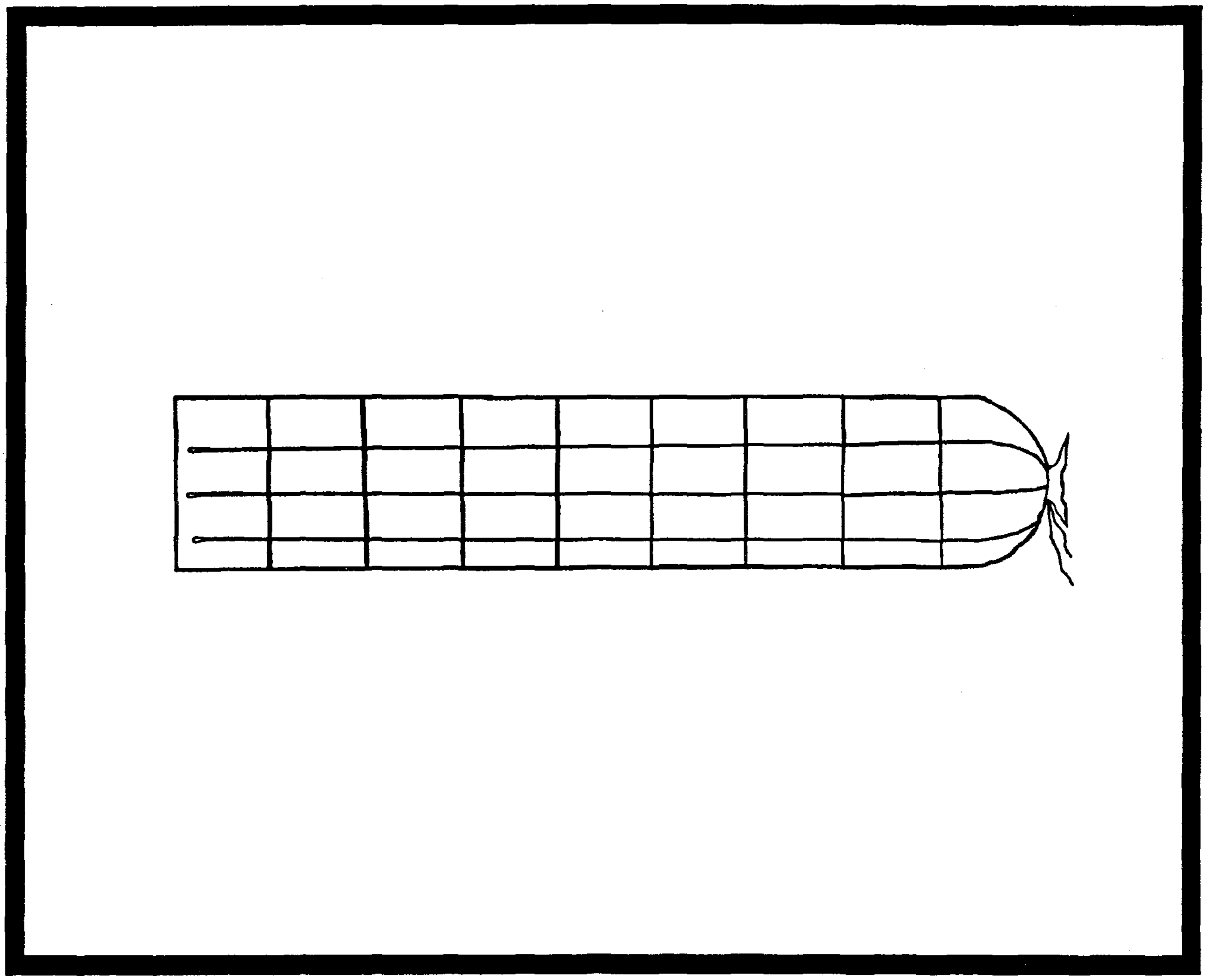


- This design consists of two aluminum frames inserted into the trawl extension. The frames are connected by stainless cables. The sides of the extension were cut and sewn inward to form lead panels and openings for fish escapement.

- Diver evalutations determined the rigid frames were not practical for this application.

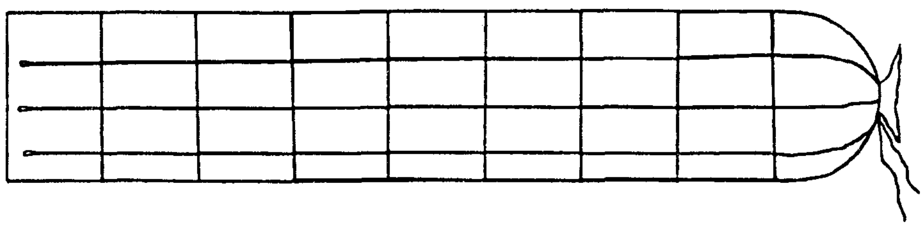
Appendix I, Figure 27

# MODIFIED NYLON CODEND



- o This design is constructed of nylon and has a rope frame around the outside of the codend which supports the load and drag on the codend.
- o Diver evaluations indicated the codend maintained an opening diameter of 24 inches.

# MODIFIED POLY CODEND

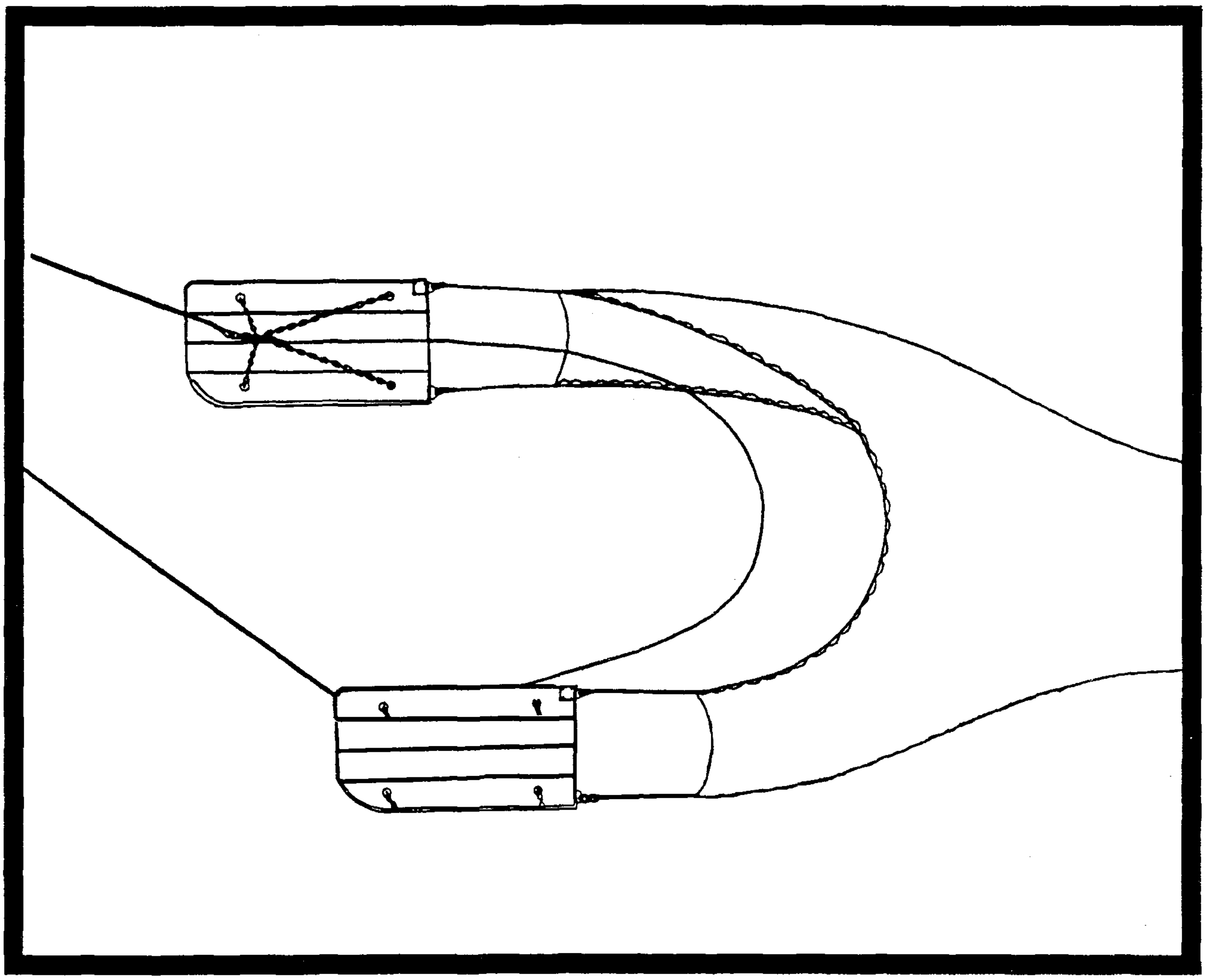


- The modified codend was designed to remain open to allow fish in the codend to swim forward and exit through fish excluder openings. This design consists of a codend constructed from polyethylene webbing with a framework of restructures and rib lines that support the load and drag on the codend allowing the codend to remain open.

- Diver evaluations indicated this codend maintained an opening diameter of 18-20 inches. The opening of the codend was increased by tying the ring flaps onto one of the rib lines.

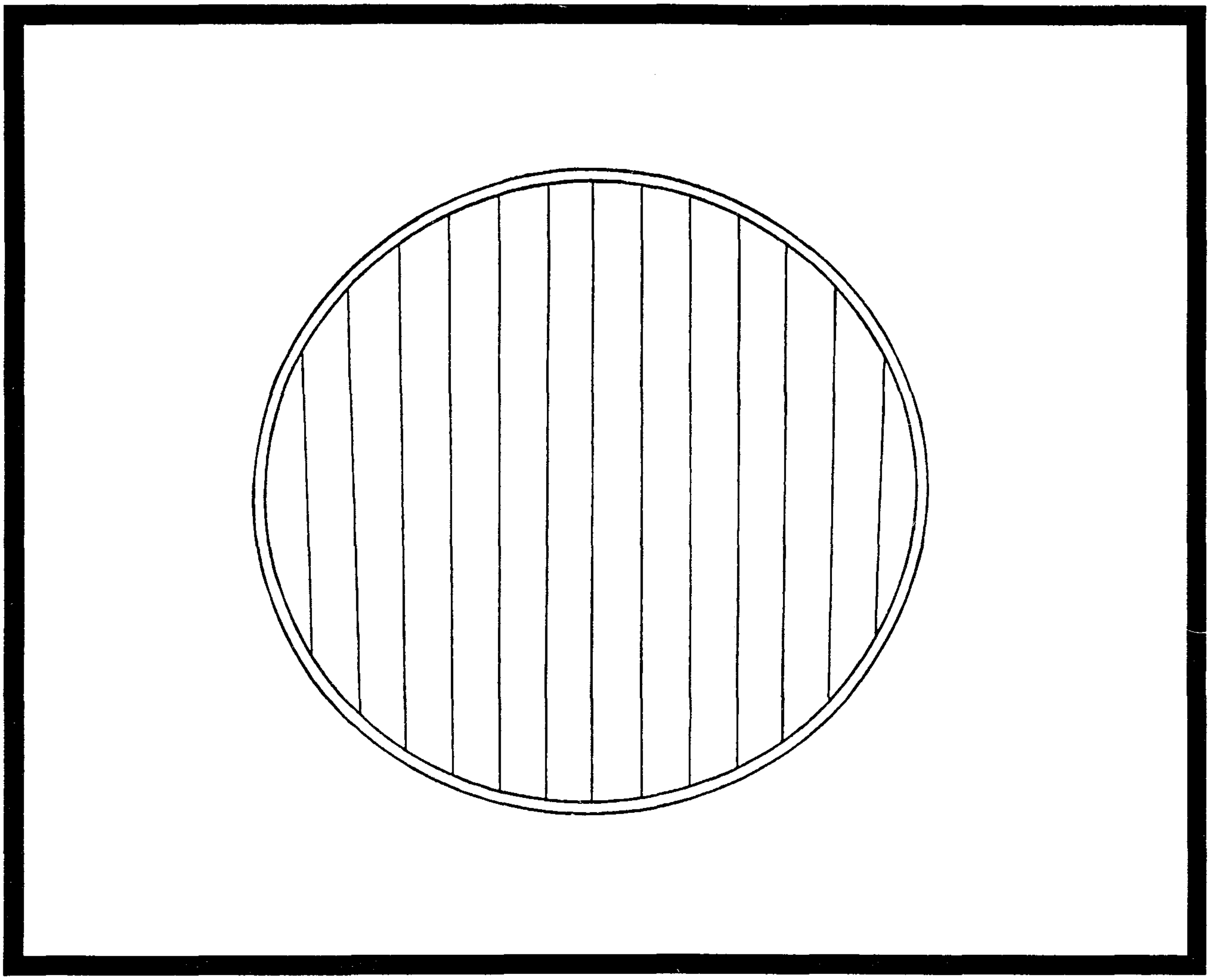
Appendix I, Figure 29

# HUMMER LINE



- o The hummer line is an industry developed technique used to stimulate fish to swim out of the path of the trawl.
- o It consists of a line of low stretch material which is positioned between the trawl doors ahead of the headrope.

# HUMMER STIMULATOR

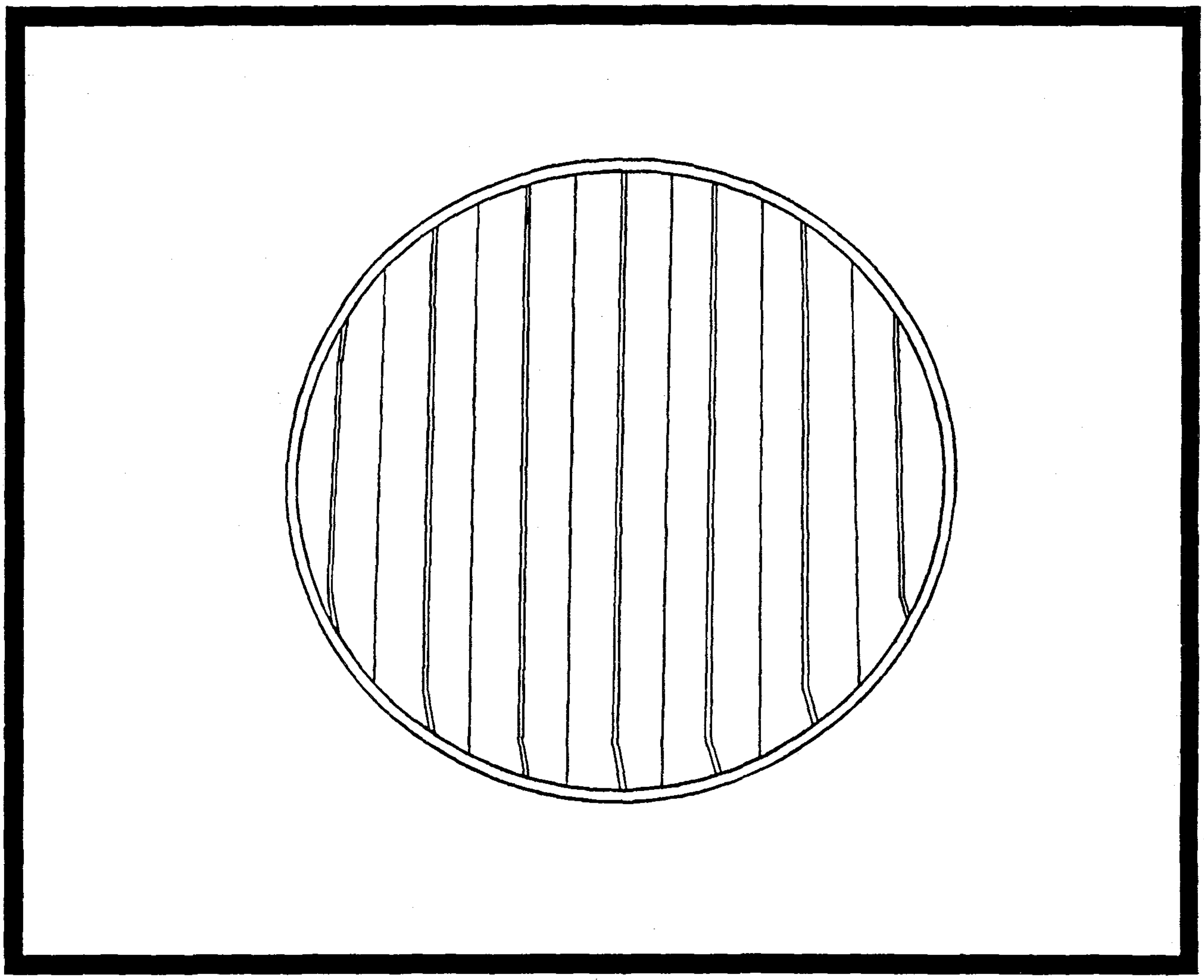


- o This design consists of a metal frame with small diameter steel cable threaded through the frame. The wires vibrate creating a stimulus which discourages fish from passing into the codend.

- o The stimulator is effective but has a tendency to become clogged with grass and other debris making it ineffective when these conditions occur.

Appendix I, Figure 31

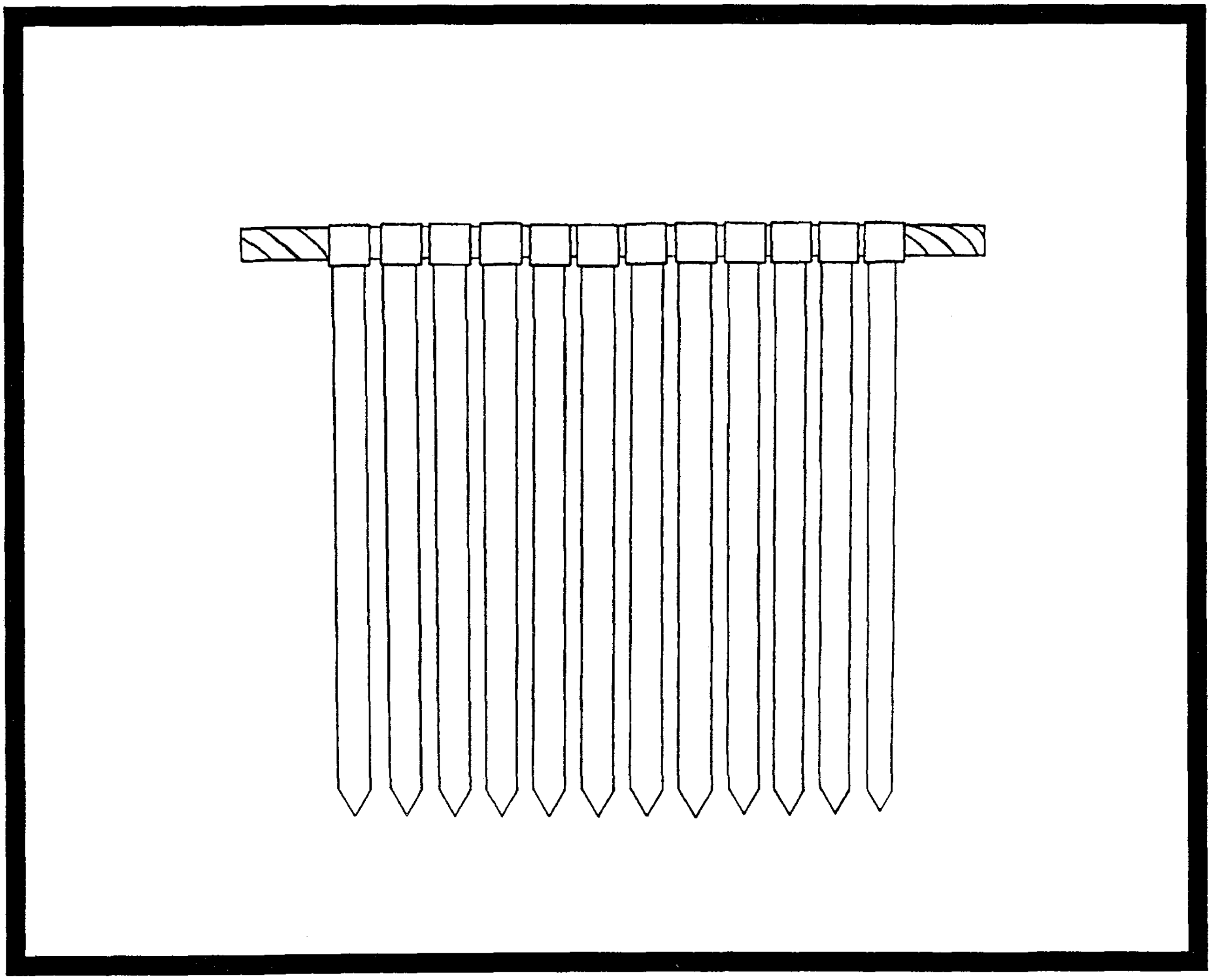
# WEEDLESS HUMMER STIMULATOR



- o This design incorporates curved bars between the small diameter wires to assist in shedding grass and other debris from the stimulator.
- o Diver evaluations and fish behavioral observations indicated that this design was not effective in eliciting desired fish response.

Appendix I, Figure 32

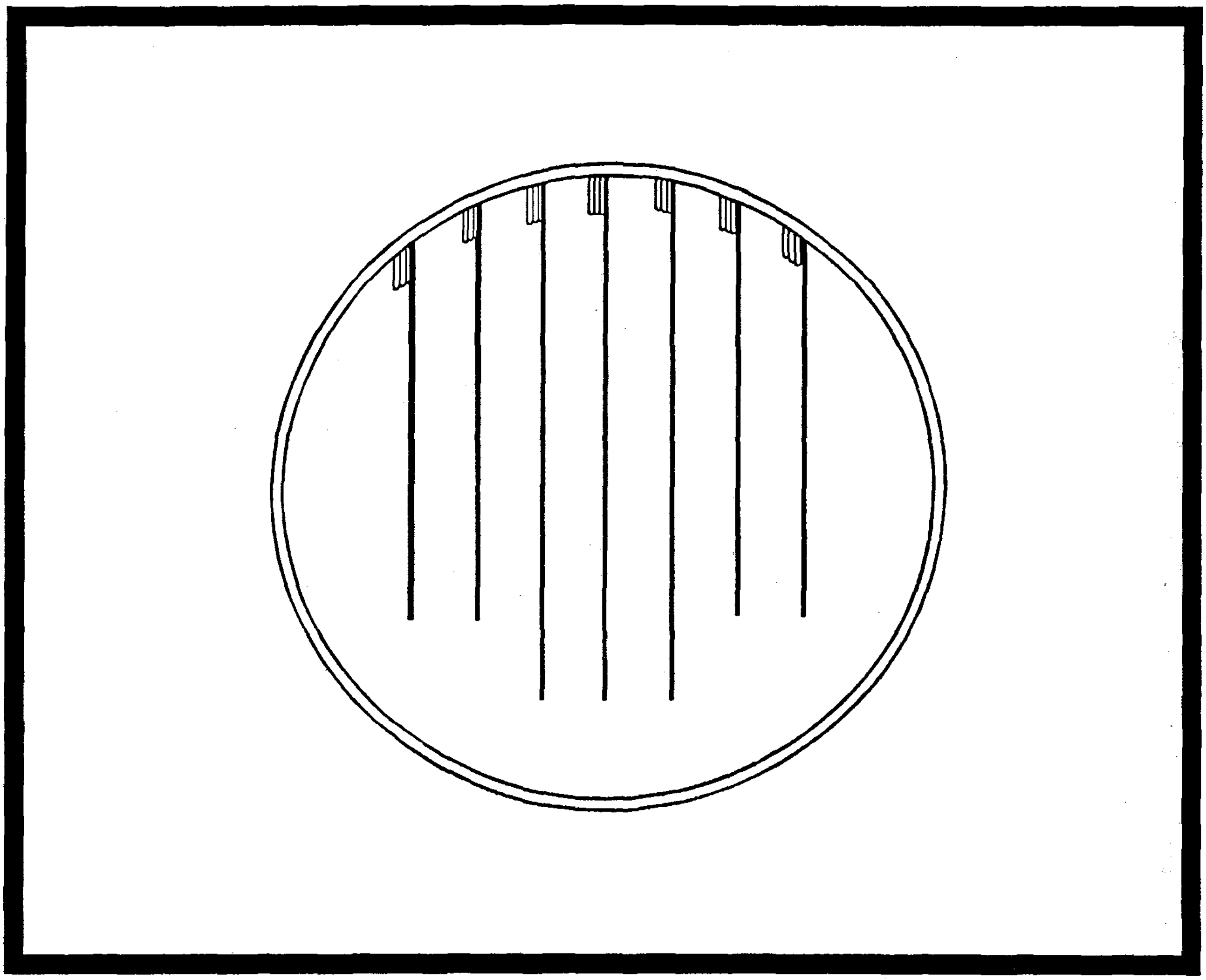
# TY-WRAP STIMULATOR



- This design consists of plastic Ty-wraps attached to a semi-rigid rope which is laced to the trawl webbing.
- The Ty-wrap stimulator was tested in conjunction with several reduction prototypes to increase fish escapement.

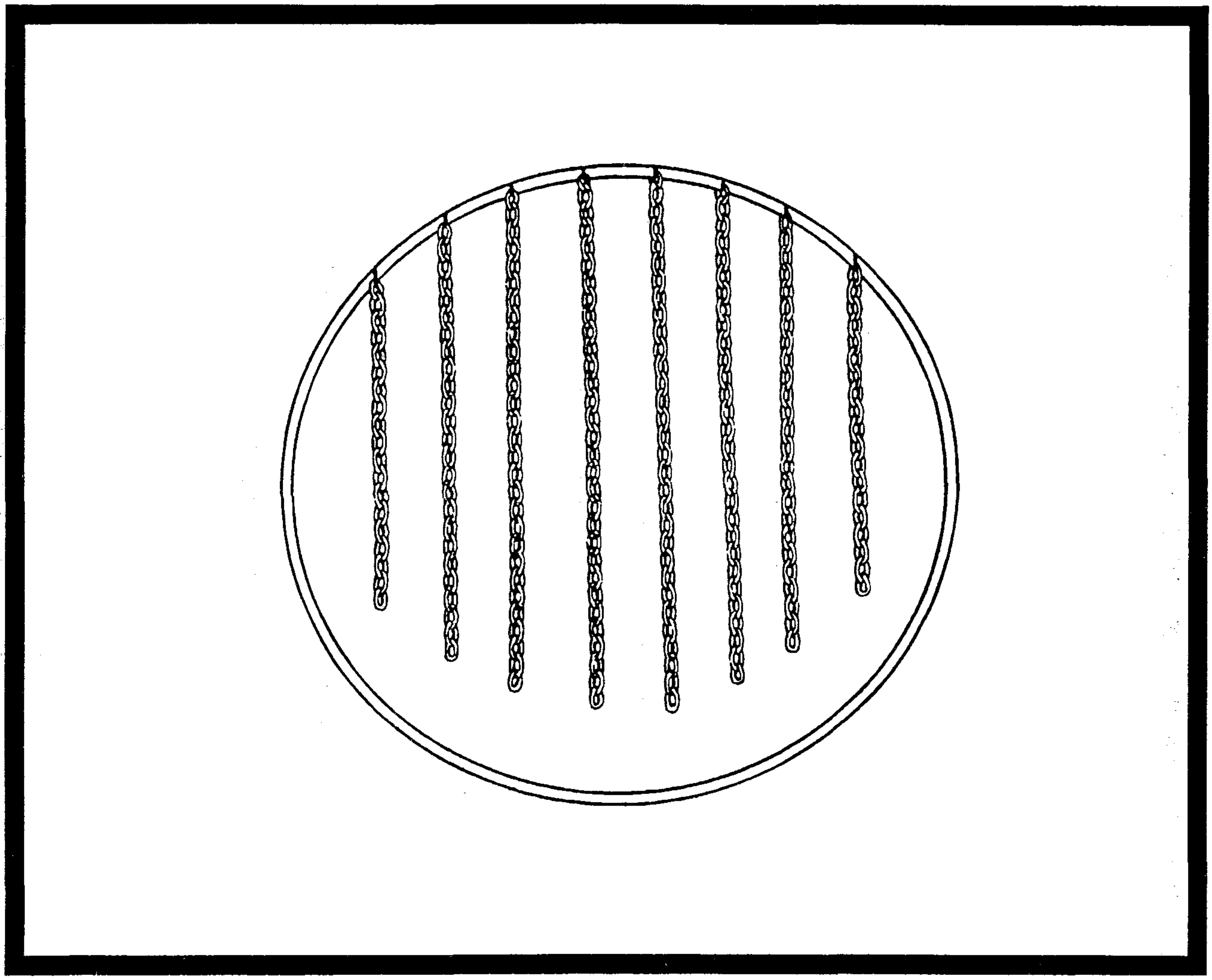
Appendix I, Figure 33

# SPRING STEEL STIMULATOR



- o This design is constructed of steel springs attached to a frame.
- o Diver evaluations and behavioral observations indicated this design was ineffective in eliciting the desired response

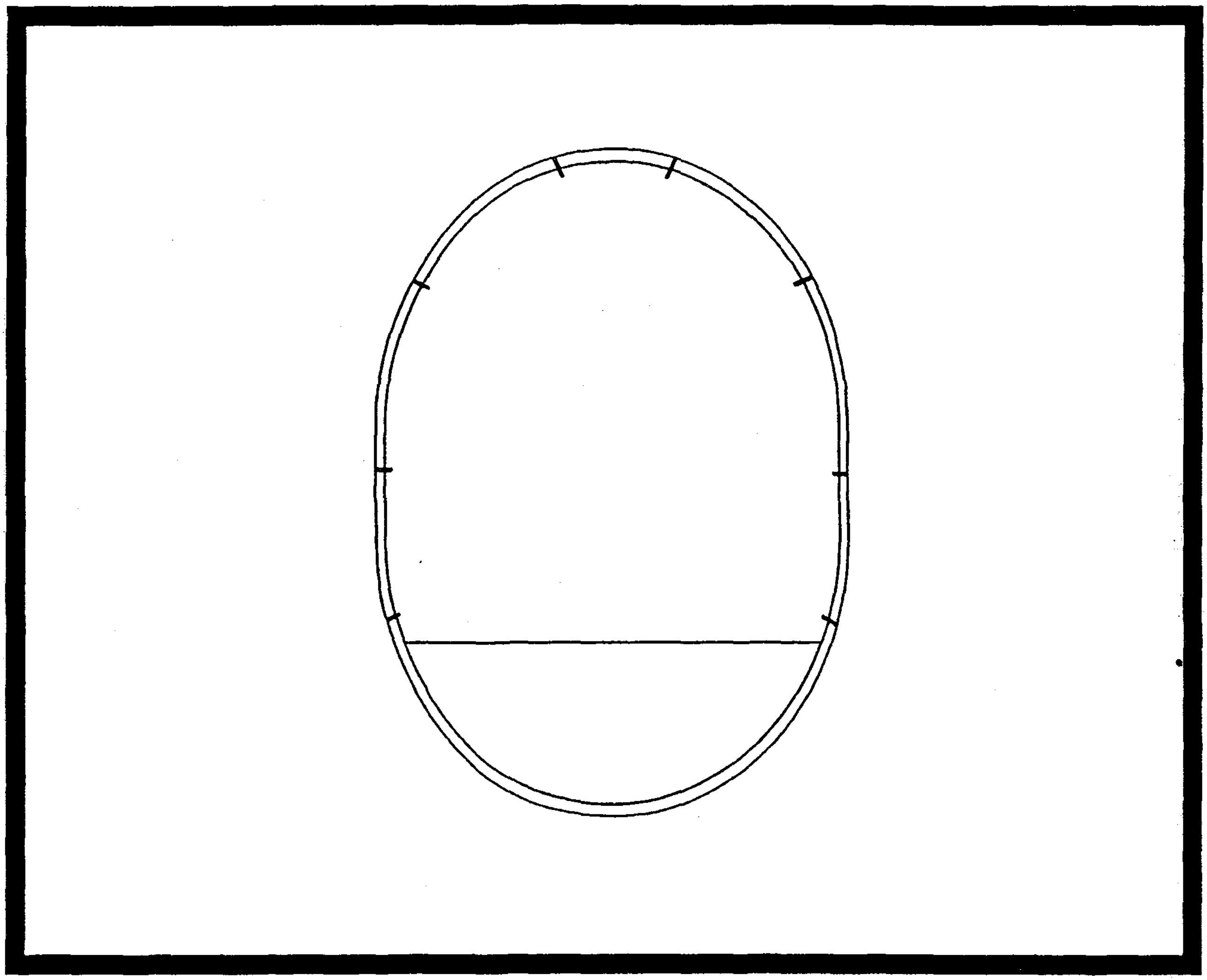
# CHAIN STIMULATOR



- o This stimulator design incorporates lengths of chain attached to a frame.
- o Diver evaluations and fish behavioral observations indicated that this design was ineffective in eliciting the desired fish response.

Appendix I, Figure 35

# SOLID PLASTIC STIMULATOR

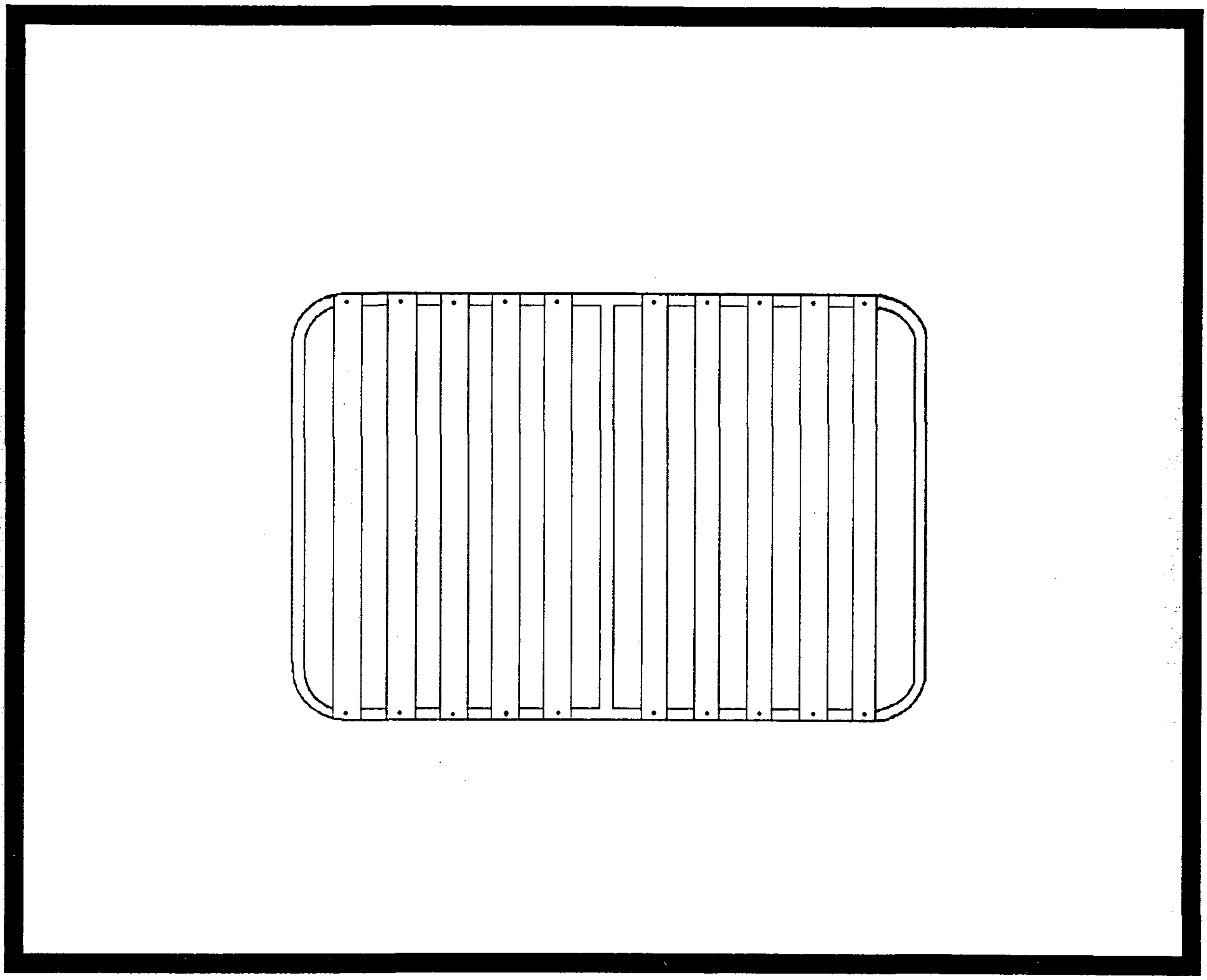


- o This fish stimulator design incorporated a solid plastic sheet attached to a frame.

- o Diver evaluations and fish behavioral observations indicated that this design was ineffective in eliciting the desired fish response.

Appendix I, Figure 36

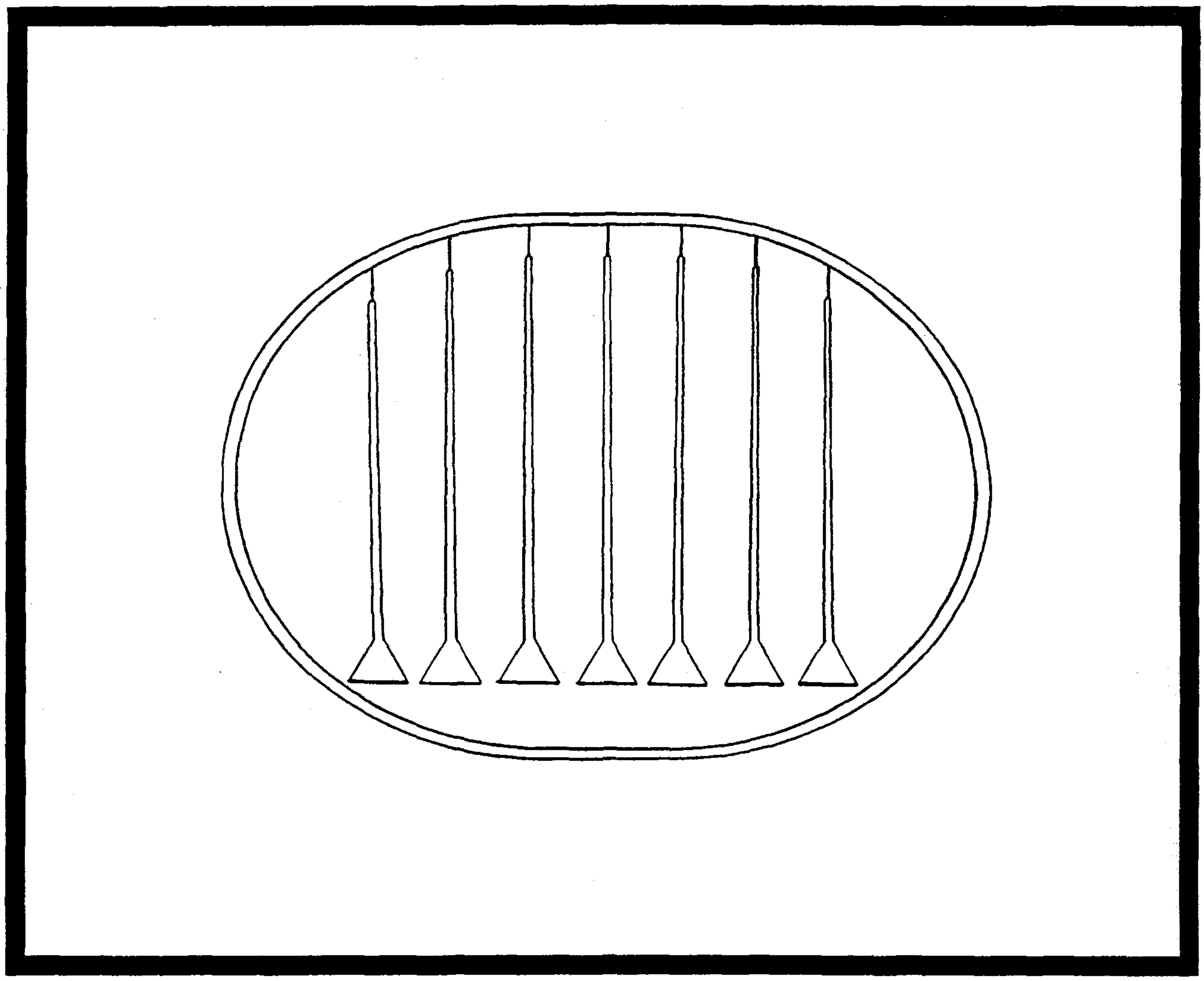
# PLASTIC STRIP STIMULATOR



- This design consists of plastic strips attached at both ends to an aluminum hoop.
- This stimulator was not effective, test results indicated that it decreased fish escapement.

Appendix I, Figure 37

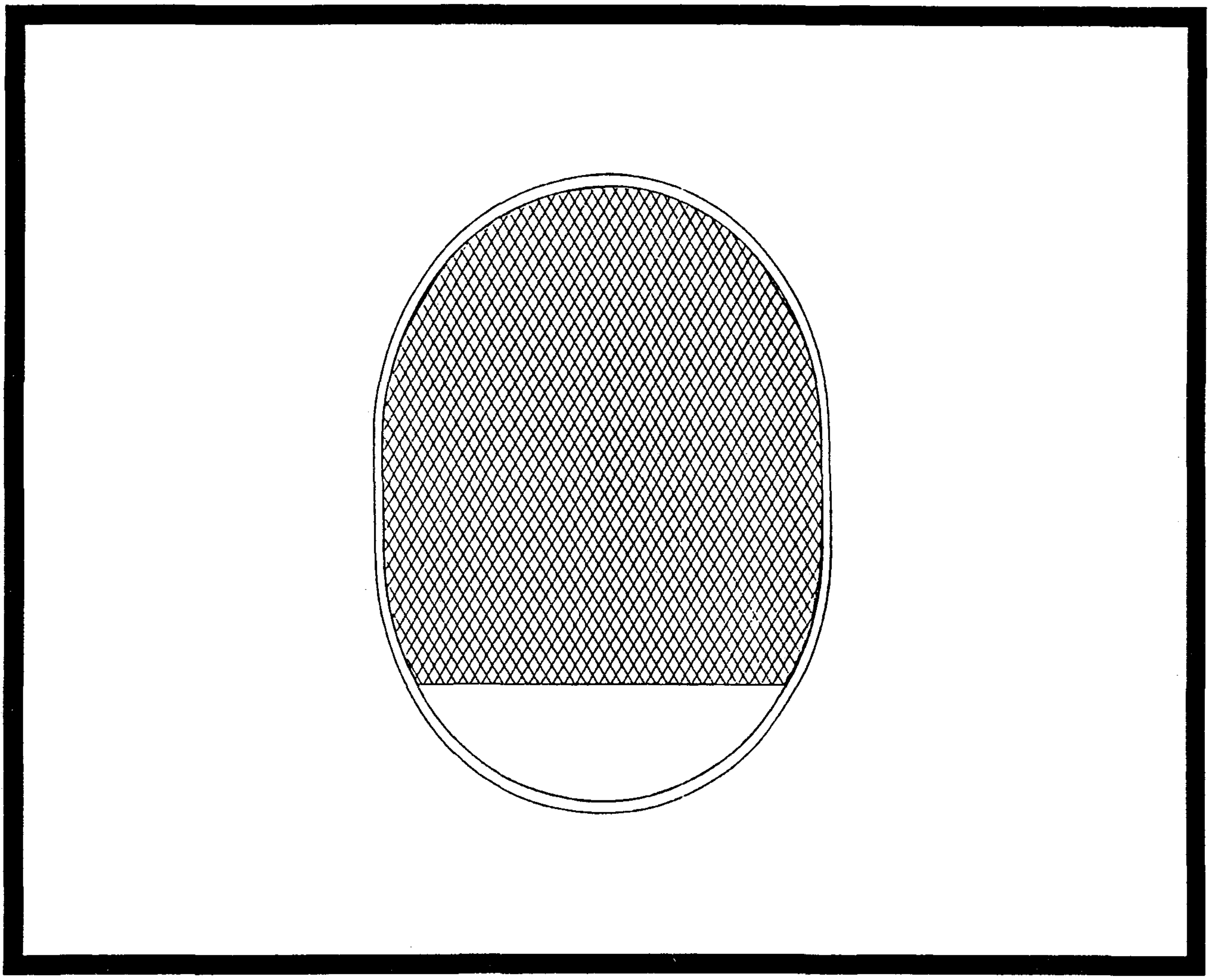
# COW BELL STIMULATOR



- This industry developed stimulator is constructed of rubber tubes, plastic funnels and lead weights and is designed to be completely weedless.

- Diver evaluations and fish behavioral observations indicated that this design was only marginally effective in eliciting the desired response.

# WEBBING STIMULATOR

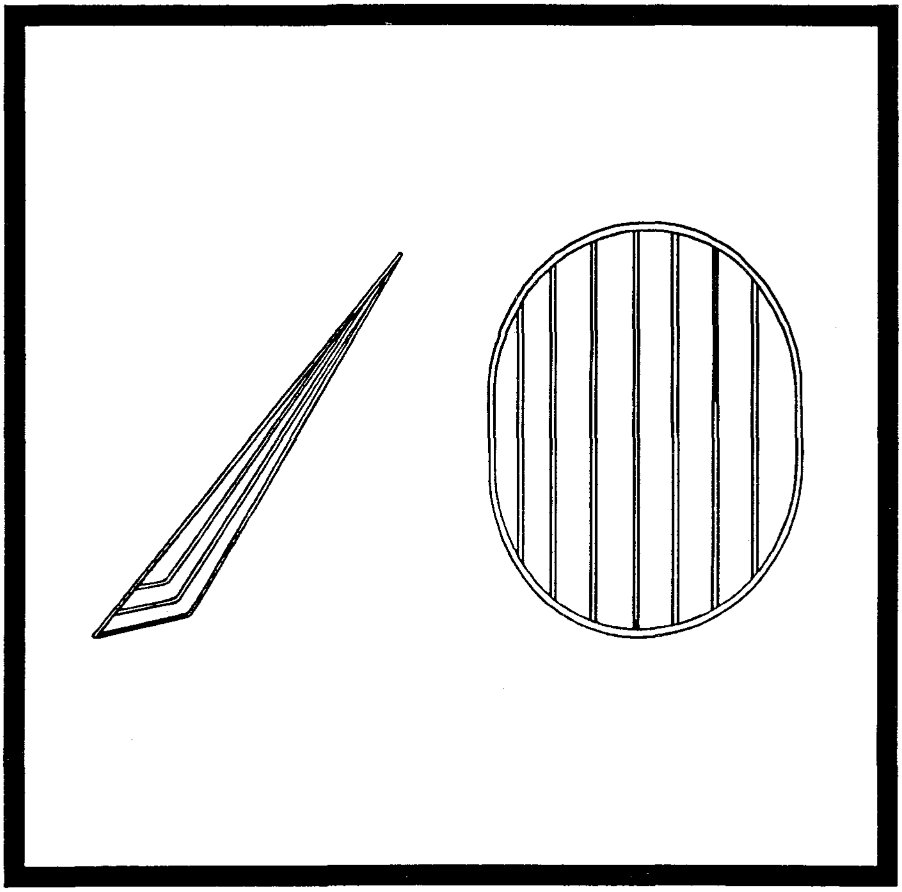


- This design incorporates a webbing panel attached to a frame.
- Diver evaluations and fish behavioral observations indicated this design was ineffective in eliciting the desired response

# APPENDIX II

# BRD PROOF OF CONCEPT TEST RESULTS

# SUPER SHOOTER TED



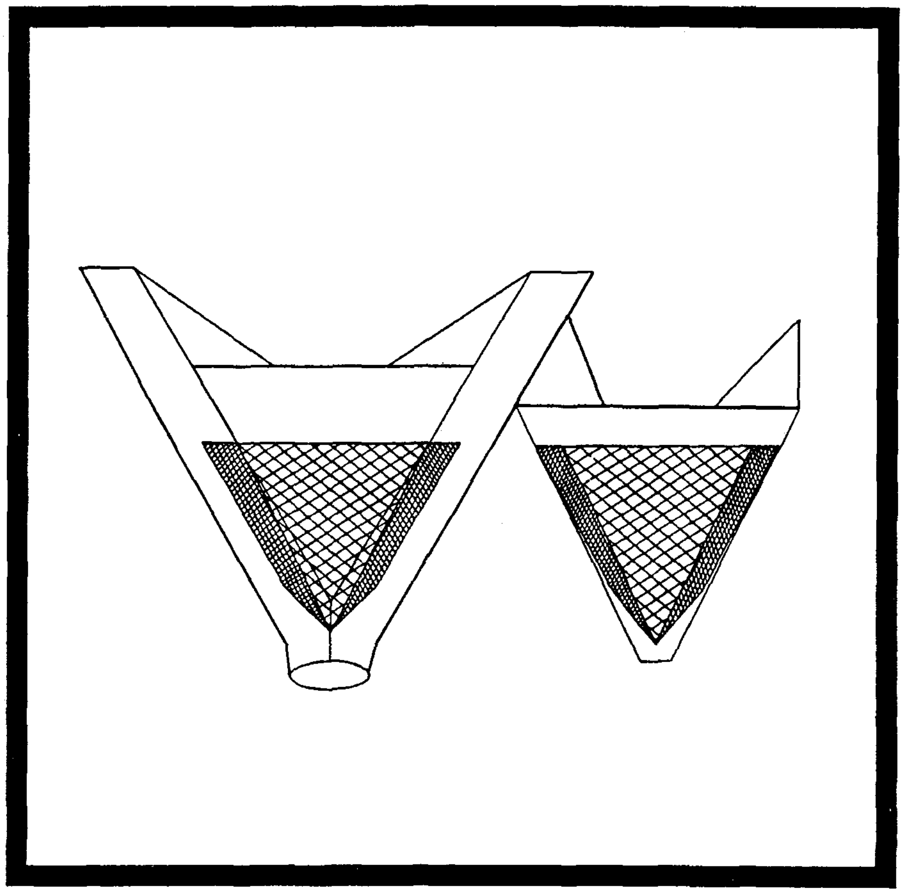
Number of Tows 237
Fish Reduction 4% NS
Shrimp Retention 99% NS

*SPECIES DATA UNAVALIBLE AT THIS TIME*

*Data presented from Renaud, Gitchlag, Klima, Shah, Koi and Nance,(1991)

Appendix II, Figure 1

# MODIFIED ANDREWS TED

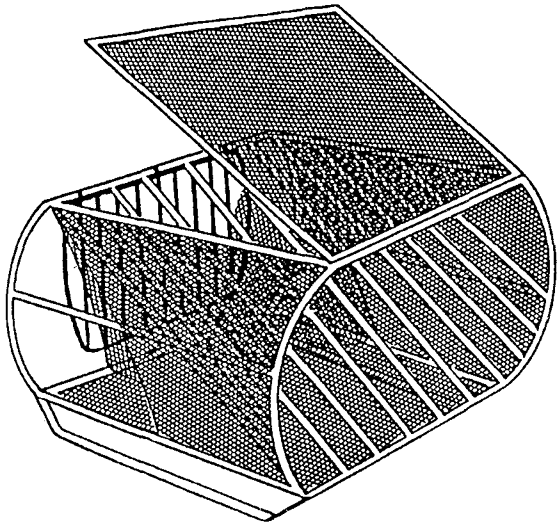


| | | |
|---|---|---|
| Number of Tows | 9 | |
| Fish Reduction | 25% | S |
| Shrimp Retention | 77% | S |

| DOMINANT SPECIES | | | IMPORTANT SPECIES | | |
|---|---|---|---|---|---|
| Croaker | 25% | NS | Red Snapper | 95% | NS |
| Spot | 30% | NS | Spanish Mackerel | ND | |
| Trout | + 142% | NS | King Mackerel | ND | |

Appendix II, Figure 2

# NMFS TED



| | | |
|---|---|---|
| Number of Tows | 16 | |
| Fish Reduction | 51% | S |
| Shrimp Retention | 98% | NS |

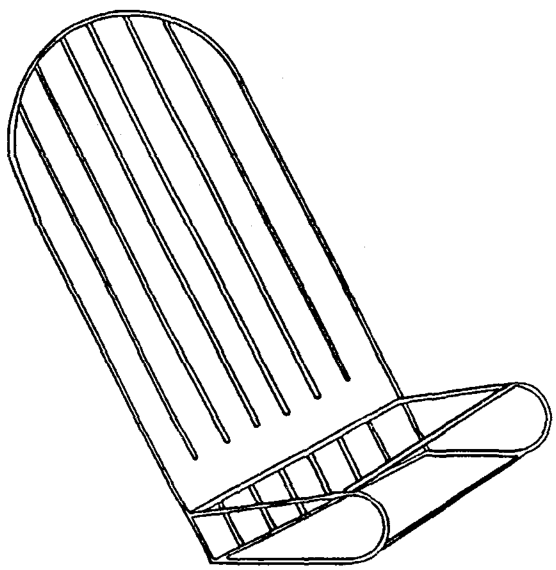
| DOMINANT SPECIES | |
|---|---|
| Croaker | 56% |
| Spot | 72% |
| Trout | 40% |
| Cutlassfish | 70% |
| Butterfish | 56% |
| Atlantic Bumper | 67% |

| IMPORTANT SPECIES | |
|---|---|
| Red Snapper | ND |
| Spanish Mackerel | ND |
| King Mackerel | ND |

* Data presented from Watson, Mitchell and Shah, (1986)

Appendix II, Figure 3

# HSB EXCLUDER



**ATTACHED TO BOTTOM OF TED**

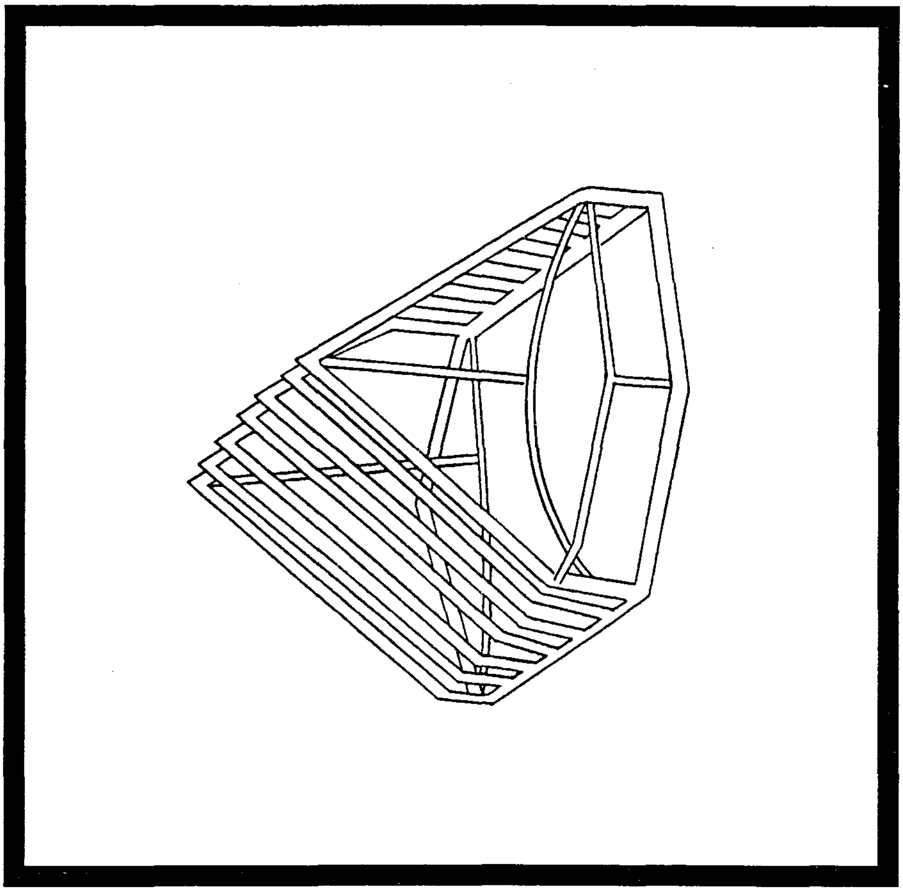
| | | |
|---|---|---|
| Number of Tows | 40 | |
| Fish reduction | 45% | S |
| Shrimp Retention | 94% | S |

| DOMINANT SPECIES | | |
|---|---|---|
| Croaker | 46% | S |
| Butterfish | 64% | NA |
| Spot | 75% | S |
| Atlantic Bumper | 60% | NA |
| Trout | 22% | NS |
| Catfish | 76% | NA |
| Whiting | 57% | NA |

| IMPORTANT SPECIES | | |
|---|---|---|
| Red Snapper | 42% | NS |
| Spanish Mackerel | 5% | NS |
| King Mackerel | 0% | NS |

Appendix II, Figure 4

# TOP AND BOTTOM OPENING TED

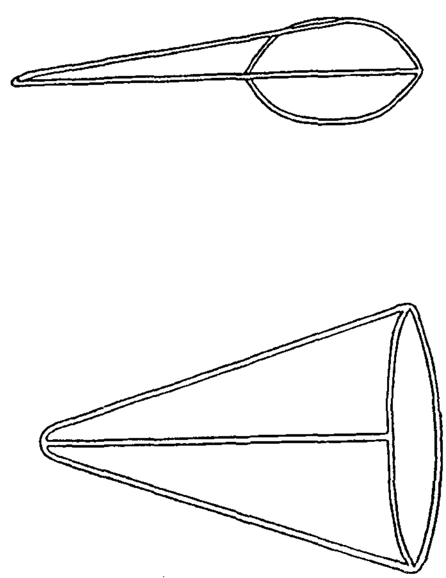


| | | |
|---|---|---|
| Number of Tows | 3 | |
| Fish Reduction | 49% | NS |
| Shrimp Retention | 90% | NS |

| DOMINANT SPECIES | | | IMPORTANT SPECIES | | |
|---|---|---|---|---|---|
| Croaker | 45% | NS | Red Snapper | + 100% | NS |
| Butterfish | 90% | NA | Spanish Mackerel | + 34% | NS |
| Catfish | 42% | NA | King Mackerel | ND | |
| Trout | 59% | NS | | | |
| Spot | 78% | NS | | | |

Appendix II, Figure 5

# FISHEYE



**TOP POSITION - POINTING AFT**

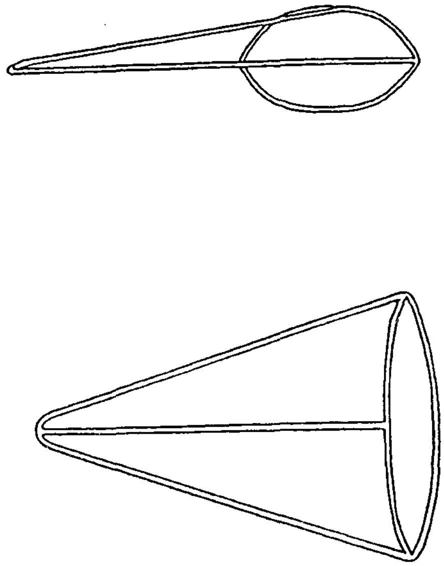
| | | |
|---|---|---|
| Number of Tows | 5 | |
| Fish reduction | 58% | S |
| Shrimp Retention | 85% | NS |

| DOMINANT SPECIES | | |
|---|---|---|
| Trout | 78% | NA |
| Spot | 86% | NS |
| Croaker | 58% | NS |
| Whiting | 77% | NA |

| IMPORTANT SPECIES | | |
|---|---|---|
| Red Snapper | ND | |
| Spanish Mackerel | 100% | NS |
| King Mackerel | ND | |

Appendix II, Figure 6

# FISHEYE



TOP OF CODEND - APEX FORWARD

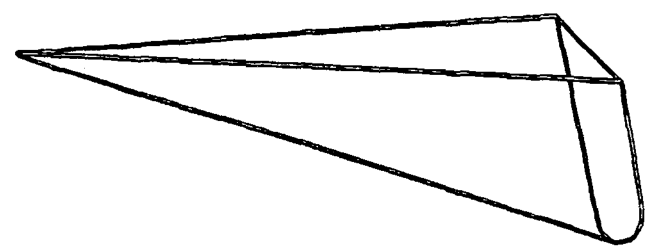
| | | |
|---|---|---|
| Number of Tows | 10 | |
| Fish reduction | 67% | S |
| Shrimp Retention | 83% | S |

| DOMINANT SPECIES | | |
|---|---|---|
| Catfish | 84% | NA |
| Spot | 59% | NS |
| Croaker | 83% | S |
| Trout | 77% | NA |

| IMPORTANT SPECIES | | |
|---|---|---|
| Red Snapper | 37% | NS |
| Spanish Mackerel | 45% | NS |
| King Mackerel | 71% | NS |

Appendix II, Figure 7

# LIONEL FISHEYE



TOP OF CODEND
APEX POINTING FORWARD

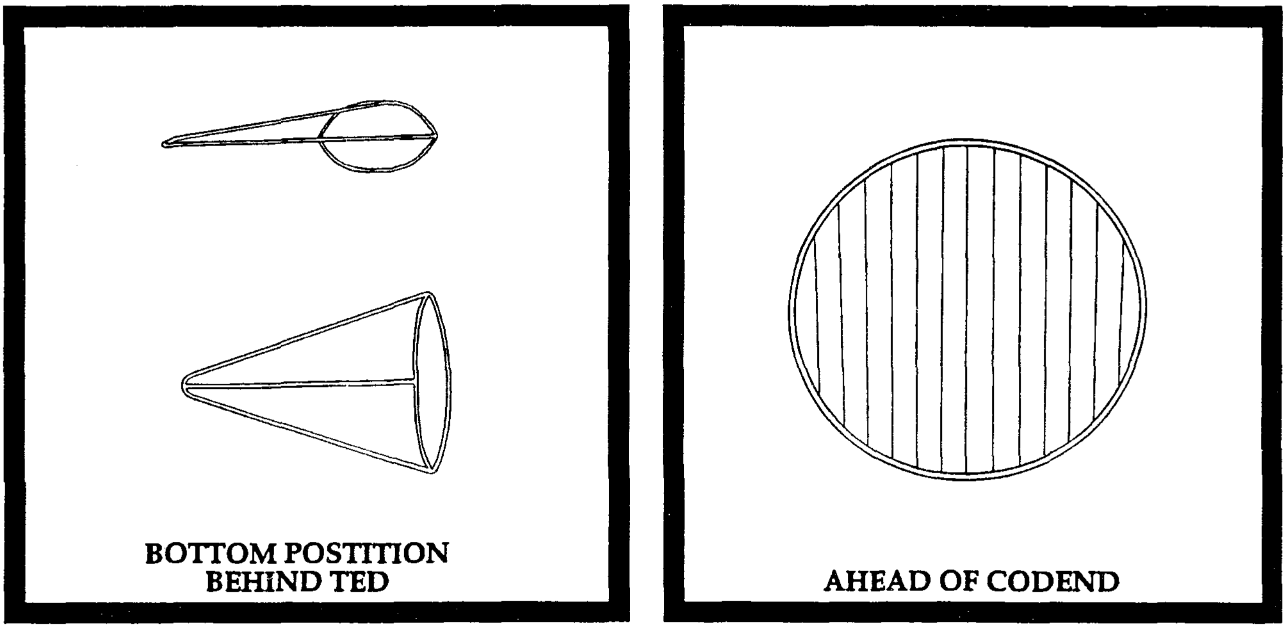
| | | |
|---|---|---|
| Number of Tows | 10 | |
| Fish reduction | 7% | NS |
| Shrimp Retention | 100% | NS |

| DOMINANT SPECIES | | |
|---|---|---|
| Croaker | 15% | NS |
| Spot | 16% | NS |
| Atlantic Bumper | + 10% | NA |
| Trout | + 69% | S |
| Cutlass Fish | 12% | NA |

| IMPORTANT SPECIES | | |
|---|---|---|
| Red Snapper | + 500% | NS |
| Spanish Mackerel | 2% | NS |
| King Mackerel | ND | |

Appendix II, Figure 8

# FISHEYE WITH HUMMER STIMULATOR




| | |
|---|---|
| Number of Tows | 20 |
| Fish reduction | 20% NS |
| Shrimp Retention | 100% NS |

## DOMINANT SPECIES

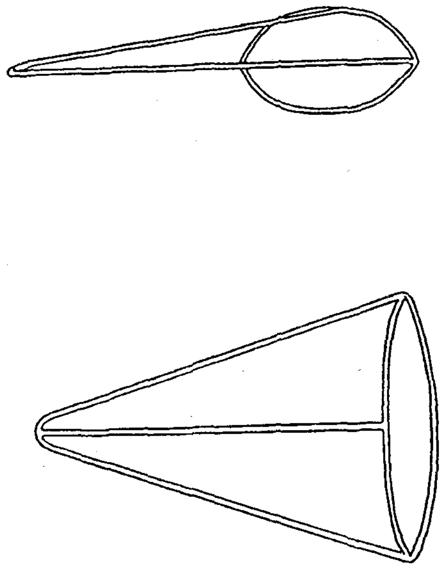
| | | |
|---|---|---|
| Atlantic Bumper | 36% | S |
| Long Spine Porgy | 11% | NA |
| Butterfish | 27% | NA |
| Catfish | 71% | NS |
| Trout | 51% | NA |

## IMPORTANT SPECIES

| | | |
|---|---|---|
| Red Snapper | + 10% | NS |
| Spanish Mackerel | 56% | NS |
| King Mackerel | 44% | NS |

Appendix II, Figure 9

# DOUBLE FISHEYE



**BEHIND TED**

| | | |
|---|---|---|
| Number of Tows | 11 | |
| Fish reduction | 25% | S |
| Shrimp Retention | 92% | NS |

## DOMINANT SPECIES

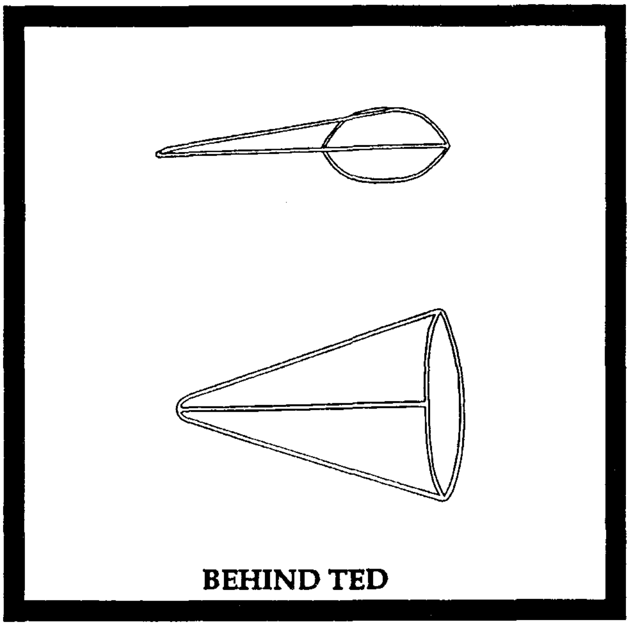
| | | |
|---|---|---|
| Croaker | 31% | S |
| Butterfish | 53% | NA |
| Spot | 51% | NS |
| Atlantic Bumper | 63% | NS |
| Long Spine Porgy | 23% | NA |
| Trout | + 19% | NA |

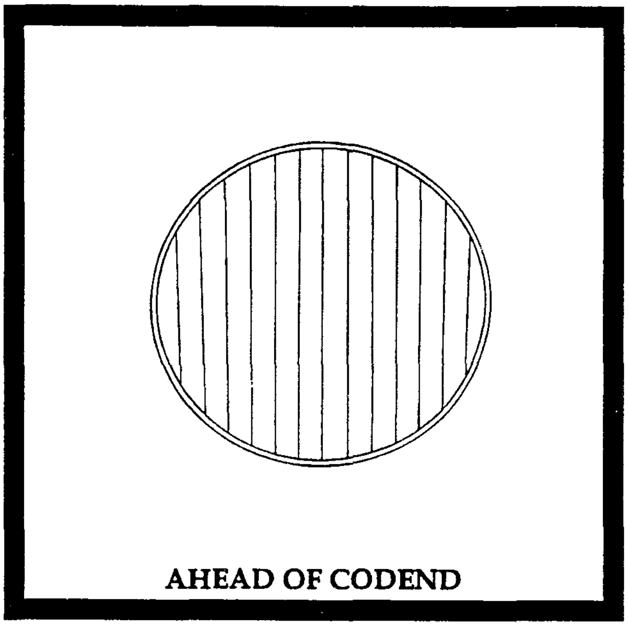
## IMPORTANT SPECIES

| | | |
|---|---|---|
| Red Snapper | 95% | NS |
| Spanish Mackerel | 14% | NS |
| King Mackerel | + 11% | NS |

Appendix II, Figure 10

# DOUBLE FISHEYE WITH HUMMER STIMULATOR




| | | |
|---|---|---|
| Number of Tows | 12 | |
| Fish reduction | 38% | S |
| Shrimp Retention | 75% | S |

DOMINANT SPECIES

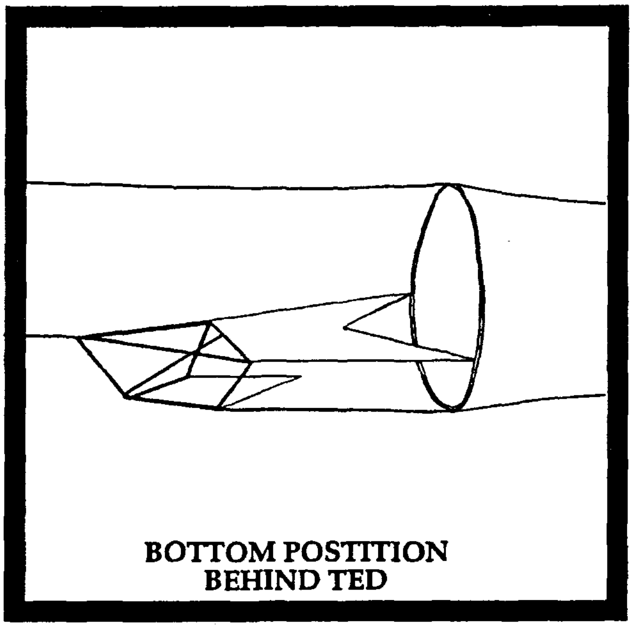
| | | |
|---|---|---|
| Croaker | 71% | NS |
| Catfish | 73% | NA |

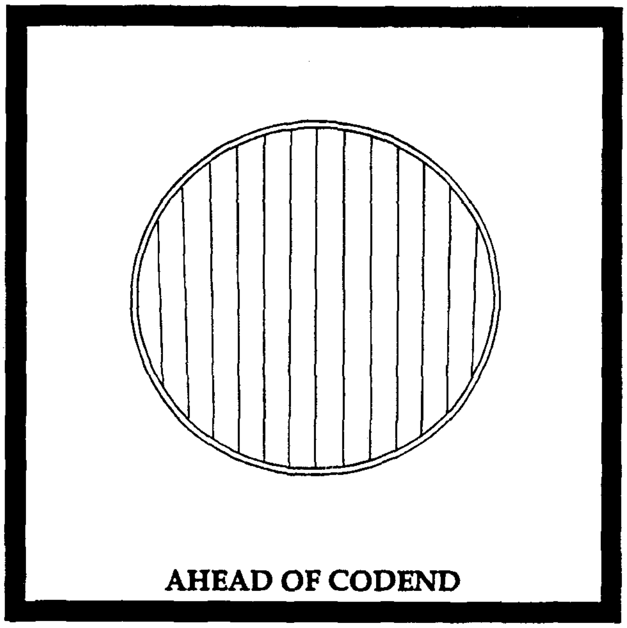
IMPORTANT SPECIES

| | | |
|---|---|---|
| Red Snapper | 38% | NS |
| Spanish Mackerel | 48% | NS |
| King Mackerel | 24% | NS |

Appendix II, Figure 11

# DOUBLE V EXCLUDER WITH HUMMER STIMULATOR




| | | |
|---|---|---|
| Number of Tows | 17 | |
| Fish reduction | 20% | S |
| Shrimp Retention | 76% | S |

## DOMINANT SPECIES

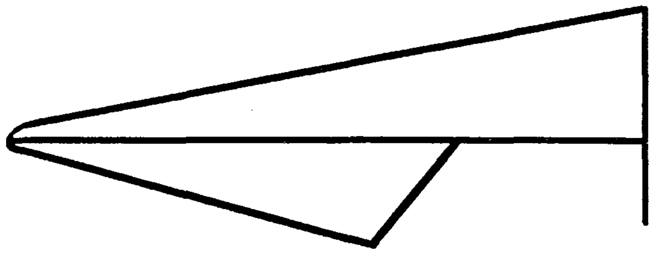
| | | |
|---|---|---|
| Long Spine Porgy | 1% | NA |
| Croaker | 37% | S |
| Trout | 56% | S |
| Catfish | 93% | NA |
| Whiting | 36% | NA |
| Spot | 66% | NS |

## IMPORTANT SPECIES

| | | |
|---|---|---|
| Red Snapper | 67% | NS |
| Spanish Mackerel | 27% | NS |
| King Mackerel | ND | |

# RWF FISHEYE

## WITH PLASTIC PANEL ATTACHED



BOTTOM POSITION
BEHIND TED

| | | |
|---|---|---|
| Number of Tows | 12 | |
| Fish Reduction | 21% | S |
| Shrimp Retention | 94% | NS |

DOMINANT SPECIES

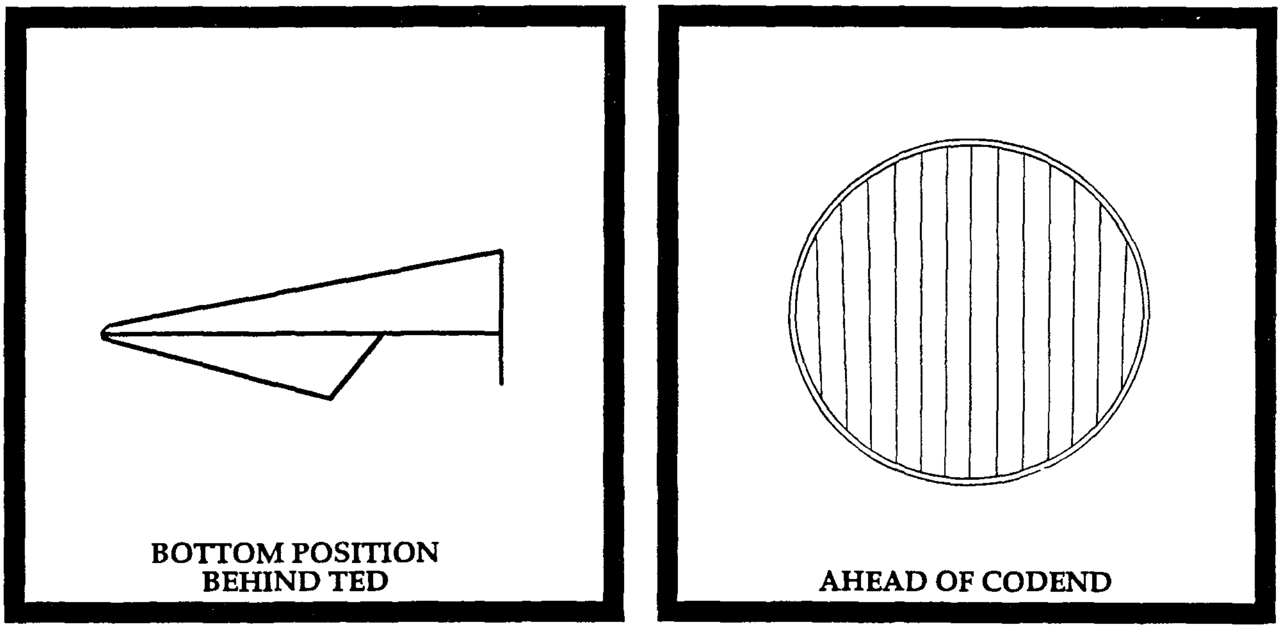
| | | |
|---|---|---|
| Long Spine Porgy | 13% | NA |

IMPORTANT SPECIES

| | | |
|---|---|---|
| Red Snapper | + 100% | NS |
| Spanish Mackerel | 35% | NS |
| King Mackerel | ND | |

Appendix II, Figure 13

# RWF FISHEYE WITH HUMMER STIMULATOR




| | | |
|---|---|---|
| Number of Tows | 16 | |
| Fish Reduction | 50% | S |
| Shrimp Retention | 85% | NS |

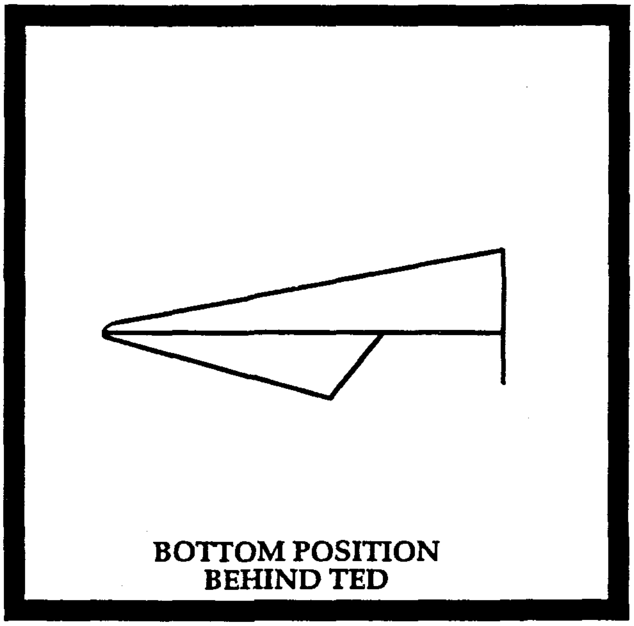
| DOMINANT SPECIES | | |
|---|---|---|
| Croaker | 60% | S |
| Catfish | 81% | NS |
| Trout | 39% | NA |
| Spot | 80% | NA |
| Cobia | + 15% | NA |

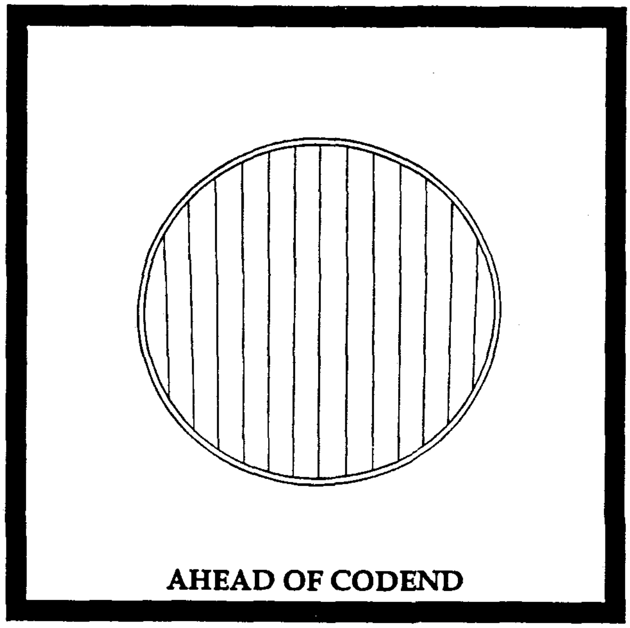
| IMPORTANT SPECIES | | |
|---|---|---|
| Red Snapper | 51% | S |
| Spanish Mackerel | 64% | NS |
| King Mackerel | 24% | NS |

Appendix II, Figure 14

# RWF FISHEYE WITH HUMMER STIMULATOR

## WITH A WEBBING LEAD PANEL ATTACHED TO THE FISHEYE




| | | |
|---|---|---|
| Number of Tows | 40 | |
| Fish Reduction | 56% | S |
| Shrimp Retention | 64% | S |

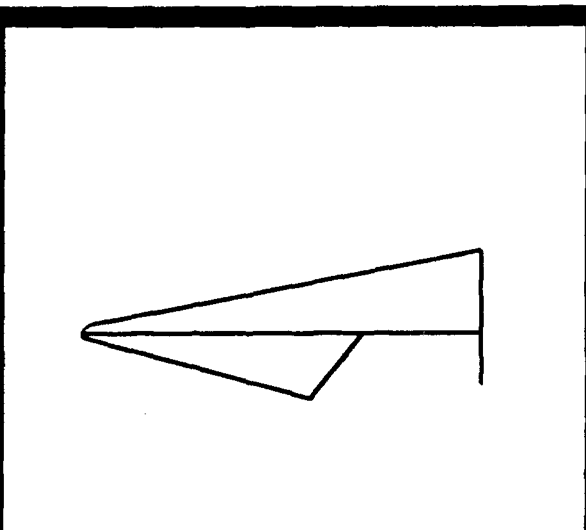
| DOMINANT SPECIES | | |
|---|---|---|
| Catfish | 89% | S |
| Croaker | 75% | S |
| Trout | 53% | NA |

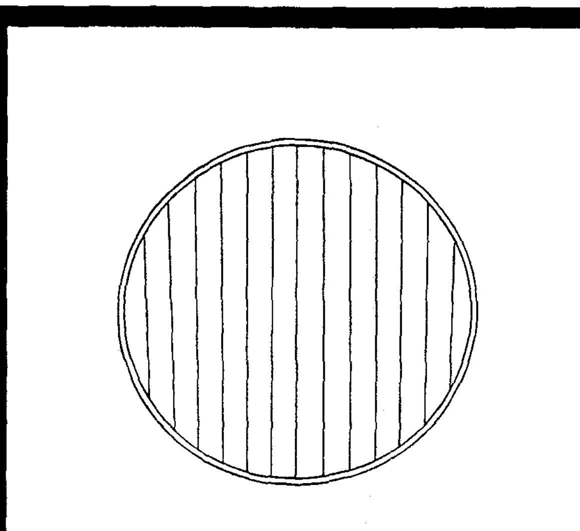
| IMPORTANT SPECIES | | |
|---|---|---|
| Red Snapper | 47% | S |
| Spanish Mackerel | 42% | NS |
| King Mackerel | 35% | NS |

Appendix II, Figure 15

# RWF FISHEYE WITH HUMMER STIMULATOR

## WITH A PLASTIC PANEL ATTACHED TO THE FISHEYE



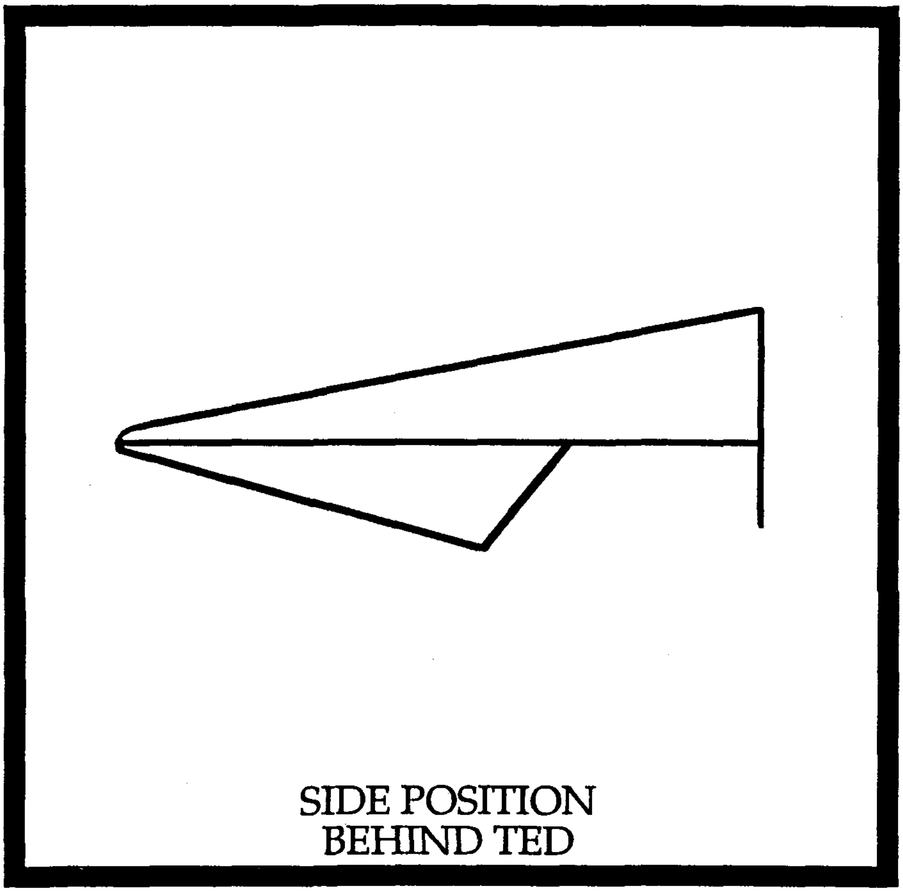

| | | |
|---|---|---|
| Number of Tows | 14 | |
| Fish Reduction | 15% | NS |
| Shrimp Retention | 80% | S |

| DOMINANT SPECIES | | |
|---|---|---|
| Long Spine Porgy | + 4% | NA |
| Butterfish | 36% | NA |
| Catfish | 79% | NA |

| IMPORTANT SPECIES | | |
|---|---|---|
| Red Snapper | + 34% | NS |
| Spanish Mackerel | + 196% | NS |
| King Mackerel | 100% | NS |

Appendix II, Figure 16

# DOUBLE RWF FISHEYE



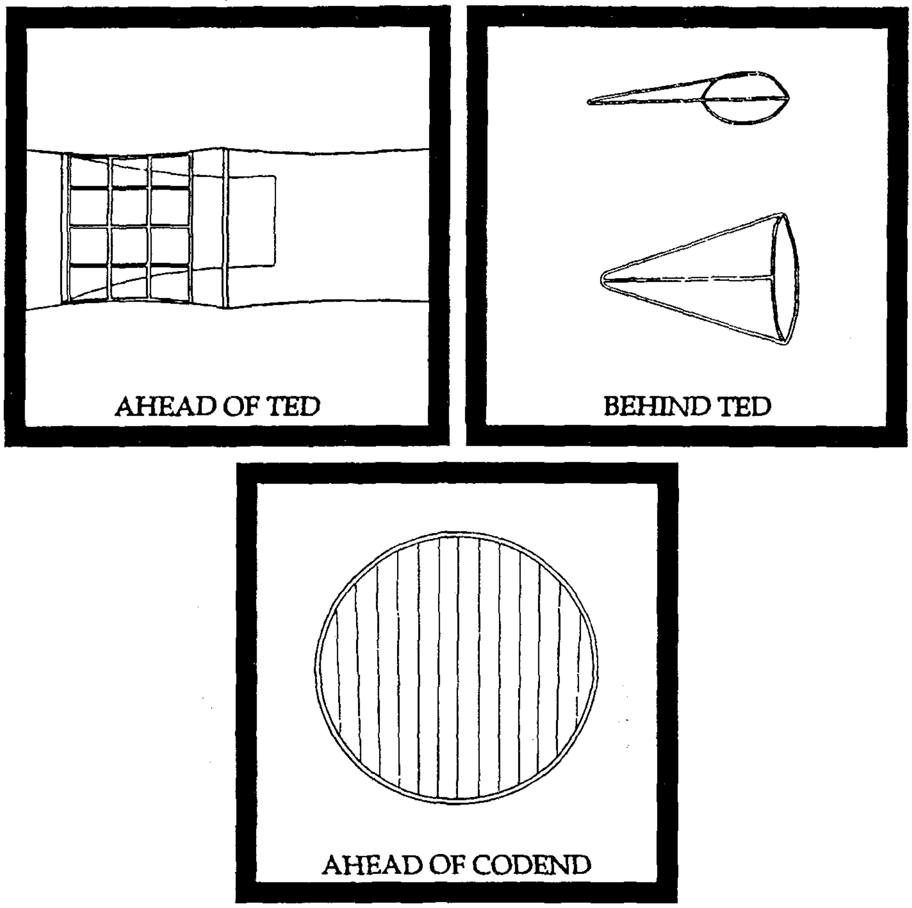

| | | |
|---|---|---|
| Number of Tows | 20 | |
| Fish Reduction | 36% | S |
| Shrimp Retention | 81% | S |

| DOMINANT SPECIES | | |
|---|---|---|
| Croaker | 43% | S |
| Spot | 25% | S |
| Trout | 38% | NS |
| Catfish | 80% | NA |
| Long Spine Porgy | 38% | NA |
| Whiting | 32% | NA |
| Atlantic Bumper | +1% | NA |

| IMPORTANT SPECIES | | |
|---|---|---|
| Red Snapper | 38% | NS |
| Spanish Mackerel | +64% | NS |
| King Mackerel | +7% | NS |

Appendix II, Figure 17

# LARGE MESH/FUNNEL EXCLUDER, DOUBLE FISHEYE & HUMMER STIMULATOR




| | | |
|---|---|---|
| Number of Tows | 16 | |
| Fish reduction | 56% | S |
| Shrimp Retention | 100% | NS |

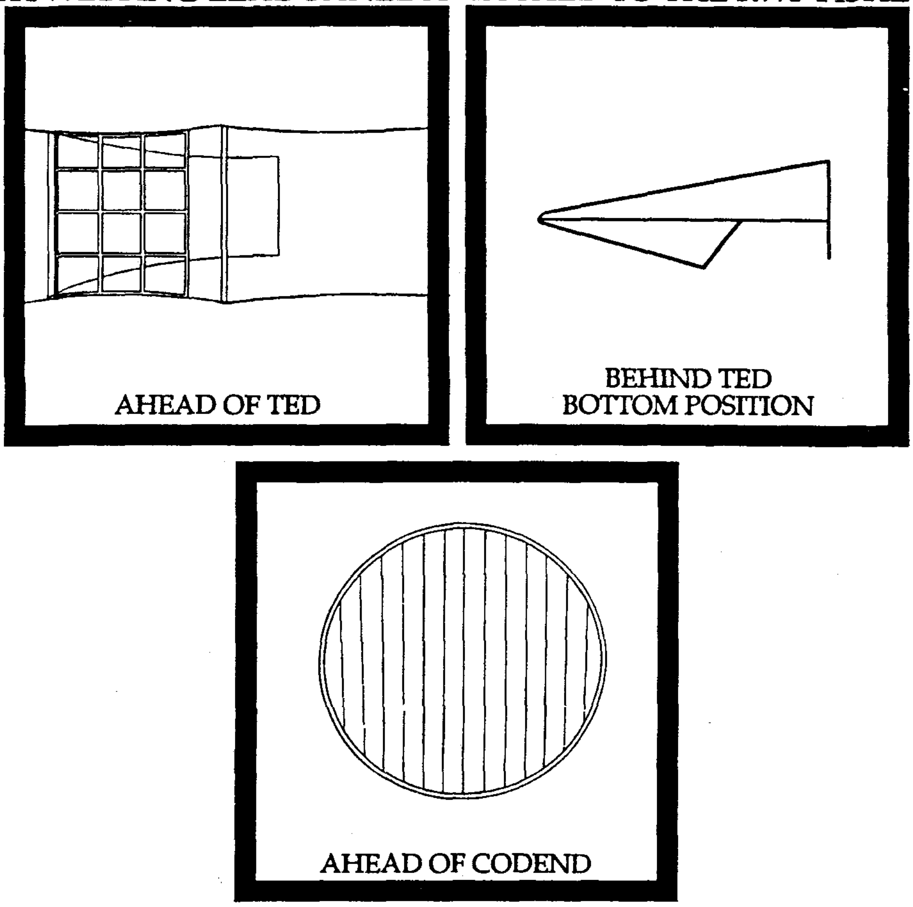
| DOMINANT SPECIES | | |
|---|---|---|
| Atlantic Bumper | 83% | S |
| Catfish | 74% | NA |
| Croaker | 25% | NS |
| Whiting | 100% | NA |
| Spot | 9% | NS |
| Long Spine Porgy | 34% | NA |
| Butterfish | 72% | NA |

| IMPORTANT SPECIES | | |
|---|---|---|
| Red Snapper | 2% | NS |
| Spanish Mackerel | 44% | NS |
| King Mackerel | + 35% | NS |

Appendix II, Figure 18

# LARGE MESH/FUNNEL & RWF FISHEYE WITH HUMMER STIMULATOR

WITH WEBBING LEAD PANEL ATTACHED TO THE RWF FISHEYE



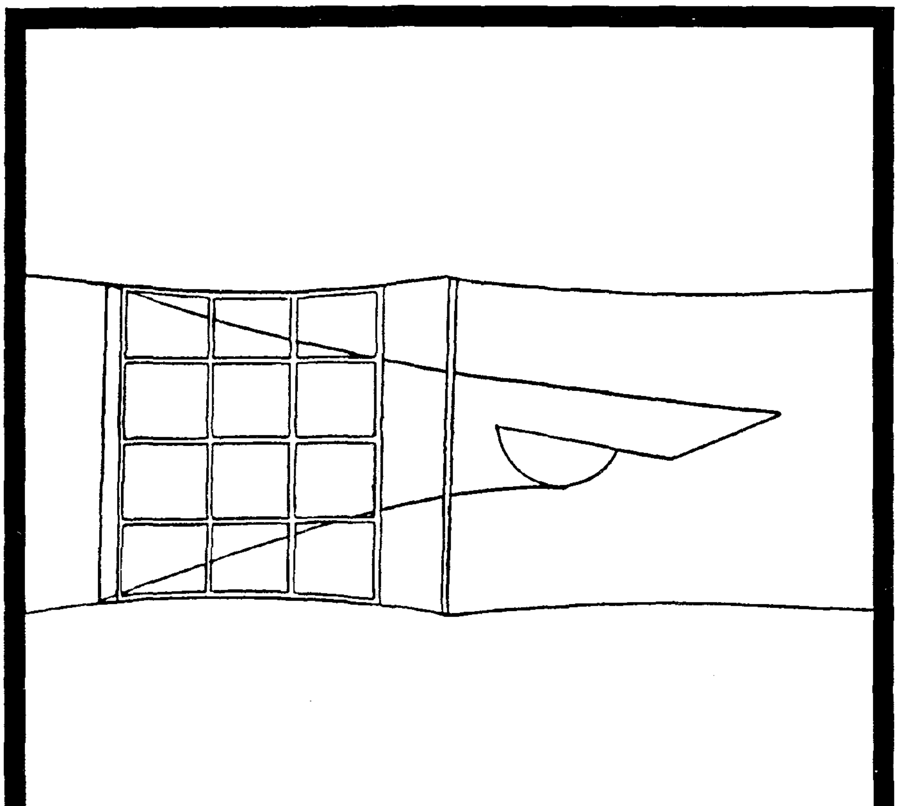

| | | |
|---|---|---|
| Number of Tows | 20 | |
| Fish Reduction | 54% | S |
| Shrimp Retention | 92% | S |

| DOMINANT SPECIES | | |
|---|---|---|
| Catfish | 98% | S |
| Croaker | 74% | NS |
| Long Spine Porgy | 3% | NA |
| Atlantic Bumper | 65% | S |
| Spot | 70% | NA |

| IMPORTANT SPECIES | | |
|---|---|---|
| Red Snapper | 51% | S |
| Spanish Mackerel | ND | |
| King Mackerel | + 315% | NS |

Appendix II, Figure 19

# EXTENDED FUNNEL EXCLUDER



**BEHIND TED**

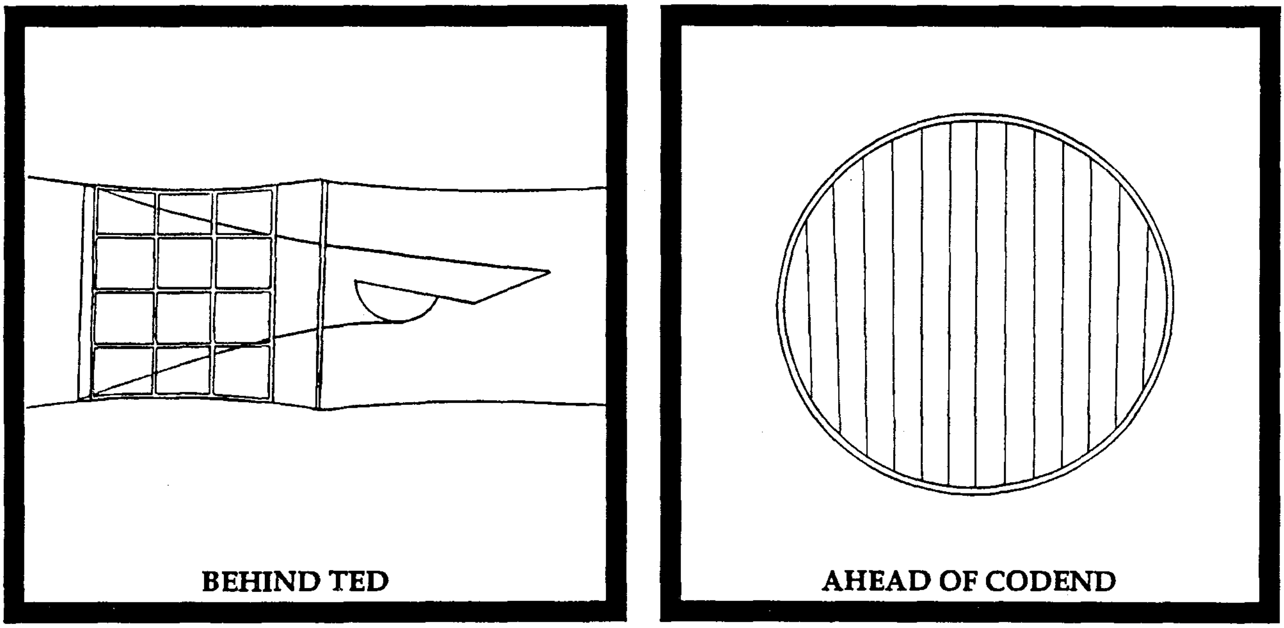
| | | |
|---|---|---|
| Number of Tows | 11 | |
| Fish reduction | 37% | S |
| Shrimp Retention | 100% | NS |

| DOMINANT SPECIES | | |
|---|---|---|
| Atlantic Bumper | 10% | NS |
| Long Spine Porgy | 23% | NA |
| Butterfish | 49% | NA |
| Spot | 47% | NA |
| Trout | 36% | NA |
| Catfish | 89% | NA |
| Croaker | 11% | NA |

| IMPORTANT SPECIES | | |
|---|---|---|
| Red Snapper | 39% | NS |
| Spanish Mackerel | 34% | NS |
| King Mackerel | 63% | NS |

# EXTENDED FUNNEL EXCLUDER WITH HUMMER STIMULATOR

## TESTED WITH A MINI-SUPER SHOOTER TED



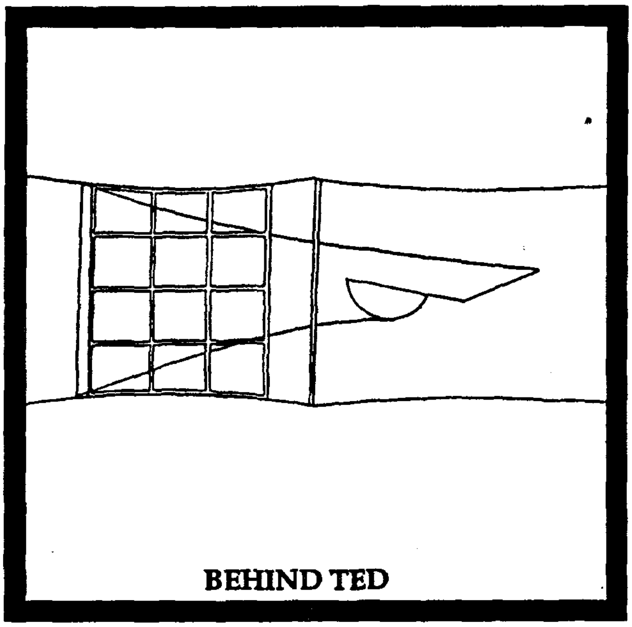

| | |
|---|---|
| Number of Tows | 20 |
| Fish Reduction | 44% S |
| Shrimp Retention | 100% NS |

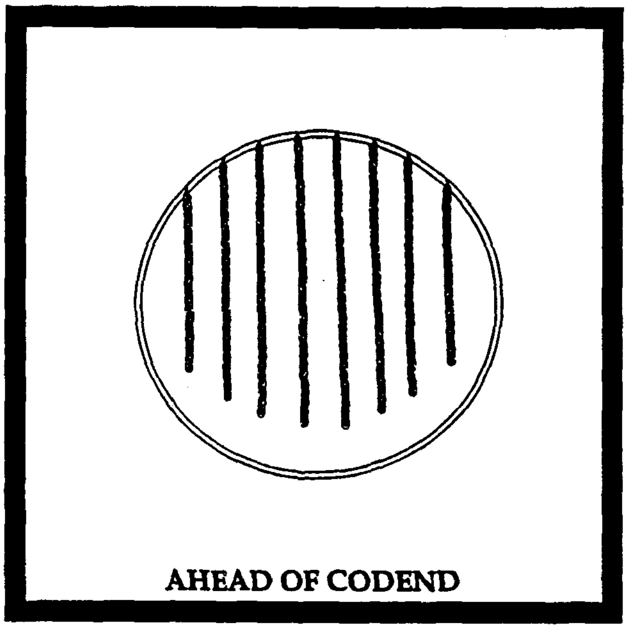
| DOMINANT SPECIES | | |
|---|---|---|
| Atlantic Bumper | 78% | S |
| Catfish | 95% | NS |
| Long Spine Porgy | + 47% | NA |

| IMPORTANT SPECIES | | |
|---|---|---|
| Red Snapper | 22% | S |
| Spanish Mackerel | + 100% | NS |
| King Mackerel | 44% | NS |

Appendix II, Figure 21

# EXTENDED FUNNEL EXCLUDER WITH CHAIN STIMULATOR




| | |
|---|---|
| Number of Tows | 19 |
| Fish reduction | 22% NS |
| Shrimp Retention | 100% NS |

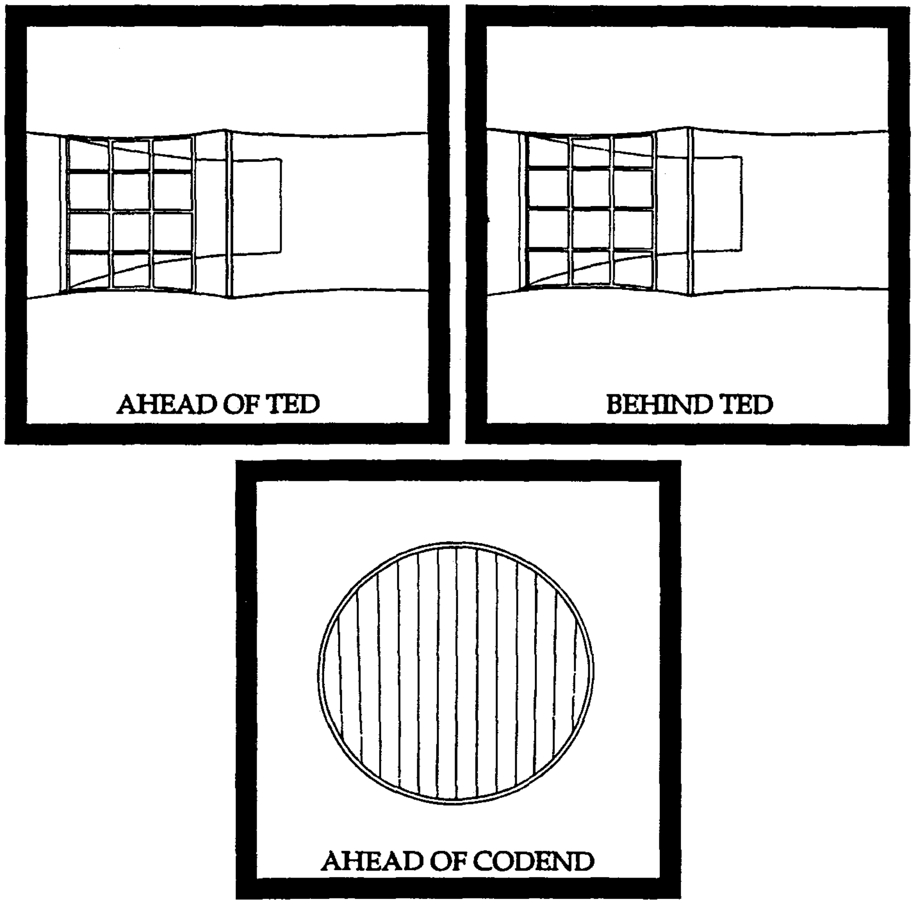
| DOMINANT SPECIES | | |
|---|---|---|
| Atlantic Bumper | 82% | S |
| Croaker | + 50% | NS |
| Long Spine Porgy | 40% | NA |
| Trout | + 7% | NA |
| Catfish | 69% | S |
| Spot | + 45% | NA |

| IMPORTANT SPECIES | | |
|---|---|---|
| Red Snapper | 20% | NS |
| Spanish Mackerel | 45% | NS |
| King Mackerel | 61% | NS |

Appendix II, Figure 22

# LARGE MESH/FUNNEL EXCLUDERS WITH HUMMER STIMUATOR

TESTED WITH SUPER SHOOTER




| | | |
|---|---|---|
| Number of Tows | 17 | |
| Fish Reduction | 37% | S |
| Shrimp Retention | 93% | NS |

## DOMINANT SPECIES

| | | |
|---|---|---|
| Croaker | 72% | S |
| Spot | 70% | S |
| Atlantic Bumper | 74% | S |
| Long Spine Porgy | 30% | NA |
| Trout | 45% | NA |
| Butterfish | 71% | NA |
| Cobia | 100% | NA |

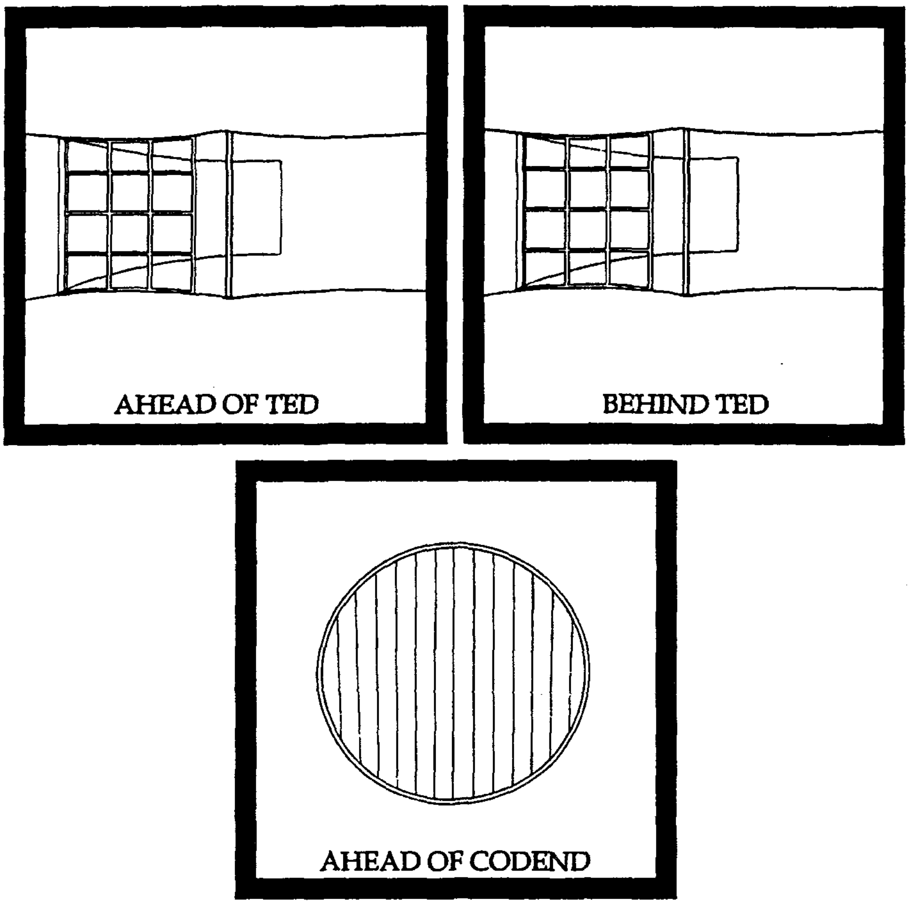
## IMPORTANT SPECIES

| | | |
|---|---|---|
| Red Snapper | 17% | NS |
| Spanish Mackerel | 47% | NS |
| King Mackerel | 34% | S |

Appendix II, Figure 23

# LARGE MESH/FUNNEL EXCLUDERS WITH HUMMER STIMUATOR

TESTED WITH DOUBLE BAR SUPER SHOOTER




| | | |
|---|---|---|
| Number of Tows | 35 | |
| Fish Reduction | 48% | S |
| Shrimp Retention | 100% | NS |

## DOMINANT SPECIES

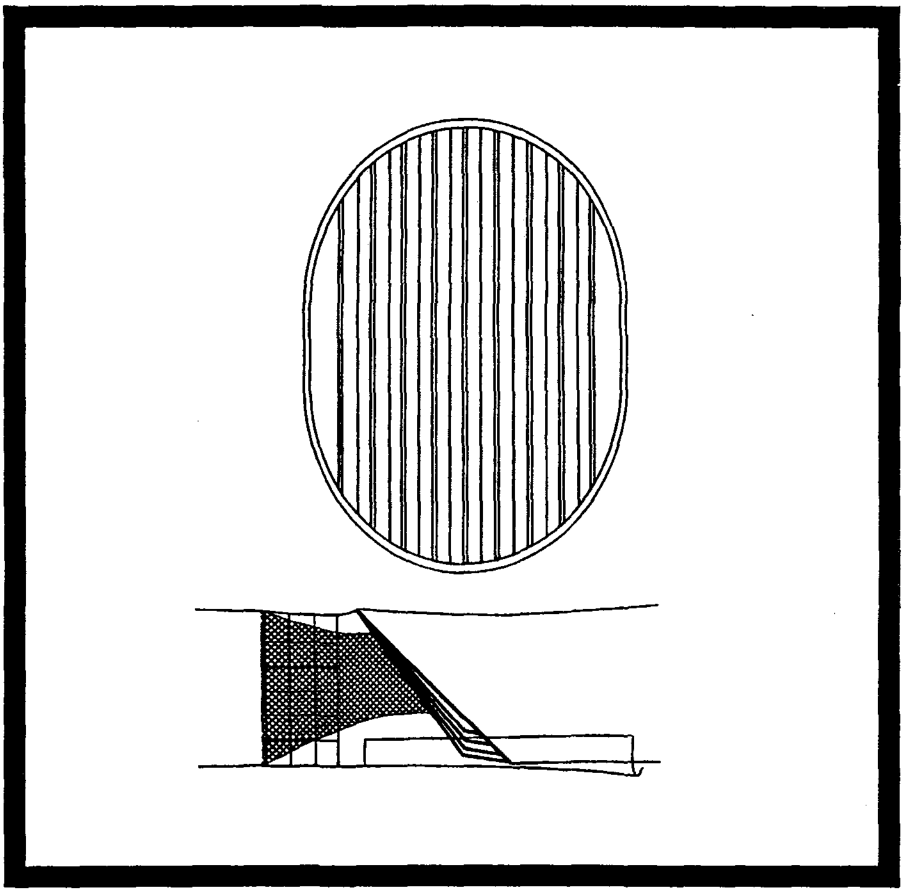
| | | |
|---|---|---|
| Croaker | 57% | S |
| Spot | 64% | S |
| Catfish | 71% | NA |
| Long Spine Porgy | 47% | NA |
| Atlantic Bumper | 74% | S |
| Trout | 12% | NA |

## IMPORTANT SPECIES

| | | |
|---|---|---|
| Red Snapper | +21% | NS |
| Spanish Mackerel | 72% | S |
| King Mackerel | 50% | S |

Appendix II, Figure 24

# SUPER SHOOTER W/ HUMMER WIRES & LARGE MESH/FUNNEL EXCLUDER



| | |
|---|---|
| Number of Tows | 19 |
| Fish Reduction | 23% S |
| Shrimp Retention | 100% NS |

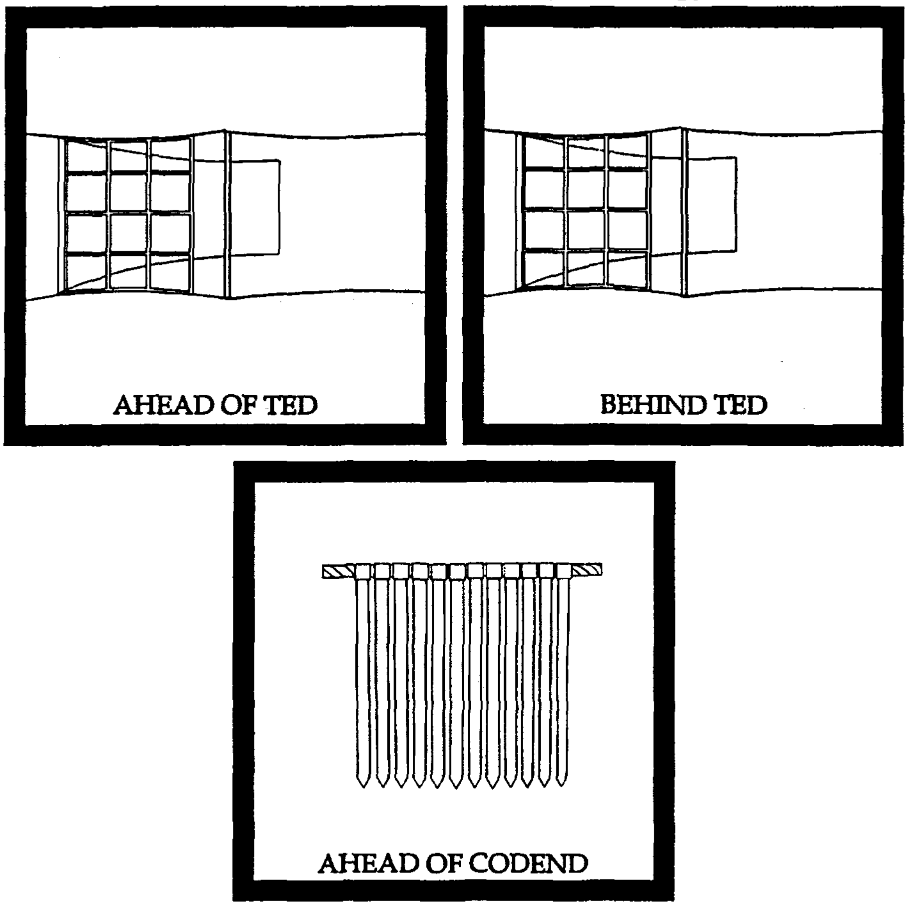
| DOMINANT SPECIES | | |
|---|---|---|
| Croaker | 31% | S |
| Butterfish | 16% | NA |
| Spot | 53% | S |
| Trout | 49% | S |
| Catfish | 81% | NA |
| Whiting | 46% | NA |
| Long Spine Porgy | 7% | NA |

| IMPORTANT SPECIES | | |
|---|---|---|
| Red Snapper | + 27% | NS |
| Spanish Mackerel | 25% | NS |
| King Mackerel | 7% | NS |

Appendix II, Figure 25

# LARGE MESH/FUNNEL EXCLUDERS WITH TY-WRAP STIMULATOR

TESTED WITH SUPER SHOOTER



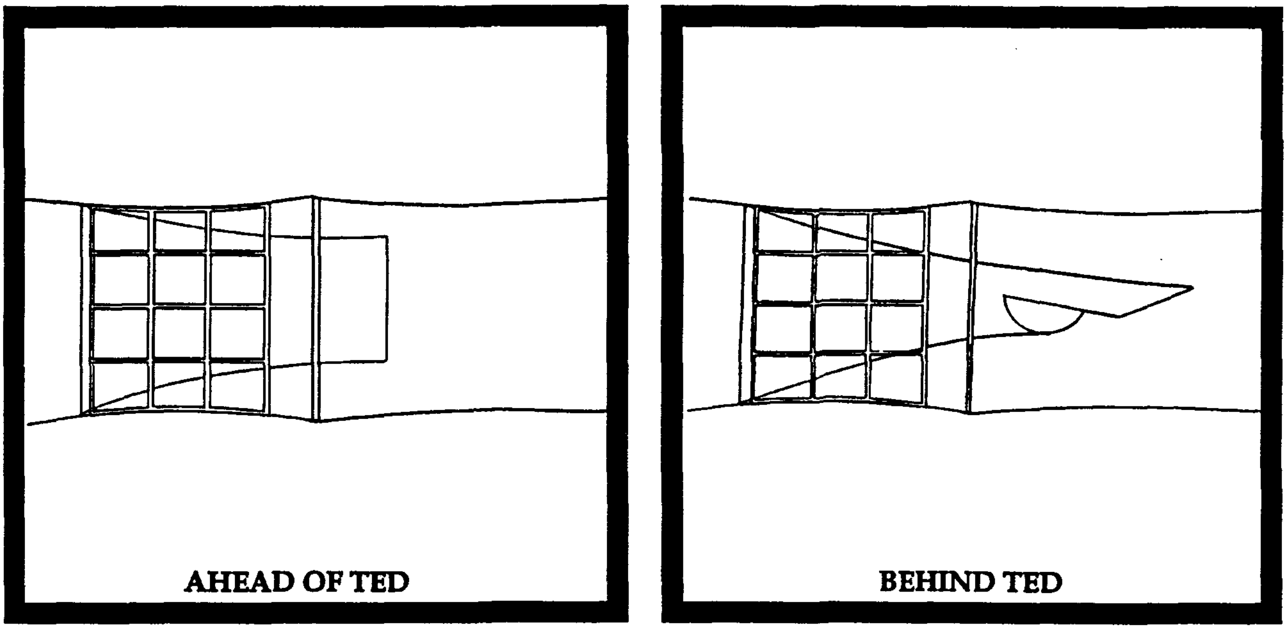

| | |
|---|---|
| Number of Tows | 26 |
| Fish Reduction | 36% S |
| Shrimp Retention | 100% NS |

| DOMINANT SPECIES | | |
|---|---|---|
| Croaker | 54% | S |
| Long Spine Porgy | 50% | NA |
| Spot | 66% | S |
| Catfish | 81% | NA |

| IMPORTANT SPECIES | | |
|---|---|---|
| Red Snapper | 11% | NS |
| Spanish Mackerel | 35% | NS |
| King Mackerel | +38% | NS |

Appendix II, Figure 26

# LARGE MESH & EXTENDED FUNNEL EXCLUDERS




| | |
|---|---|
| Number of Tows | 8 |
| Fish reduction | 46% S |
| Shrimp Retention | 100% NS |

DOMINANT SPECIES

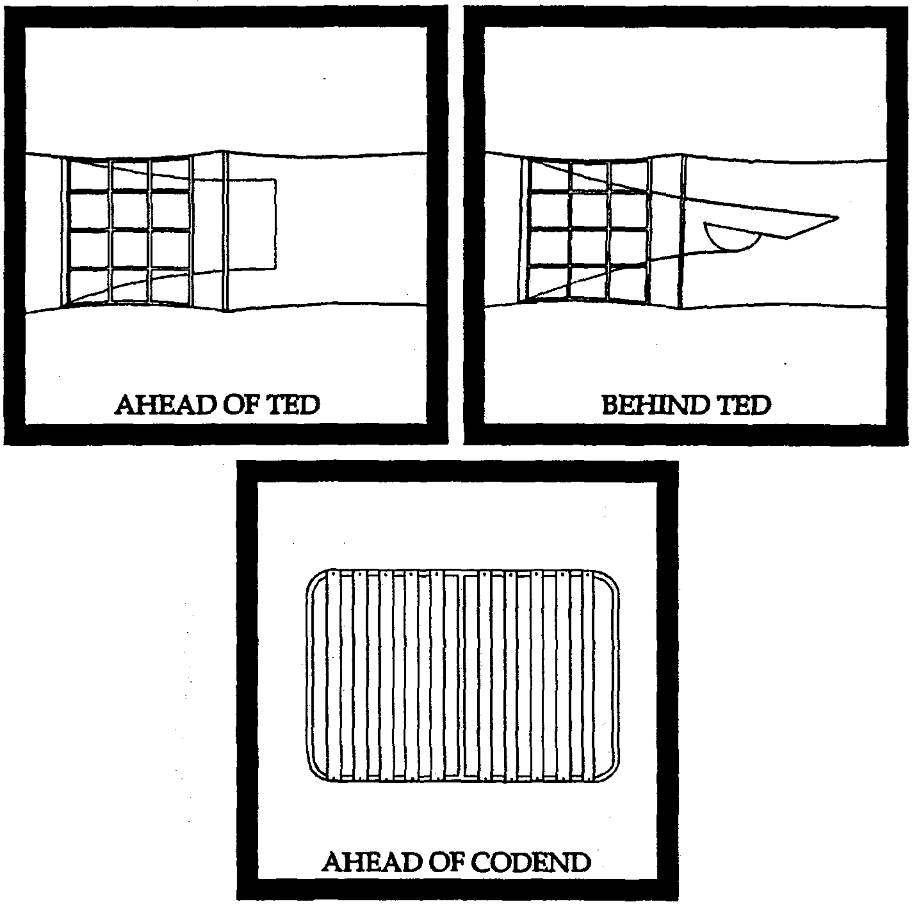
| | | |
|---|---|---|
| Butterfish | 90% | NA |
| Croaker | 37% | NS |
| Atlantic Bumper | 99% | NS |
| Trout | 37% | NA |
| Long Spine Porgy | 34% | NA |

IMPORTANT SPECIES

| | | |
|---|---|---|
| Red Snapper | + 4% | NS |
| Spanish Mackerel | 57% | NS |
| King Mackerel | 54% | NS |

Appendix II, Figure 27

# LARGE MESH & EXTENDED FUNNEL EXCLUDERS WITH PLASTIC STRIP STIMULATOR




| | |
|---|---|
| Number of Tows | 5 |
| Fish Reduction | 9% NS |
| Shrimp Retention | 100% NS |

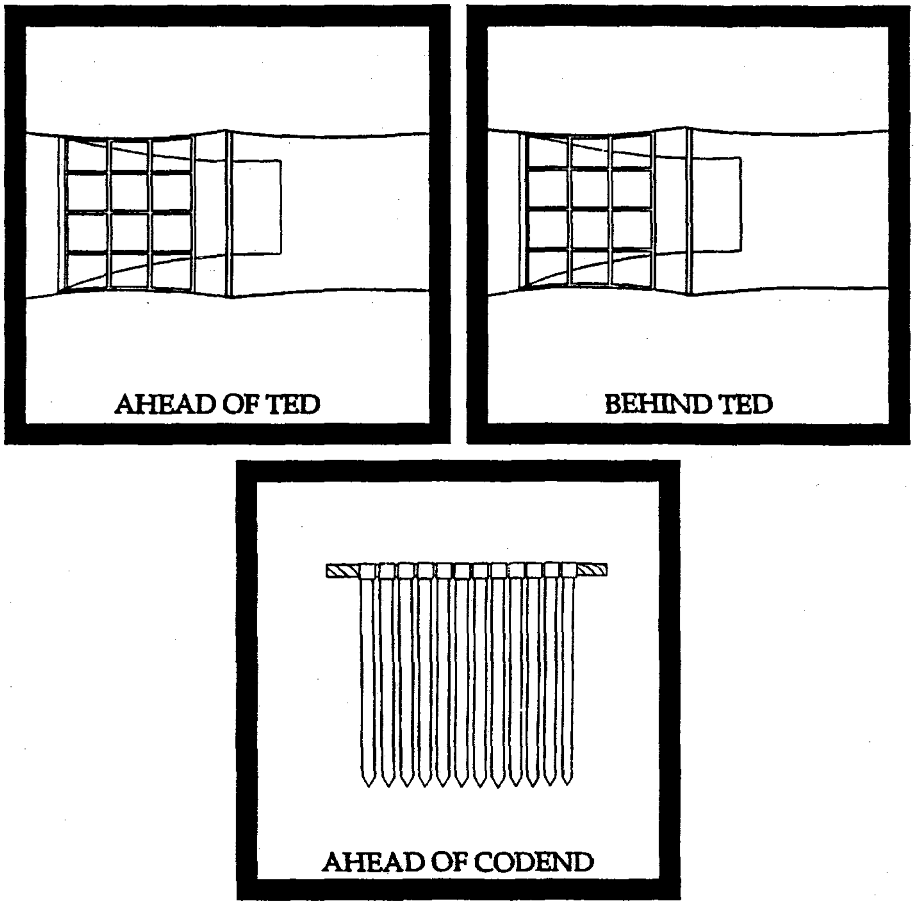
| DOMINANT SPECIES | |
|---|---|
| Croaker | 12% NS |
| Butterfish | 49% NA |
| Spot | 43% NS |
| Atlantic Bumper | 91% NS |

| IMPORTANT SPECIES | |
|---|---|
| Red Snapper | 100% NS |
| Spanish Mackerel | 53% NS |
| King Mackerel | 47% NS |

Appendix II, Figure 28

# LARGE MESH/FUNNEL EXCLUDERS WITH TY-WRAP STIMULATOR

TESTED WITH DOUBLE BAR SUPER SHOOTER




| | | |
|---|---|---|
| Number of Tows | 23 | |
| Fish Reduction | 41% | S |
| Shrimp Retention | 100% | NS |

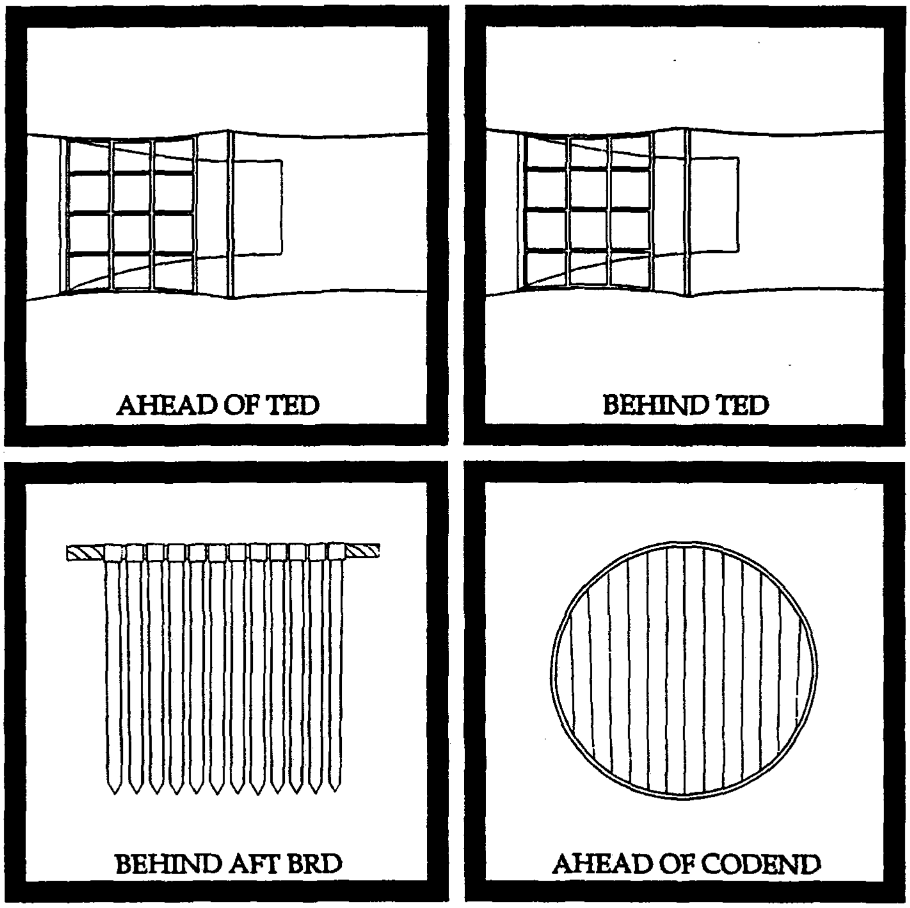
| DOMINANT SPECIES | | |
|---|---|---|
| Croaker | 71% | S |
| Atlantic Bumper | 40% | S |
| Catfish | 47% | NA |
| Spot | 71% | NS |
| Long Spine Porgy | 49% | NA |

| IMPORTANT SPECIES | | |
|---|---|---|
| Red Snapper | + 36% | NS |
| Spanish Mackerel | 60% | NS |
| King Mackerel | + 14% | NS |

Appendix II, Figure 29

# LARGE MESH/FUNNEL EXCLUDERS WITH HUMMER & TY-WRAP STIMULATORS

TESTED WITH DOUBLE BAR SUPER SHOOTER




| | | |
|---|---|---|
| Number of Tows | 2 | |
| Fish Reduction | 40% | NS |
| Shrimp Retention | 25% | NS |

## DOMINANT SPECIES

| | | |
|---|---|---|
| Catfish | 42% | NA |
| Atlantic Bumper | 71% | NS |

## IMPORTANT SPECIES

| | | |
|---|---|---|
| Red Snapper | 21% | NS |
| Spanish Mackerel | ND | |
| King Mackerel | 100% | NS |