Status of Bycatch Reduction Device (BRD) Performance and Research in North-Central and Western Gulf of Mexico

April 2004

United States Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southeast Fisheries Science Center
Mississippi Laboratories
Pascagoula Facility
P.O. Drawer 1027
Pascagoula, MS 39568-1207

Executive Summary

Bycatch reduction devices have been required in the Gulf of Mexico shrimp fishery since 1998. The "Gulf Fisheye" BRD and the "Jones/Davis BRD" were certified for use in the GOM shrimp fishery based on criteria for the reduction of red snapper bycatch achieved during the cooperative industry/government research effort (1992-1997). In 1998 an intensive monitoring effort provided data on the effectiveness of mandatory use of these devices. The 1998 study indicated that there were performance problems with the fisheye BRD in some configurations, and the regulations were amended modifying the allowable placement of the fisheye to improve performance.

Monitoring of the performance of BRDs in the fishery was continued through an observer program from 2001 to 2003 (Scott-Denton, 2004). Analysis of observer data indicates that the fisheye BRD performance has not improved but rather is much worse. The total finfish reduction estimate was 16.5%, and F reduction for red snapper was 11.7%. The shrimp reduction was 2.0%. Fisheye compliance with the regulations was poor (75% of observed trips had fisheyes installed in illegal positions). Analysis of data, however, indicates that BRD performance was poor in both legal and illegal installations.

Several changes in fishing gear characteristics and practices in the fishery may be reducing fisheye performance. These changes include; increased haulback speed, retrieving lazy lines early, lightweight fisheyes, installation of webbing funnels behind the fisheyes, change to larger TEDs causing increased diameter of codend under forward position fisheyes, and illegal forward installation of fisheyes. There may be other factors involved, and we do not have sufficient information to determine the extent of each of these changes in the fishery. Fisheye performance appears to be highly variable over the range of vessels and gear configurations, but poor performance is most likely due to changes in fishing practices to minimize shrimp loss. The majority of finfish reduction with the fisheye BRD takes place during trawl retrieval and this is also the time when shrimp loss can occur. Changes in fishing practice to minimize shrimp loss without effort to evaluate and maintain finfish reduction will always reduce the effectiveness of the fisheye device.

Efforts have continued since 1998 to develop new improved BRD designs, but progress was slow until infrared (IR) observation capabilities were developed in 2002. The most promising approaches incorporated designs that stimulate juvenile red snapper to exit through BRD openings, which due to their behavior they are reluctant to do. Research has found that modifying water flow patterns can induce snapper to escape through BRD openings. Several new designs were found to be highly effective during daytime operations, but were not effective during nighttime operations. The inability to observe fish behavior at night or under very low light conditions without affecting fish behavior has prevented technological advancement in BRD design. The ability to observe fish during low light conditions and during nighttime operations was developed during 2001 and 2002 with the development of new infrared LED technology and low light camera technology. Experiments were conducted to ensure that the newly developed technology did not affect red snapper behavior in April 2003, and in May of 2003 this

technology was used during trawling operations to observe fish behavior under dark conditions. Fish behavior under dark conditions differed greatly from daylight conditions, which explained why prototype designs with high potential developed using daytime behavioral observations were not effective under commercial fishing operations. Nightime behavioral observations indicate that snapper stay very near the bottom of the trawl and new BRD designs were developed based on this information. Testing results for the new designs are very promising, but additional research is necessary to ensure maximum shrimp retention and to solve operational problems.

Options:

Gulf Fisheye BRD: The Gulf Fisheye BRD performance is highly variable. The flexibility of current regulations, which was intended to allow fishers to adjust the fisheye position for maximum performance, has apparently been used to maximize shrimp retention without regard to fish reduction. Without adequate industry incentive to maximize fish reduction it is unlikely that the use of fisheye BRDs will achieve the reduction rate desired. Regulations can be modified to mandate the fisheye device be used in only the position which achieves maximum fish reduction (installed no further forward than 10.5 feet from the bag tie off rings) but this will likely be at a cost of increased shrimp loss. Based on the lack of response to the 1998 regulation changes, any new changes will not likely be effective without a substantial enforcement effort. Fishers must be encouraged to develop operational procedures that maximize fish reduction with the best possible shrimp retention rates. We recommend that a series of workshops or meetings be held with the industry to stress the need to consider finfish reduction as well as shrimp loss, to provide information on the status of fisheye performance, and to elicit recommendations from the industry to achieve this goal.

Jones/Davis BRD: The Jones/Davis BRD performance has continued to meet criteria for red snapper reduction, but is not used by the fleet except by the original developers, due to high cost and operational complexity. If the Jones/Davis device were mandated (i.e. fisheye decertified) we would expect industry resistance. Successful implementation would require substantial investments in enforcement and technology transfer, at the cost of reducing research effort on new BRD designs. Without those investments, finfish reduction in the general fleet via mandated Jones-Davis BRDs would probably never approach the potential already shown by the Jones-Davis device.

New BRD Designs: Work can continue on the newly developed designs using infrared observation technology. With this approach, we must encourage industry innovation by providing information to fishers for cooperative research to solve operational problems and maximize shrimp retention. The key to development of effective designs is getting new designs into the fleet, but this will result in innovation only if the industry has incentive to develop new technology. Providing this incentive is the only route to success. An additional impediment is the present certification protocol. It has been too rigid, and has inhibited getting new devices into the fleet for more general trials. We believe that successful development of new technology will require either a relaxed certification protocol with an allowance for preliminary certification of promising designs and discontinued use if the designs to not perform adequately, or an extended permitting system to allow widespread testing of promising designs.

Observer Coverage of the US Gulf of Mexico and Southeastern Atlantic Shrimp Fishery, February 1992 – December 2003 - Methods[1] Report to SEDAR

Elizabeth Scott-Denton
NOAA Fisheries
Southeast Fisheries Science Center
4700 Avenue U
Galveston, Texas 77551

Introduction

Significant declines in landings of several species of finfish in the US Gulf of Mexico and southeastern Atlantic in the mid-1980's brought about federal management measures to identify reasons for decline and expedite necessary actions to rebuild affected stocks. Shrimp trawl bycatch (or discarded non-target catch) was identified as a significant source of mortality on both commercial and recreational species. National Marine Fisheries Service (NOAA Fisheries) in cooperation with the Gulf and South Atlantic Fisheries Foundation, Inc. (Foundation) and the Gulf of Mexico and South Atlantic Fishery Management Councils initiated a large-scale observer program in February 1992. The two primary objectives of this research effort were (1) to estimate catch rates during commercial shrimping operations for both target and non-target species by area, season and depth, and (2) to evaluate bycatch reduction devices (BRDs) designed to eliminate or significantly reduce non-targeted catch, particularly red snapper, *Lutjanus campechanus*.

Since the program's implementation, more than 150 bycatch reduction device and turtle excluder device (TED) combinations have been evaluated. Currently five BRDs and 20 TED designs are certified for use in the US Gulf of Mexico and southeastern Atlantic shrimp fishery. Since 1992, data from more than 21,000 tows (Figure 1) have been collected during 1,310 trips (12,749 sea days).

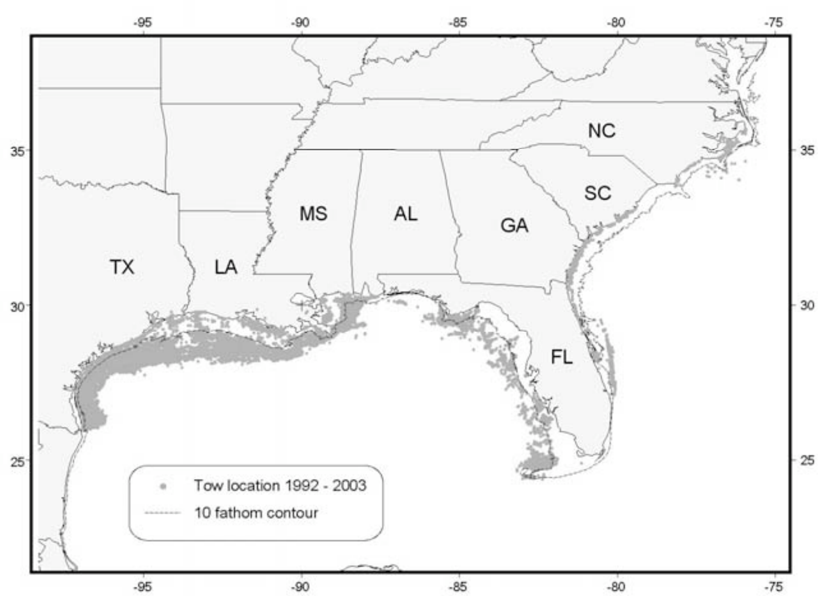


Figure 1. Distribution of sampling effort (tows) based on observer coverage of the US Gulf of Mexico and southeastern Atlantic shrimp fishery from February 1992 through December 2003.

NOAA Fisheries and the Foundation provided the greatest levels of observer coverage (i.e., sea days of observations) during the study period. Texas Shrimp Association, North Carolina Division of Marine Fisheries, and Georgia Department of Natural Resources also collected data from commercial shrimp vessels and contributed to the Southeast Regional shrimp trawl database. The resulting database, housed and managed at NOAA Fisheries Galveston Laboratory, continues to be used extensively by NOAA Fisheries scientists, Fishery Management Councils, universities and state resource agencies for stock assessment, ecosystem-based modeling, and as a foundation for many fishery management decisions.

The primary focus of this report addresses program data collection methods for bycatch characterization and BRD evaluation and certification efforts in the US Gulf of Mexico and southeastern Atlantic shrimp fishery. Trip, tow and sea day statistics are given by region (i.e., Gulf of Mexico - Texas, Louisiana, Alabama/Mississippi and West Florida; and east coast - North Carolina, South Carolina, Georgia, and East Florida). Species-specific catch-per-unit-effort estimations from bycatch characterization data collected in the Gulf of Mexico by area, season and depth will be presented in a subsequent report. A concurrent report, prepared by NOAA Fisheries Pascagoula Laboratory, will also be presented that includes finfish percent reduction values relative to BRD evaluation and certification efforts in the Gulf of Mexico.

[1]Adapted from E. Scott-Denton (in preparation). Gulf of Mexico shrimp and red snapper fishery resources and their management. Ph.D. Dissertation, Texas A&M University, College Station, Texas.

Background

The Gulf of Mexico Fishery Management Council (Gulf Council) implemented a Fishery Management Plan (FMP) for the shrimp fishery in May 1981 in an effort to increase shrimp yield and value through measures designed to allow for optimal shrimp growth. Three commercially important penaeid shrimp species, brown shrimp *(Farfantepenaues aztecus),* white shrimp *(Litopenaeus setiferus)* and pink shrimp *(Farfantepenaeus duorarum)* historically comprise the majority of shrimp landed in the Gulf of Mexico. In 2002, these three species accounted for 96 percent of annual shrimp landed in the Gulf of Mexico, approximately 137 million pounds (heads-off), valued at 364 million dollars.

Since 1981, the shrimp FMP has been amended twelve times with several regulatory mandates enacted in the Gulf of Mexico shrimp fishery. Following a red snapper quantitative assessment in 1988, NOAA Fisheries concluded that the directed fisheries for red snapper (both commercial and recreational) as well as incidental take of juvenile red snapper by shrimp trawlers were responsible for annual declines in red snapper stock (Goodyear, 1988; Goodyear and Phares, 1990).

Growing concerns over bycatch prompted Congressional amendments in 1990 to the Magnuson Fishery Conservation and Management Act (Magnuson Act), and in 1996 to the Magnuson-Stevens Fishery Conservation and Management Act (Magnuson-Stevens Act). These legislative mandates required the Secretary of Commerce, and consequently NOAA Fisheries, to conduct a multi-year shrimp trawl bycatch research program to identify and minimize the impacts of shrimp trawling on federally-managed species in the US Gulf of Mexico and southeastern Atlantic.

One component of the multi-year research program involved the deployment of fishery observers on commercial shrimp vessels. Through a cooperative effort and a voluntary observer program, NOAA Fisheries and the Foundation began placing observers on commercial shrimp vessels in February 1992 to collect fishery-specific catch and BRD evaluation data. Other organizations including Texas Shrimp Association, North Carolina Division of Marine Fisheries, and Georgia Department of Natural Resources also placed observers. From 1992 through 1996, sixteen BRD designs were evaluated during commercial shrimp operations (Watson, et al. 1999). From these data, five designs were identified for potential use in federal waters in the Gulf of Mexico and southeastern Atlantic including the fisheye, expanded mesh, extended funnel, Gulf fisheye and the Jones-Davis. Based on red snapper reduction rates, the Gulf fisheye and the Jones-Davis were proposed for the western Gulf of Mexico (Cape San Blas, Florida to the Texas/Mexico border).

The Gulf fisheye and Jones-Davis BRD designs were certified by interim rule May 19, 1998, for the western Gulf of Mexico. These regulations followed the 1997 Congressionally-mandated independent red snapper peer review panel's recommendations pertaining to data collection and stock assessment methods for red snapper in the Gulf of Mexico. Improvement in data to assess bycatch in the shrimp fishery, better shrimp effort estimates, statistically designed data collection programs to avoid opportunistic samplings, and non-reported landings were specifically identified. The panel concluded that observers were needed on all vessels involved with the fishery to quantify catch and associated bycatch, and release mortality of red snapper (MRAG Americas, 1997).

In May 1998, the NOAA Fisheries component of the regional observer program intensified coverage of the shrimp fishery operating in the western Gulf of Mexico. This increased effort was in response to Gulf Council's recommendation to maintain the 1998 red snapper TAC of 9.12 million pounds. The Gulf Council based this decision on the 1998 proposed legislation that mandatory BRDs in the shrimp fishery should reduce red snapper mortality by 60%. Through legislative measures in May 1998, mandatory BRDs (Amendment 9 to Gulf shrimp FMP), observers, logbooks and vessel monitoring systems (VMS) units were required for the western Gulf of Mexico shrimp fishery. Efforts to place observers, logbooks and VMS units on randomly-selected shrimp vessels were met with a high refusal rate from the fishing industry. Based on safety concerns and the lack of an enforcement mechanism for a non-permitted fishery, the mandatory observer program became a voluntary charter program. The mandatory BRD requirement remained in effect, and later became permanent with the final rule for the Gulf BRD protocol in 1999.

Based on the number of operating units, the commercial shrimp industry is the largest and most valuable fishery in the US southeast region, and until recently, one of only a few commercial fisheries not required to have a federal permit. Amendment 11 to the Gulf shrimp FMP required all commercial shrimp vessels operating in federal waters of the Gulf of Mexico to obtain a renewable federal permit. That permit requirement became effective December 5, 2002.

Methods

Observers

Through a cooperative effort among several organizations, standardized observer training, sampling protocols and data forms were established in 1992. A detailed description of at-sea collection methods and data requirements are presented in NOAA Fisheries Galveston Laboratory's observer manual entitled "Characterization of the US Gulf of Mexico and Southeastern Atlantic Otter Trawl and Bottom Reef Fish Fisheries" May 2002.

Initially, all observers were trained at NOAA Fisheries Galveston Laboratory. Since the program's implementation, 132 observers have been trained and deployed from February 1992 through December 2003. NOAA Fisheries and the Foundation deployed the greatest number of observers. Other organizations, including Texas Shrimp Association, North Carolina Division of Marine Fisheries, and Georgia Department of Natural Resources, placed observers at some times during the study period.

The majority of observers held a Bachelor's degree in marine science or closely related field, and had previous at-sea experience. NOAA Fisheries contracted observers primarily through three contracting companies. Foundation observers contracted directly with the Foundation.

Projects

While the major emphasis from February 1992 through December 2003 was bycatch characterization and BRD evaluation aboard shrimp vessels operating in the US Gulf of Mexico and southeastern Atlantic shrimp fishery, several other projects evolved: TED evaluations, BRD certifications, rock shrimp characterization and BRD evaluations in the rock shrimp fishery. Projects contained in the data set were coded as follows:

B = BRD Evaluation
C = Bycatch Characterization
E = Effort
G = BRD Certification, Gulf of Mexico
M = Modified Bycatch Characterization
N = Naked Net (TED alternative)
R = Red Snapper Initiative
S = BRD Certification, South Atlantic
T = TED Evaluation
X = Rock Shrimp Characterization
Y = Rock Shrimp BRD Evaluation
Z = Soft TED Evaluation

Both the data and the methods of collection varied among projects. BRD evaluations (B) recorded catch data for shrimp and selected finfish from nets equipped with BRD/TED (experimental) versus nets with the same type of TED (control). BRDs used in these evaluation trials were non-certified; the majority of trials were prior to 1998. Bycatch characterization (C) identified all species in a subsample (approximately 20% of the total catch) from one randomly-selected net during a tow. During Effort (E) trips all shrimp and red snapper weights were recorded from all nets during a tow. BRD Certification, Gulf of Mexico (G) trips which occurred after 1998, were similar to BRD evaluations relative to data collection methods, and designed to provide data to certify new BRDs based on specified criterion. Applicants seeking to certify BRDs were required in July 2001 to apply to NOAA Fisheries Southeast Regional Office (SERO) for a letter of authorization (LOA). Modified Bycatch Characterization (M) trips, similar to bycatch characterization, selected 20 species (or taxa) of finfish with the remaining organisms from the subsample grouped. Naked Net or Alternative to TED (N) obtained sea turtle catch data from TED-equipped nets versus non-TED equipped nets; limited tow time restrictions applied for nearshore waters. Red Snapper Initiative (R) compared data from nets equipped with certified BRDs/TED (experimental) versus nets equipped with a TED (control); all trials were conducted in the Gulf of Mexico. BRD Certification, South Atlantic (S) evaluations trials were the same as described for (G), but occurred off the southeastern Atlantic. TED Evaluation (T) were designed to evaluate new or modified TED designs; TED equipped nets versus modified or non-TED equipped nets were tested. Rock Shrimp Characterization (X) trips occurred primarily of the east coast and were similar to project (C), with rock shrimp the target species. Soft TED Evaluation (Z) trips were the same as described for project (T), and involved catch comparisons from nets equipped with soft TEDs versus modified or non-TED equipped nets.

Trip, sea day and tow summaries are based on computerized trip report data. Detailed collection methods presented below include (1) bycatch and modified bycatch characterization, and (2) BRD evaluation, red snapper initiative, and BRD certification efforts. The latter contained paired-tow data. For all projects, shrimping activities were observed under commercial operation. No direction was given by the Program relative to location or duration of shrimping activities other than for limited tow time restrictions for non-TED equipped nets.

Vessel Selection

NOAA Fisheries-approved observers were placed year round on cooperating shrimp vessels. Placement intensity was based on vessel availability and current commercial effort trends by area and season. From February 1992 through May 1998 vessel operators were solicited to participate through phone and mail correspondence, port agents, and the Foundation. In May 1998, the NOAA Fisheries component of the program became mandatory following federal requirements for mandatory observer coverage, BRDs and VMS units in the Gulf of Mexico. Federal regulations in June 17, 1998, required vessels to have a current US Coast Guard (USCG) Safety Decal prior to taking an observer. Under the mandatory selection process, vessels were randomly selected based on the previous complete year of effort (i.e., 1996) stratified by statistical area, depth and season. These data were derived from NOAA Fisheries shrimp landings file and cross-referenced with USCG documentation records. This yielded a list of active vessels with owner names and addresses. Port agents, when possible, obtained the contact information (e.g., owner phone numbers) for selected vessels; the Internet was also used. Efforts to place observers randomly, through mandatory measures, were met with a high rate of refusal from industry. Observer safety, inadequate sleeping facilities, liability insurance concerns, combined with the lack of an enforcement mechanism for a non-permitted fishery, ultimately resulted in the program becoming a voluntary charter program in June 1998. Since that time, efforts to randomize the selection of charter vessels have been based on selecting vessels from the previous complete year of shrimp effort as described above. Similarly, port agents, when possible, provided owner contact information. In May 2003, a portion of the shrimp permit file (vessel name, documentation number, vessel owner's name and phone number) was obtained from SERO, and used to facilitate contacting selected vessels. Vessel operators who volunteered to participate were used if vessels, selected under the randomized process, were not available.

From the available vessel contact information, efforts were made to quantify and categorize recorded responses related to the random selection for the NOAA Fisheries component for Gulf of Mexico vessels from 1998 through 2003. Using recorded attempts, ten categories were established. From a list of approximately 315 randomly selected vessels, 21% were contacted by phone and a message was left; 18% did not have a phone, did not answer, reported a wrong phone number, or had a disconnected phone number; 17% did not have a federal shrimp permit as of May 2003; 13% expressed interest, but did not return the information package; 13% responded positively and took an observer; 6% used other types of gear or fished in non-federal waters; 5% each expressed no interest or could not speak English; and 1% each hung up, or had non-functional vessels. Collectively, throughout the study period (1992 through 2003), the majority of vessel operators volunteered to participate; vessel selection, for the most part, was non-random.

Vessel owners (or operators) were compensated a flat rate for the observer's food and lodging while aboard the vessel, and for potential shrimp loss when gear modifications occurred. Compensation rates varied among organizations and projects, and were dependent on annual funding levels. Effective October 2003, vessel owner/operators participating in the NOAA Fisheries component of the program were required to complete vendor profiles, register online with the Central Contractor Registration (CCR), and obtain a D-U-N-S number in order to be compensated by the federal government.

At-Sea Data Collection Methods

Vessel and Gear Characteristics

For all projects specific data relative to vessel and gear characteristics were recorded. Vessel length, hull construction material, gross tonnage, engine horsepower and crew size information were obtained for each vessel. Characteristics related to BRD, TED, net type and other associated gear were recorded at the start of each trip, or when changes were made. For each tow, bottom time, vessel speed and operational aspects relative to each net were documented.

Bycatch Characterization

Onboard data collection for the purpose of bycatch characterization consisted of sampling trawl catches taken from commercial shrimp vessels operating in the US Gulf of Mexico and southeastern Atlantic. The first characterization trips occurred in April 1992 in the Gulf of Mexico, and in June 1992 off the east coast. Fishery-specific data were collected from one randomly-selected net for each tow. Nets trailing behind the try net were not selected for sampling. The catch from the selected net was placed into a partitioned area (e.g., separated from the catch from the remaining nets). The catch was then mixed to ensure randomness, shoveled into baskets, and a total weight obtained. A subsample (approximately 20% of the total catch weight) was processed for species composition. Species weight and number were obtained from the subsample. Length frequencies for 30 specimens were recorded for selected species.

Bycatch characterization efforts involved identifying all species in the subsample to species level. During modified characterization trips, 20 selected species (or taxa) of finfish were processed with the remaining subsample grouped into one of the following categories: non-shrimp crustaceans, fish, other non-crustacean invertebrates, or debris (e.g., rocks, logs, trash).

All sea turtles were identified to species, measured, tagged, photographed and released. Sea turtles were handled and released according to the Cooperative Marine Turtle Tagging Program protocol.

BRD Evaluation, Red Snapper Initiative and BRD Certification

BRD evaluations began in the Gulf of Mexico in February 1992 and off the east coast in July 1992. NOAA Fisheries-approved observers collected data for the evaluation of specific BRD designs. Comparisons of catch data for nets equipped with BRD/TED gear combinations (experimental) versus nets with the same type of TED (control) were conducted. Experimental and control nets were alternated, typically mid-trip, from starboard to port outboard nets to reduce net and side biases. Generally, only the two outboard nets were sampled. The total catch and shrimp weights were obtained from the experimental and control nets. A subsample of approximately 32 kg (70 pounds) from each net (experimental and control) was processed for a modified bycatch characterization. When time permitted, all red snapper from the subsamples were counted and weighed.

Following the certification of the Gulf fisheye and Jones-Davis designs in 1998, an intensive effort was made to evaluate the effectiveness of these BRD designs under commercial operation in the western Gulf of Mexico. This project, identified as the red snapper initiative, involved the use of certified BRDs (i.e., Gulf fisheye and Jones-Davis). Evaluation efforts followed the guidelines set forth in to the bycatch reduction criterion proposed for the Gulf of Mexico as presented in the Federal Register, July 2, 1997. The onboard sampling methods were similar to the BRD evaluation described above, with minor exceptions. The control net had a closed BRD; the experimental net was equipped with the Gulf fisheye or Jones-Davis BRD design. The gear was alternated every third day. Total shrimp weights and red snapper counts and weights were obtained from each net (experimental and control), with all red snapper measured. If time permitted, typically the last tow of the night, a subsample was processed for a modified bycatch characterization.

BRD precertification and certification procedures are described at length in the 1999 document entitled “Gulf of Mexico Bycatch Reduction Device Testing Protocol Manual”. Onboard data collection procedures are similar to those described above. A minimum of 30 successful tows, a specific number of red snapper caught, and consistent tow times are among some of the testing requirements required for BRD certification.

Results and Discussion

Sampling Effort

Trips and Sea Days

A total of 1, 310 trips was completed in the US Gulf of Mexico and southeastern Atlantic from February 1992 through December 2003 during 12,749 sea days of observations. More than 117,000 hours of trawling were observed. Six hundred thirty-seven trips (11,147 sea days) operated in the Gulf of Mexico, with an average trip length of 17.5 days. Six hundred sixty-eight trips (1,475 sea days) occurred off the east coast, with average trip length of 2.2 days. Five trips (127 sea days) targeted waters off both the east coast and in the Gulf of Mexico, and averaged 25.4 days.

Annual observer coverage levels were less than 1% of the total shrimp effort. The number of sea days varied from 1992 through 2003 (Figure 2), and were directly correlated to the amount of funding received. Coverage levels were highest in 2002 with 3,063 sea days, followed by 1998 with 1,472 sea days. In 1994 and 1993, coverage levels were 1,235 and 1,228 sea days, respectively. In all other years during the study period, coverage was less than 1000 sea days. The lowest coverage occurred in 1996 with 300 sea days.

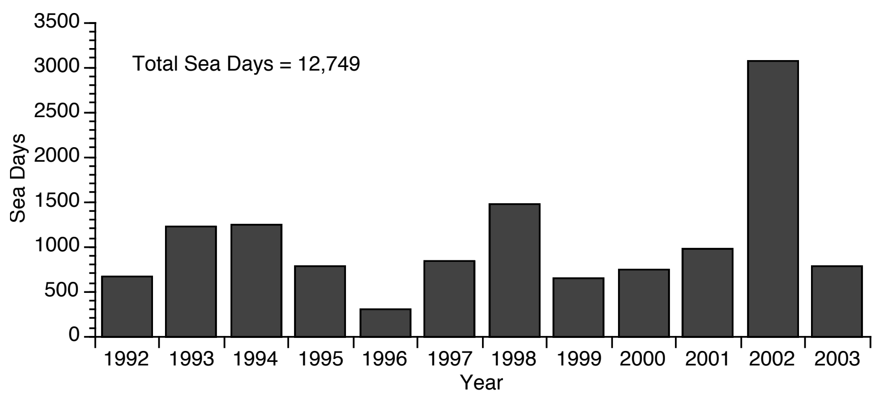


Figure 2. Number of sea days completed by year based on observer coverage of the US Gulf of Mexico and southeastern Atlantic shrimp fishery from February 1992 through December 2003.

Sea day coverage in the Gulf of Mexico was substantially higher (note y-axis values when comparing figures) than for waters off the east coast. A total of 11,220 sea days was completed during the study period (Figure 3). Observer coverage occurred off Texas, Louisiana and off the west coast of Florida in all years. Typically, Alabama/Mississippi coverage was lower, except in 2002, and more variable as compared to the other states. An annual trend was evident and involved higher coverage off Texas and Louisiana in summer and fall, and off southwest Florida in winter and early spring. In addition, the greatest concentrated effort occurred annually off Texas after the opening of the Texas Closure in July.

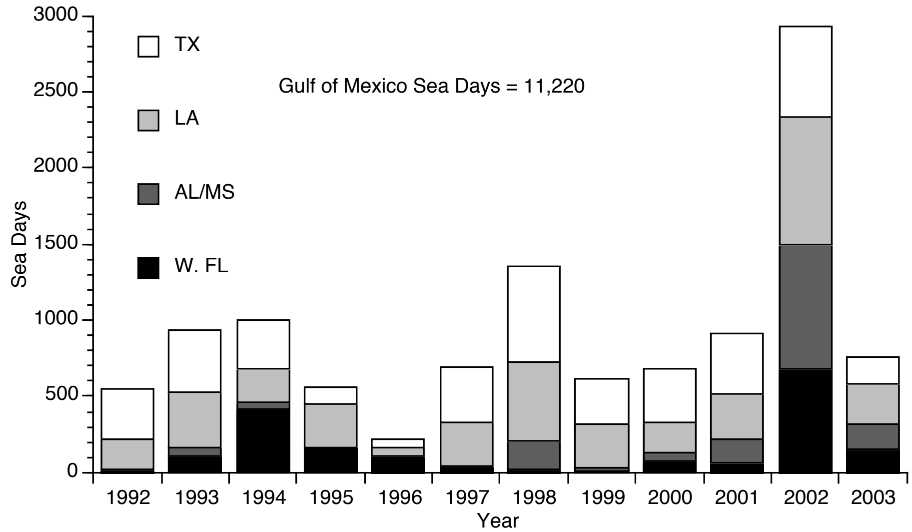


Figure 3. Sea days completed by year and state in the Gulf of Mexico based on observer coverage of the US Gulf of Mexico and southeastern Atlantic shrimp fishery from February 1992 through December 2003.

A total of 1,529 sea days of observations was completed in waters off the east coast (Figure 4). Highest coverage for North Carolina occurred from 1992 through 1994. Coverage off South Carolina and Georgia was fairly consistent through 2000. Increased coverage off the east coast of Florida occurred from 2001 through 2003, with increased monitoring of the rock shrimp fishery.

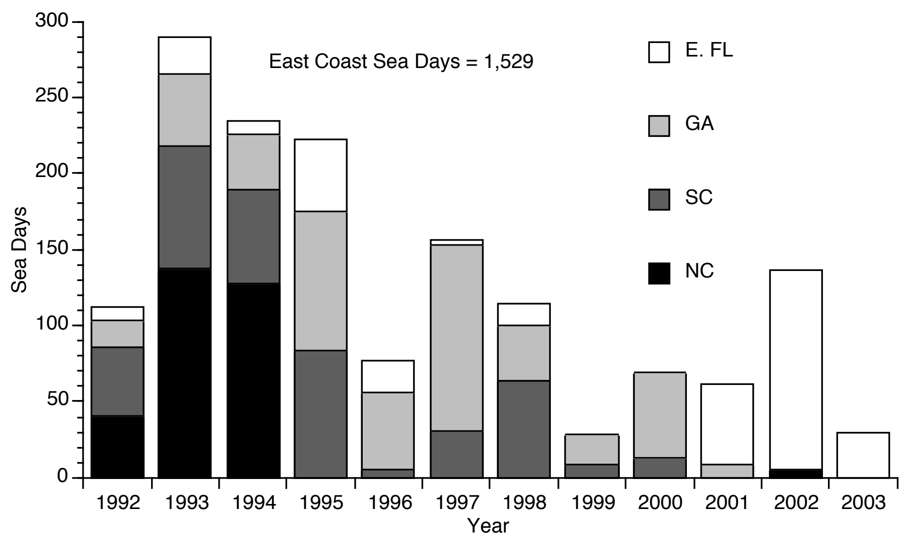


Figure 4. Sea days completed by year and state in waters off the east coast based on observer coverage of the US Gulf of Mexico and southeastern Atlantic shrimp fishery from February 1992 through December 2003.

Collectively, based on the number of sea days, coverage was greatest off Texas at 32%, followed by Louisiana at 30%, west coast of Florida at 14%, Alabama/Mississippi at 12%, Georgia at 4%, South Carolina and the east coast of Florida at 3% each, and North Carolina at 2%. The number of sampled tows by state followed a similar pattern.

Tows

For the Gulf of Mexico, 18,355 tows were sampled from February 1992 through December 2003 (Figure 5). Samples were processed from each Gulf State in all years, with the exception of 1995, when no samples were obtained off Alabama/Mississippi.

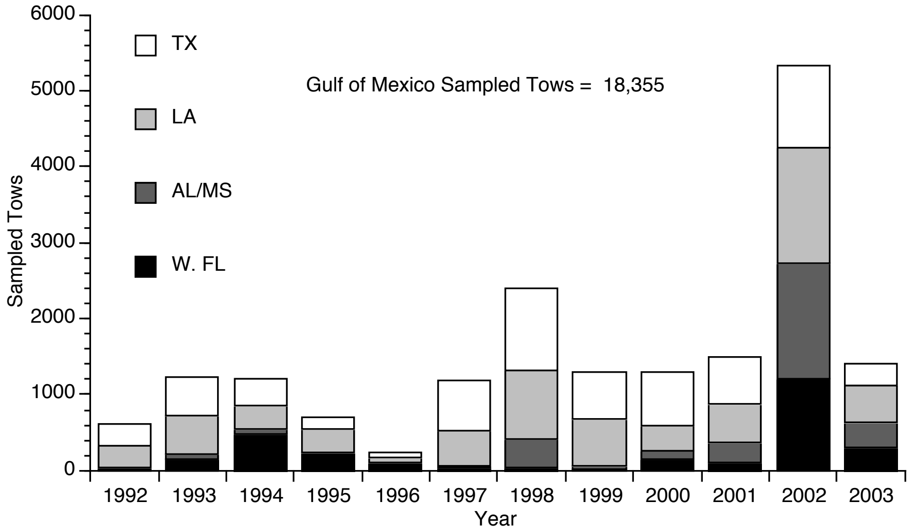


Figure 5. Number of tows sampled by year and state in the Gulf of Mexico based on observer coverage of the US Gulf of Mexico and southeastern Atlantic shrimp fishery from February 1992 through December 2003.

A total of 3,255 tows was sampled off the east coast during the study period (Figure 6). North Carolina had the highest number of tows processed during 1992 and 1994. Both Georgia and South Carolina had tows sampled in most years, with highest effort in 1997. East Florida had samples in all years, with the exception of 1999 and 2000.

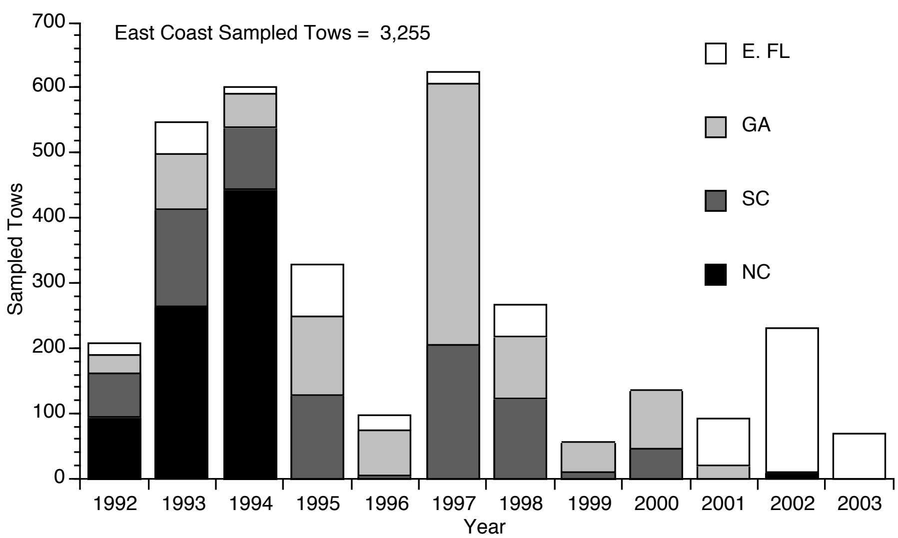


Figure 6. Number of tows sampled by year and state off the east coast based on observer coverage of the US Gulf of Mexico southeastern Atlantic shrimp fishery from February 1992 through December 2003.

Projects

During the study period 1,310 trips completed in the Gulf of Mexico and southeastern Atlantic were categorized by project type (Figure 7). BRD evaluation comprised 27% of trips, followed by bycatch characterization at 24%, red snapper initiative at 13%, naked net or alternative to TEDs at 11%, TED and soft TED evaluations at 6% each, effort at 5%, Gulf certification at 3%, south Atlantic (east coast) certification at 2%, and modified characterization and rock shrimp characterization at 1% each.

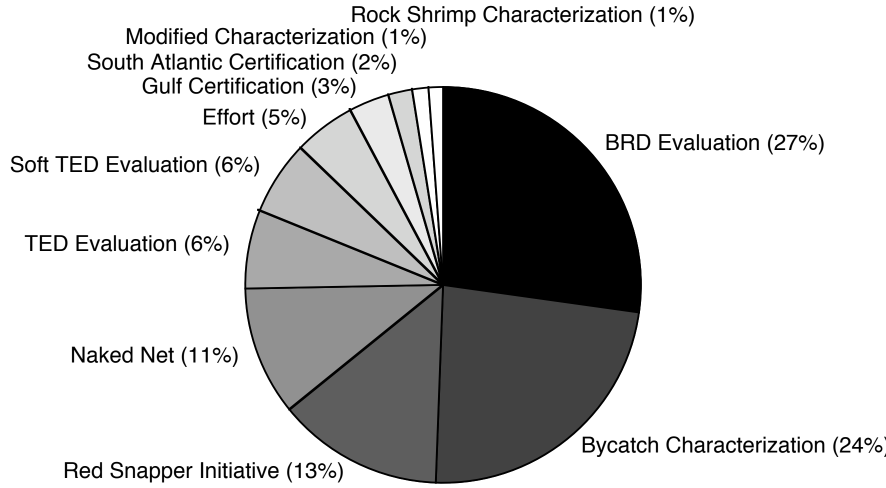


Figure 7. Percentage of 1,310 trips by project from observer coverage of the US Gulf of Mexico and southeastern Atlantic shrimp fishery from February 1992 through December 2003.

Sea days allocated to each project are shown in Figure 8. Approximately 27% of sea days were dedicated to red snapper initiative, followed by BRD evaluation at 24%, bycatch characterization at 16%, effort at 10%, Gulf certification at 7%, naked net at 6%, TED evaluation at 5%, modified bycatch characterization at 3%, rock shrimp characterization at 2% and south Atlantic certification and soft TED evaluation at 1% each.

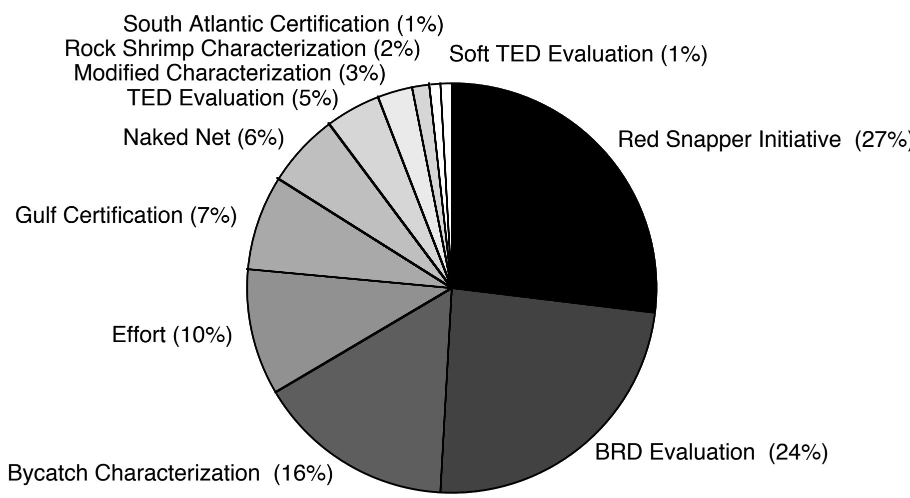


Figure 8. Percentage of 12,749 sea days by project from observer coverage of the US Gulf of Mexico and southeastern Atlantic shrimp fishery from February 1992 through December 2003.

All projects combined, trip duration ranged from 1 to 62 days. Trips were consistently longer in the Gulf of Mexico than on the east coast. By project, average trip length in days, was 21.7 for Gulf certification trips, followed by 20.2 for effort, 19.5 for red snapper initiative, 17.5 for modified characterization, 14.8 for rock shrimp, 8.6 for BRD evaluation, 6.9 for TED evaluation, 6.4 for bycatch characterization, 5.4 for naked net, 3.7 for south Atlantic certification, and 1.2 for soft TED evaluation.

Vessel, Gear and Fishing Characteristics

Two hundred forty-five vessels participated in the study. Overall vessel length ranged from 36 to 98 feet (74.5 ± 10.0 s.d.). One hundred forty vessels contained ice holds, 95 had some freezer capacity and 10 had unidentified cold storage. The majority of vessels (128) were steel hulls, followed by 85 of wood, 27 of fiberglass, 4 of wood and fiberglass, and one of aluminum. Engines averaged 406.2 hp. Crew size, including the captain, ranged from 1 to 5 individuals.

The number of nets pulled per tow varied from 1 to 4, with 3.7 nets the average. Headrope length, on a per net basis, ranged from 15 to 85 feet with an average of approximately 48 feet.

Among all projects, tow time ranged from 0.1 to 20.5 hours (4.8 ± 2.5 s.d.). Tow times were longer in the Gulf of Mexico (5.2 ± 2.4 s.d.) than off the east coast (2.4 ± 1.5 s.d.) Setting aside non-TED equipped nets towed in waters of ≤ 15 fathoms (i.e., tow time restricted), tow times averaged 5.0 hours (± 2.4 s.d) for all projects and areas.

Based on starting latitude and longitude coordinates, 32% of tows occurred in waters of ≤ 10 fathoms, with 68% of tows in offshore waters > 10 fathoms. All projects combined, tow depth ranged from 0.3 to 73.2 fathoms (17.6 ± 12.0 s.d). Although rock shrimp tows took place in deeper water than those targeting penaeid shrimp exclusively; removing those trips from the analysis made no substantial difference in average depth (17.4 ± 11.9 s.d.).

Controversial Aspects

Vessel selection, for the most part, was opportunistic, and may not be representative of the commercial shrimp fleet as a whole. Data collected throughout the study period have been entered into three different data sets; creating files from all sets can be a lengthy process. And finally, data contributors were responsible for editing and proofing their own data and for providing hard copies of the source data. Archived data on the server were not changed or altered (e.g., keystroke errors or outliers) unless written permission was granted by the contributing organization.

Literature Cited

Goodyear, C. P. 1988. Recent trends in the red snapper fishery of the Gulf of Mexico. National Marine Fisheries Service, Southeast Fisheries Center, Miami Laboratory, Contribution CRD-87/88-16, 125 p.

Goodyear, C. P., and P. Phares. 1990. Status of red snapper stocks of the Gulf of Mexico - Report for 1990. National Marine Fisheries Service, Southeast Fisheries Science Center, Miami Laboratory, Miami, FL. Laboratory Report, Contribution CRD 89/90-05, 72 p.

MRAG Americas. 1997. Consolidated report on the peer review of red snapper (*Lutjanus campechanus*) research and management in the Gulf of Mexico. Prepared by MRAG Americas Inc. for the Office of Science and Technology, National Marine Fisheries Service, 86 p, plus annexes.

Watson, J., D. Foster, A. Shah, E. Scott-Denton, S. Nichols and J. Nance. 1999. The development of bycatch reduction technology in the southeastern United States shrimp fishery. Marine Technology Society Journal 33(2): 51-56.

1999 – 2003
North-Central and Western Gulf of Mexico BRD Performance Report to SEDAR

Daniel G. Foster
NOAA Fisheries
Southeast Fisheries Science Center
P.O. Drawer 1207
Pascagoula, MS 39678

Introduction

In Response to the mandates of the Magnuson Conservation and Management Act amendments passed by Congress in 1990, shrimp trawl Bycatch Reduction Devices (BRDs) were developed for use in the Gulf of Mexico under the cooperative industry/government regional Research Program between 1992 and 1997 (Branstetter, 1997;Watson et al, 1999a) to reduce the unwanted bycatch of commercially and recreationally important finfish species such as red snapper (*Lutjanus campechanus*). The use of bycatch reduction devices by commercial shrimp vessels operating in federal waters was made mandatory in 1998 under amendment 9 to the fishery management plan for the shrimp fishery in the Gulf of Mexico region.

During the Summer of 1998 an intensive project identified as the Red Snapper Initiative was conducted by the National Marine Fisheries Service (NOAA Fisheries), Southeast Fisheries Science Center to provide data on the effectiveness of mandatory use of bycatch reduction devices by the commercial shrimp fishery in the north central and western Gulf of Mexico. The results of this study indicated that there were performance problems with the Gulf fisheye BRD in some configurations, one of the BRDs certified for use under amendment 9 (Watson et al, 1999b). Analysis of the data indicated that the reduction rate of age class 1 red snapper was negatively affected when the fisheye installed in the area of the codend where the lazy-line attachment system (elephant ear) could impede fish escapement. In an attempt to improve the performance of the Gulf Fisheye in reducing snapper, regulations were amended disallowing the installation of fisheyes in the area of the codend associated with the elephant ear (Federal Register, 1999).

NOAA Fisheries continues to collect data on the effectiveness of mandatory use of bycatch reduction devices by the commercial shrimp fishery in the north central and western Gulf of Mexico. In addition, NOAA Fisheries along with the Gulf and South Atlantic Fisheries Foundation, Inc. provide observers for certification tests of prototype BRD designs. Presented in this report are the results of the data collected under the Red Snapper Initiative from 2001 – 2003 and BRD Certification Project from 1999 – 2003.

Methods

The NOAA Fisheries, Mississippi Laboratories conducted analysis of the data base to calculate reduction rate estimates for shrimp (weight), total fish (weight), and red snapper fishing mortality (F).

Bycatch reduction device evaluation data were collected using a paired trawl sampling technique where a control net (net with a disabled or no bycatch reduction device) is towed on one side of the vessel and an identical net with a functional BRD is towed on the other side of the vessel. Both the control and experimental nets were required to have Turtle Excluder Devices. To control for possible net and/or side bias the bycatch reduction device was moved between nets. An alternative to this procedure was to have the control net with a disabled BRD. In this case BRDs were alternately disabled and enabled to address the biases previously mentioned. Data collection was conducted by trained fishery observers following procedures described in the 1999 document entitled "Gulf of Mexico Bycatch Reduction Device Testing Protocol Manual" (NMFS, 1999).

The ratio estimate for bycatch and shrimp reduction for each BRD type was computed by expressing the difference between the average CPUE per tow of the control and experimental trawl (experimental over control) from 1 and multiplying the difference by 100. Point estimates and 95% confidence intervals (computed through ratio estimation approach) are reported for various BRDs (Watson et al., 1999). Procedures for calculating red snapper F reduction are described in Nichols, 1999.

Industry Performance with Certified BRDs

NOAA Fisheries-approved observers were placed on cooperating shrimp vessels to evaluate BRD performance during commercial trawling operations. The vessel selection process is described in Scott-Denton, 2004. BRDs evaluated were provided by the vessels. BRD types, construction, installation methods and locations were determined by vessel operators. Observers documented BRD construction and installation materials, escape opening dimensions, installation distance from tie off rings, and placement in lazy-line attachment system.

Due to the low number of tows observed with Gulf Fisheyes in the region around 8.5 ft. from the codend tie-off rings, in 2003 a small number of vessel operators were asked to voluntarily install the fisheyes between 8.5 ft. and 9.0 ft. from the codend tie-off rings. The data set contains three trips where the fisheye was moved. These trips are not reflected in the overall results. A note occurs in the results where the data from the three trips have been added for the analysis of fisheye installation position.

The criteria used for the data analysis for data collected under the Red Snapper Initiative project were:

- Paired tows with a functional BRD in the experimental net and a disabled or no BRD in the control net
- Successful tows (tows with no non-BRD related problems)
- Red snapper analysis (tows with at least one snapper in one of the two test nets)

BRD Certification

NOAA Fisheries and the Gulf and South Atlantic Fisheries Foundation, Inc. (Foundation) conducted BRD certification tests on commercial vessels to evaluate performance of new prototype BRDs. Procedures and sampling protocol were the same as those previously mentioned. However, the current analysis deviated from the criteria found in 1999 Protocol Manual (NMFS, 1999) in that the protocol requires that tow times not vary more than 10% from a selected tow time. Certification tests of some prototype BRDs designs took place over a range of seasons and years making adherence to 10% tow time criteria of the protocol impractical.

The criteria used for data analysis in BRD certification testing were:

- Paired tows with a functional BRD in the experimental net and a disabled or no BRD in the control net
- Successful tows (tows with no non-BRD related problems)
- Red snapper analysis (minimum of 30 tows with at least 5 snapper in one of the two test nets)
- Tow times from 2 to 8 hours in duration

Results

Industry Performance with Certified BRDs

All of the vessels selected for the Red Snapper Initiative Project chose to use the Gulf Fisheye BRD. A total of 4089 tows from 32 vessels had been archived in the regional bycatch database by February 13, 2003. Of those, 2202 tows met the criteria for analysis.

The overall results for the Gulf Fisheye are presented in table 1. The estimated shrimp reduction rate for the Gulf Fisheye was 2.0% with a 95% confidence interval of 1.1% - 2.9%. Total finfish reduction estimate was 16.5% with a 95% confidence interval of 15.2% - 17.8%. The estimated F reduction for red snapper was 11.7% with a 95% confidence interval of 4.3% - 19.1%.

Table 1: Shrimp, total fish, and snapper F reduction for the Gulf Fisheye.

Species	n	Reduction rate (%)	95% C.I.
Shrimp	2190	2.0	1.1 – 2.9
Total Fish	2089	16.5	15.2 – 17.8
Red Snapper	1226	11.7	4.3 – 19.1

Red snapper F reduction estimates between vessels, which had at least 30 tows containing snapper, are presented in Figure 1. The point estimates for individual vessels varied greatly. Twelve (12) of the 17 vessels indicated a positive reduction in snapper mortality with the highest being 34%. The point estimates of five of the vessels indicated a negative reduction (increase) of up to 43%.

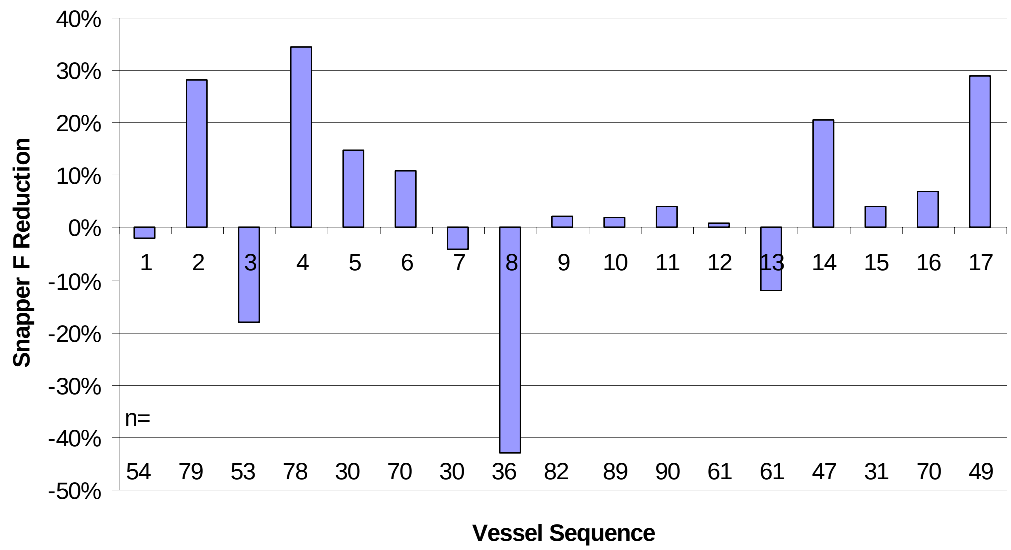


Figure 1: Gulf Fisheye red snapper F reduction by vessels with greater than 30 tows containing snapper.

Documentation of Gulf Fisheye configurations indicate that 75% of the fisheyes used had illegal configurations. The determination of whether a fisheye was legal or illegal was based on three criteria; distance from tie-off rings, placement in relation to codend retrieval system (elephant ear), and minimum dimensions of the escape opening. Federal regulations require that fisheye be installed in the codend between 8.5 ft. - 12.5 ft. from the tie-off rings (Federal Register, 1999) (Figure 2). Twenty-five percent of the documented tows had fisheyes outside of the legal area. The majority of the fisheyes with illegal distances from the rings were forward of the legal area, with 23.2% installed at a distance greater than 12.5 feet. Federal regulations state that when the fisheye is installed behind attachment point of the codend retrieval system, no part of the lazy-line attachment system may overlap the fisheye escape opening (Figure 3). Of the tows documented, 61.9% of the tows had fisheyes overlapped by the lazy-line attachment system.

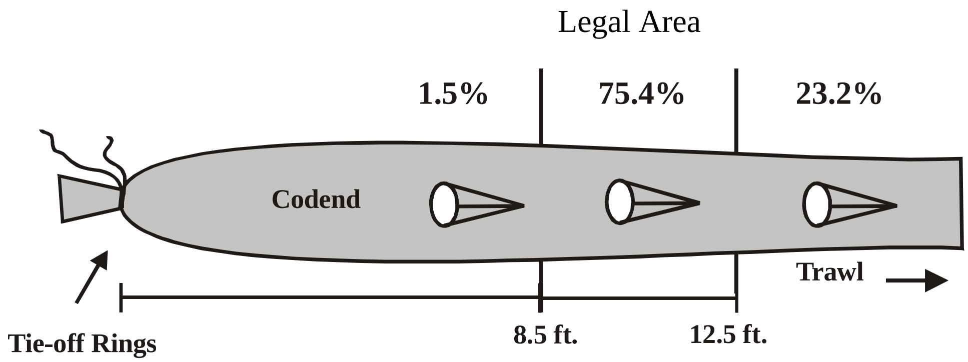


Figure 2: Percentage of tows occurring behind, between, and forward of the allowed installation range of 8.5ft. to 12.5ft. from the codend tie-off rings.

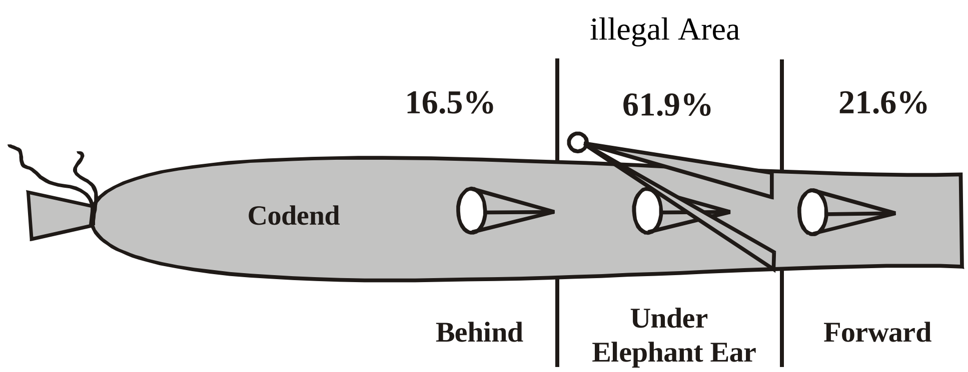


Figure 3: Percentage of tows occurring behind, under the elephant ear, and forward of the elephant ear region of the codend.

Data for the Gulf Fisheye for legal and illegal configurations are presented in Tables 2 and 3. The estimated shrimp reduction rate for the legal Gulf Fisheye was 3.5% with a 95% confidence interval of 1.7% - 5.3%. The estimated shrimp reduction rate for the illegal Gulf Fisheye was 1.6% with a 95% confidence interval of 0.1% - 2.6%. Total finfish reduction estimate for the legal configuration was 15.3% with a 95% confidence interval of 12.6% - 17.9%. Total finfish reduction estimate for the illegal configuration was 16.8% with a 95%

confidence interval of 15.3% - 18.4%.The estimated F reduction for red snapper with the fisheye in the legal configuration was 13.2% with a 95% confidence interval of 0.0% - 27.1%. In the illegal configuration, the snapper F reduction was 13.2% with a 95% confidence interval of 4.5% - 16.9%.

Table 2: Shrimp, total fish, and red snapper F reduction for fisheyes fished in a legal configuration.

Species	n	Reduction rate (%)	95% C.I.
Shrimp	535	3.5	1.7 – 5.3
Total Fish	522	15.3	12.6 – 17.9
Red Snapper	327	13.2	0.0 – 27.1

Table 3: Shrimp, total fish, and red snapper F reduction for fisheyes fished in an illegal configuration.

Species	n	Reduction rate (%)	95% C.I.
Shrimp	1552	1.6	0.1 – 2.6
Total Fish	1468	16.8	15.3 – 18.4
Red Snapper	823	13.2	4.5 – 16.9

In order to compare the results of the current study to the 1998 project, an analysis of snapper (age 1) reduction was conducted for the fisheye in the 8.5 to 12.5 ft position when installed ahead of the elephant ear, under the elephant ear, and behind the elephant ear. The estimated reduction rates and 95% confidence intervals for the 01-03 study and the 1998 study are presented in Figure 4. The point estimates for the 01-03 period are 31.1% for the fisheyes behind the elephant ear, 9.7% when fished in the zone under the elephant ear and -16.8% (increase) in the position ahead of the elephant ear. The results from the 1998 study were 47%, 25%, and 42% respectively. As shown in the figure, the point estimates for the current study in all three positions are lower than the estimates achieved in 1998. The most dramatic difference occurs at the position forward of the elephant ear.

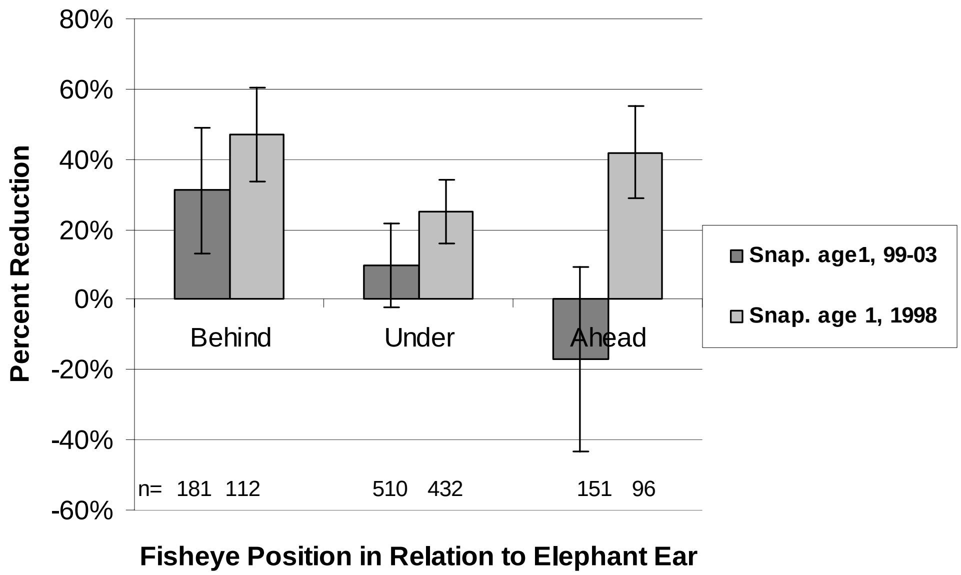
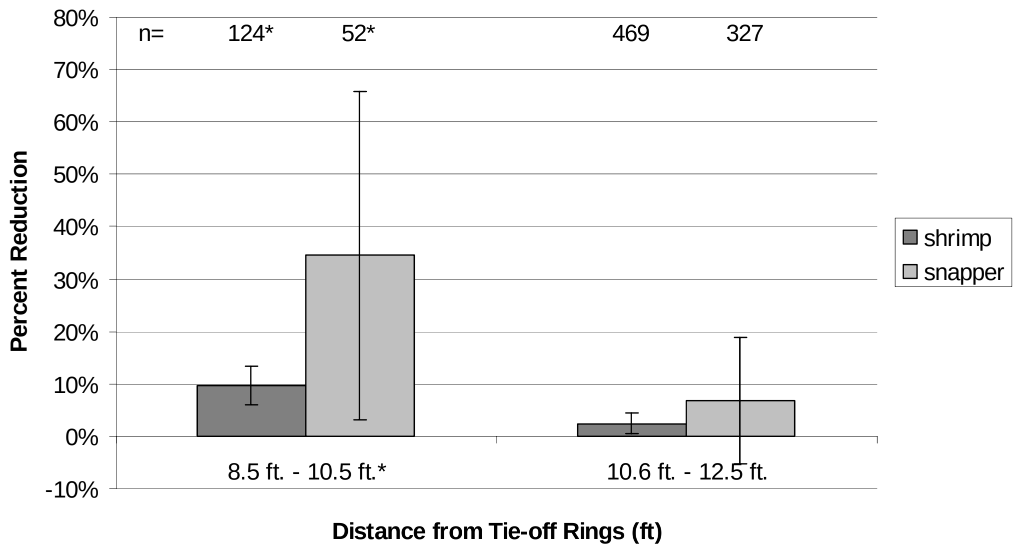


Figure 4: Fisheye reduction rates for red snapper and shrimp for fisheye between 8.5 ft. and 12.5 ft. from the tie-off rings as fished ahead, under, and behind the elephant ear.

An analysis was conducted comparing snapper and shrimp reduction rates for fisheyes, not impeded by the elephant ear, placed in the codend in the 8.5 ft.–10.5 ft. position and 10.6 ft.-12.5 ft. from the tie- off rings. The point estimates and 95% confidence intervals for shrimp and red snapper are presented in Figure 5. The estimated reduction for shrimp in the 8.5 ft.–10.5 ft. position was 9.7% with a 95 % confidence interval of 6.0% - 13.3%. The estimated shrimp reduction for fisheyes in the 10.6 ft.–12.5 ft. position was 2.4% with a confidence interval of 0.4% - 4.4%. The F reduction estimate for red snapper with the fisheye in the 8.5 ft.–10.5 ft. position was 34.5% with a 95% confidence interval of 3.1% - 65.8%. The F reduction estimate for red snapper with the fisheye in the 10.6 ft.-12.5 ft. position was 8.1% with a 95% confidence interval of -3.5% - 19.8%.



* Includes three additional commercial trips where NMFS specified installation at the 8.5 to 9.0 ft. position (see Methods section)

Figure 5: Reduction rates for snapper and shrimp for legal fisheyes installed in the 12.5 ft. to 10.6 ft. positions and the 10.5 ft. to 8.5 ft. positions.

BRD Certification Tests

Twenty (20) prototype BRD designs were tested on commercial vessels between 1999 and 2003. The BRD types and total number of paired tows completed are presented in Table 4. While 13 designs had more than 30 completed tows, only 6 BRD designs had 30 successful tows with the minimum number of snapper needed to be considered for certification tests. The results of the BRD performance analysis are summarized in Tables 5–10. Results presented in the Tables appear in descending order of performance based on red snapper F reduction point estimates. The devices with compete certification tests are the Jones-Davis with a Double Hoop, Modified Jones-Davis, Fish Box, Double Opposed Fisheye, Modified Fish Box, and the Hickman III.

Estimates for the reduction rates for the Jones-Davis with Double Hoop are presented in Table 5. The estimated shrimp reduction rate was 3.8% with a 95% confidence interval of 0.4% -7.4%. The total fish reduction estimate was 43.9% with a 95% confidence interval of 39.4% - 48.4%. The F reduction estimate for red snapper was 57.3% with a 95% confidence interval of 53.5% - 61.1%.

Estimates for the reduction rates for the Modified Jones-Davis are presented in Table 6. The estimated shrimp reduction rate was 3.8% with a 95% confidence interval of 1.7% -5.9%. The total fish reduction estimate was 33.5% with a 95% confidence interval of 31.1% - 35.9%. The F reduction estimate for red snapper was 29.4% with a 95% confidence interval of 23.3% - 35.4%.

Estimates for the reduction rates for the Fish Box are presented in Table 7. The estimated shrimp reduction rate was 1.2% with a 95% confidence interval of -1.4% -3.9%. The total fish reduction estimate was 28.0% with a 95% confidence interval of 21.8% - 34.1%. The F reduction estimate for red snapper was 23.8% with a 95% confidence interval of 15.2% - 32.4%.

Estimates for the reduction rates for the Double Opposed Fisheye are presented in Table 8. The estimated shrimp reduction rate was 1.2% with a 95% confidence interval of -3.5% - 5.9%. The total fish reduction estimate was 12.9% with a 95% confidence interval of 6.4% - 19.3%. The F reduction estimate for red snapper was 19.3% with a 95% confidence interval of 8.7% - 22.2%.

Estimates for the reduction rates for the Modified Fish Box are presented in Table 9. The estimated shrimp reduction rate was 4.1% with a 95% confidence interval of -1.4% -6.9%. The total fish reduction estimate was 21.7% with a 95% confidence interval of -10.8% - 54.2%. The F reduction estimate for red snapper was 18.3% with a 95% confidence interval of 4.3% - 32.2%.

Estimates for the reduction rates for the Hickman III are presented in Table 10. The estimated shrimp reduction rate was 7.7% with a 95% confidence interval of 4.0% -11.4%. The total fish reduction estimate was 15.5% with a 95% confidence interval of 8.0% - 23.0%. The F reduction estimate for red snapper was 0.4% with a 95% confidence interval of -20.7% - 21.5%.

Three (3) prototype BRD designs tested had 20 - 29 tows with the required number of snapper. To evaluate the potential for further testing, the results of performance analysis for these BRDs are summarized in Tables 11 - 13. Results presented in the Tables for the Jones-Davis with a fisheye on bottom, Fish Tube, and Extended funnel appear in descending order of performance based on red snapper F reduction point estimates.

Estimates for the reduction rates for the Jones-Davis with a Fisheye on Bottom are presented in Table 11. The estimated shrimp reduction rate was 16.6% with a 95% confidence interval of 10.0% -23.1%. The total fish reduction estimate was 69.4% with a 95% confidence interval of 40.6% - 98.2%. The F reduction estimate for red snapper was 42.4% with a 95% confidence interval of 33.6 – 51.2%.

Estimates for the reduction rates for the Fish Tube are presented in Table 12. The estimated shrimp reduction rate was 3.1% with a 95% confidence interval of -1.8% -7.9%. Finfish data was no obtained for this BRD. The F reduction estimate for red snapper was 36.1% with a 95% confidence interval of 24.9% - 47.3%.

Estimates for the reduction rates for the Extended Funnel are presented in Table 13. The estimated shrimp reduction rate was -0.8% (increase) with a 95% confidence interval of -5.3% - 3.5%. The total fish reduction estimate was 37.3% with a 95% confidence interval of 30.2% - 44.4%. The F reduction estimate for red snapper was 17.8% with a 95% confidence interval of – 8.0% - 43.4%.

Discussion

Research conducted from 1990 to 1996 under the auspices of the regional bycatch program produced two BRD designs that demonstrated potential to reduce shrimp bycatch of juvenile red snapper. The Jones-Davis device demonstrated potential to reduce juvenile snapper mortality 52%- 67%. For the Gulf Fisheye BRD, the estimate reduction in juvenile snapper mortality ranged from 59%-77% (Watson et al, 1997).

In 1998, under the Red Snapper Initiative Project research was conducted to provide data on the effectiveness of mandatory use of bycatch reduction devices by the commercial shrimp fishery in the north central and western Gulf of Mexico (Watson et al, 1999b). The 1998 results for the Jones-Davis were similar to previous research in that the point estimate for the reduction of age class 1 snapper was 69%. However, the results for the Gulf Fisheye BRD were lower than expected. The analysis indicated that placement of the fisheye in the area immediately behind the elephant ear attachment point had the potential to impede fish escapement. The estimated reduction of age 1 snapper in the area of the elephant ear was only 25% as opposed to 42% ahead of the elephant ear and 47% behind the area of the elephant ear. As an attempt to improve fisheye performance, the federal regulations were amended in 1999 to require fisheyes be place in the codend in an area away from the elephant ear. (Federal Register, 1999).

The current study indicates that the 1999 regulation amendment has had little affect on fishing practices since 1998. In 1998, the percentage of tows occurring behind the elephant ear was 13%. The percentage occurring in the zone of (under) the elephant ear was 67% and the percentage occurring ahead was 19%. In the 01–03 study the results were 17%, 62%, and 22% respectively. Even though a large percentage of tows made were with fisheyes installed an illegal configuration, a comparison of results between legal and illegal fisheyes indicate that even legally placed fisheyes performed poorly

One of the more notable differences between the 1998 study results and the current study involved the red snapper reduction rate forward of the elephant ear. In the 1998 study, the estimated red snapper reduction rates for age 1 snapper for fisheyes installed forward of the elephant ear was 42%. The point estimate for snapper age 1 reduction for the 01-03 results was -17% (increase) with the upper end of the 95% confidence interval at 7% reduction. It is not clear what factors or changes in fishing practices may have precipitated these results. However, video observations of fish behavior associated with fisheyes indicate a large portion of snapper escapement occurs at the surface during haulback (Workman, 1999). Observations also indicate that the portion of escapement that occurs at the surface is highest when the fisheye is installed in the forward position. When the fisheye is installed farther back toward the tie-off rings, more snapper escape during the tow. Video observation of shrimp behavior and fisheyes obtained by Texas A&M and Georgia Sea Grant specialist indicates that the majority of shrimp loss also occurs at the surface during haulback. This information suggests that any operational efforts to reduce shrimp loss with fisheyes during haulback may have an adverse impact on snapper reduction. In this case, the potential negative impact on fish reduction would be highest for the fisheye installed in the forward position. Observations of the Jones-Davis BRD indicate that the majority of juvenile escapement occurs during the tow.

Potential variables identified by gear technologists which could affect fisheye BRD performance include: codend length, location of bag tie-off rings, location of the elephant ear, length of the elephant ear, circumference of the codend, and knot orientation of the codend. Fishing practices identified include: towing speeds, winch retrieval speed, codend hauling procedures, hauling direction, and frequent turning.

Of the BRDs evaluated under the certification protocol, the Jones-Davis with a double hoop appears to be the most likely candidate for certification with an estimated snapper F reduction rate of 57.3% and 95% confidence interval of 53.5% - 61.1%. However, the information presented is only for data that has been archived on the database. For many of the BRDs presented, certification tests are ongoing and data from completed trips have yet to be archived.

Table 4. Bycatch reduction devices (BRDs) tested under the regional bycatch program 1999-2003 (February, 2003 analysis).

Data Criteria:

- Paired tows with a functional BRD in the experimental net and a disabled or no BRD in the control net
- Successful tows (tows with no non-BRD related problems)
- Red snapper analysis (minimum of 30 tows with at least 5 snapper in of the two test nets)
- Tow times from 2 to 8 hours in duration

Organization	BRD Type	Total Tows
NMFS Galveston	Modified Jones-Davis	500
Foundation	Sea Eagle II	195
Foundation	Coulon TED	194
Foundation	Double Opposed Fisheye	184
Foundation	Mod. Fisheye in Mesh Tunnel	110
NMFS Galveston	Fish Box	88
NMFS Galveston	Extended Funnel	70
NMFS Galveston	Hickman III	65
NMFS Galveston	Fish Tube	61
Foundation	Jones-Davis w/ Double Hoop	60
Foundation	Jones-Davis w/ fisheye on bottom	53
NMFS Galveston	Modified Fish Box	53
Foundation	Dubberly TED	31
NMFS Galveston	Side Opening Grid 5	16
NMFS Galveston	Split Ring	15
NMFS Galveston	Side Opening Grid 1	11
NMFS Galveston	Side Opening Grid 2	4
NMFS Galveston	Side Opening Grid 3	2
NMFS Galveston	Side Opening Grid 4	2
Foundation	C. J. Keiffe	2

Table 5: Reduction rate estimates for the Jones-Davis with a Double Hoop

Species	n	Reduction rate (%)	95% C.I.
Shrimp	34	3.8	0.4 – 7.4
Total Fish	32	43.9	39.4 – 48.4
Red Snapper	32	57.3	53.5 – 61.1

Table 6: Reduction rate estimates for the Modified Jones-Davis

Species	n	Reduction rate (%)	95% C.I.
Shrimp	322	3.8	1.7 – 5.9
Total Fish	379	33.5	31.1 – 35.9
Red Snapper	220	29.4	23.3 – 35.4

Table 7: Reduction rate estimates for the Fish Box

Species	n	Reduction rate (%)	95% C.I.
Shrimp	49	1.2	-1.4* - 3.9
Total Fish	20	28.0	21.8 – 34.1
Red Snapper	35	23.8	15.2 – 32.4

* Negative values represent an increase

Table 8: Reduction rate estimates for the Double Opposed Fisheye

Species	n	Reduction rate (%)	95% C.I.
Shrimp	74	1.2	-3.5* – 5.9
Total Fish	53	12.9	6.4 – 19.3
Red Snapper	37	19.3	8.7 – 22.2

* Negative values represent an increase

Table 9: Reduction rate estimates for the Modified Fish Box

Species	n	Reduction rate (%)	95% C.I.
Shrimp	37	4.1	1.4 – 6.9
Total Fish	5	21.7	-10.8 – 54.2
Red Snapper	36	18.3	4.3 – 32.2

* Negative values represent an increase

Table 10: Reduction rate estimates for the Hickman III

Species	n	Reduction rate (%)	95% C.I.
Shrimp	46	7.7	4.0 – 11.4
Total Fish	36	15.5	8.0 – 23.0
Red Snapper	33	0.4	-20.7* – 21.5

* Negative values represent an increase

Table 11: Reduction rate estimates for the Jones-Davis with a Fisheye on Bottom

Species	n	Reduction rate (%)	95% C.I.
Shrimp	29	16.6	10.0 – 23.1
Total Fish	30	69.4	40.6 – 98.2
Red Snapper	29	42.4	33.6 – 51.2

Table 12: Reduction rate estimates for the Fish Tube

Species	n	Reduction rate (%)	95% C.I.
Shrimp	27	3.1	-1.8* - 7.9
Total Fish	0	-	-
Red Snapper	27	36.1	24.9 – 47.3

* Negative values represent an increase

Table 13: Reduction rate estimates for the Extended Funnel

Species	n	Reduction rate (%)	95% C.I.
Shrimp	23	-0.8*	-5.3* – 3.5
Total Fish	28	37.3	30.2 – 44.4
Red Snapper	20	17.8	-8.0* – 43.4

* Negative values represent an increase

References

Branstetter, S. 1997. Bycatch and its reduction in the Gulf of Mexico and south Atlantic shrimp fisheries. Gulf and Atlantic Fisheries Development Foundation, Inc. Tampa FL, 54p.

Federal Register 1999. [62 FR 18539, Apr. 16, 1997, as amended at 64 FR 37694, July 13, 1999]. Government Printing Office, Washington, DC.

Nichols, S. 1999. Estimating fishing mortality rate reduction by BRDs. Report to the Gulf of Mexico Fishery Management Council. (Included in Summer 98 Project Report.)

NMFS 1999. Gulf of Mexico Bycatch Reduction Device Testing Protocol Manual. National Marine Fisheries Service, Southeast Regional Office, 9721 Executive Center Drive, St. Petersburg, Florida 33702.

Scott-Denton, E. 2004. Observer Coverage of the US Gulf of Mexico and Southeastern Atlantic Shrimp Fishery, February 1992 – December 2003 – Methods. Report to red Snapper SEDAR.

Watson, J., Foster, D, Shah, A, Scott-Denton, E, Nichols, S. and Nance, J. 1999a. The development of bycatch reduction technology in the southeastern United States shrimp fishery. Marine Technology Society Journal 33(2): 51-56.

Watson, J, Foster, D, Shah, A, & Nance, JM. 1999b. Red Snapper / Shrimp Research Program BRD Performance Report. Report to the Gulf of Mexico Fishery Management Council. (Included in Summer 98 Project Report.)

Watson, J, Shah, A, Nichols, S, & Foster, D. 1997. Bycatch reduction estimates for selected species in the Gulf of Mexico for Bycatch Reduction Device evaluated under the Regional Bycatch Program. Report to the Gulf of Mexico Fishery Management Council.

Workman, I.K. 1999. Fate of Juvenile red snapper, *Lutjanus campechanus,* that escape from shrimp trawls. Report to the Gulf of Mexico Fishery Management Council. (Included in Summer 98 Project Report.)

1999 – 2003 Research Summary
Shrimp Trawl Bycatch Reduction Technology
NOAA Fisheries
Harvesting Systems and Engineering Division

Daniel G. Foster
NOAA Fisheries
Southeast Fisheries Science Center
P.O. Drawer 1207
Pascagoula, MS 39678

Introduction

Research in the 1980s and early 1990s have indicated that bycatch in the Gulf of Mexico and southeastern Atlantic shrimp fisheries are a significant source of fishing mortality for many species including federally-managed species such as red snapper (*Lutajnus campechanus*), Spanish mackerel (*Scomberomorus maculatus*) , and weakfish (*Cynoscion regalis).* Nichols et al. (1990) estimated that 20 million red snapper were caught by Gulf shrimp trawlers in 1989. Goodyear and Phares (1990) estimated that over 90 percent of the fishing mortality on age 0 and age 1 red snapper was attributed to shrimp trawling. Recent estimates indicate that Gulf finfish bycatch is about 1 billion pounds a year, which includes 34 million juvenile red snapper (Warren, 1994).

In 1990, studies were initiated by the Harvesting Systems and Engineering Division of NOAA Fisheries Mississippi Laboratories were directed at evaluating existing commercial bycatch reduction device designs and assisting the industry in the development of improved trawl modification capable of reducing finfish bycatch without significantly impacting shrimp capture efficiency. In 1992, a broad scoped Regional Research Program was established in the Southeast Region as a cooperative partnership between industry, federal and state agencies, and academia to address the problem of bycatch in shrimp trawls and seek workable solutions. One hundred and forty five conceptual designs for bycatch reduction contributed by fishers, net shops, gear technicians, and biologist were evaluated between 1990 and 1997. These evaluations included observations of fish behavior, video documentation of operational characteristics, water flow measurements, and delineation of water flow patterns associated with bycatch reduction designs (Watson et al., 1993). Working cooperatively with the shrimping industry, state, and federal researchers and academia, this information was used to modify and evaluate bycatch reduction devices capable of reducing shrimp trawl bycatch. This research resulted in certification of two BRDs designs, the Gulf Fisheye and the Jones-Davis BRD, under Amendment 9 for use in the Gulf of Mexico shrimp fishery.

The development of effective bycatch reduction technology is dependent on the knowledge of fish behavior. One of the greatest impediments to using fish behavioral observations to develop BRDs for use in the Gulf of Mexico is the fact that the majority of commercial shrimping operations occur during night conditions. Lacking a better alternative, observations have been obtained either during daylight conditions or by using artificial lighting in trawls. However, work done by Wardle (1986) using flash photography under very low light conditions suggest that night behavior differs from the typical patterns of behavior which are shown in daylight. Research conducted by Ruggles and Ryan (1964) indicates that exposing dark adapted fish to artificial lights can alter fish behavior in relation to gear. These observations accentuated the need to develop methods for observing fish behavior under night trawling conditions.

In the past, scientists have been successful in using infrared lights and video cameras that are sensitive to infrared light in laboratory conditions to observe fish behavior under darkness (Batty, 1983; Olla and Davis, 1990; Ryer and Olla, 1998;

Fuiman and Delbos, 1998). However, this technology has been difficult to apply in situ and has only been employed a few times (Matsuoka et al., 1997, Olla et al., 2000). Recent advances in the technology of ultra-bright infrared LED lights and low light CCD video cameras have made the use of infrared lights a simple and cost effect means of observing fish behavior in night trawling conditions.

Since the initial development phase of the Regional Bycatch Program from 1990 to 1996, the Harvesting Systems and Engineering Division has made many advances in our understanding of fish behavior in trawls. There have also been major advances in our ability to observe fish behavior under commercial shrimping conditions using infrared technology. The research conducted from 1999-2003 is reviewed here and the findings are outlined.

A Review of Research

Inclined Water Flow Studies

Because of the similarity in the size of the target catch and bycatch species, bycatch reduction technology in the Gulf of Mexico has had to rely on behavioral differences to achieve reduction. Observations of the Jones-Davis and Gulf Fisheye BRDs indicate that these BRD designs rely on snapper locating and electively exiting through an opening in the trawl. The problem observed in these BRD types is that, after capture, young snapper are reluctant to exit a trawl and many stay in the trawl until haulback. These observations imply that it may be beneficial to stimulate/force fish out of the escape opening during towing. To use water flow to stimulate/force fish to escape seems to be a promising approach.

Preliminary observations of a prototype BRD Device (Figure 1) connected to the lower part of the Turtle Excluder Device (TED) grid, featuring plastic covers attached to create a low flow area adjacent to the escape area, showed that these covers also created a vortex which stimulated/forced fish to continuously escape as they entered the area (Engas et al., 1999). Dye flow studies showed that the water circulated through the escape opening, back into the trawl, and forward toward the escape opening. In addition, dye flow studies showed that water coming through the lower part of the TED funnel (i.e. just above the top plastic cover) was drawn down, right behind the end of the top plastic cover. Fish that passed the TED grid were drawn down into the turbulent flow, turned towards the codend as they entered the escape area, then slowly dropped down under the trawl and escaped. There is strong indication that it was the inclined water flow through the escape opening that led to this high and continuous escapement. This design gave a strong indication that it is possible create a flow pattern around the escape openings of BRDs that will induce continuous fish escapement throughout towing. However, even though no shrimp were present during the evaluation, it was obvious to researchers that the circulating flow pattern observed at the escape opening of this particular design would create a greater potential for shrimp loss.

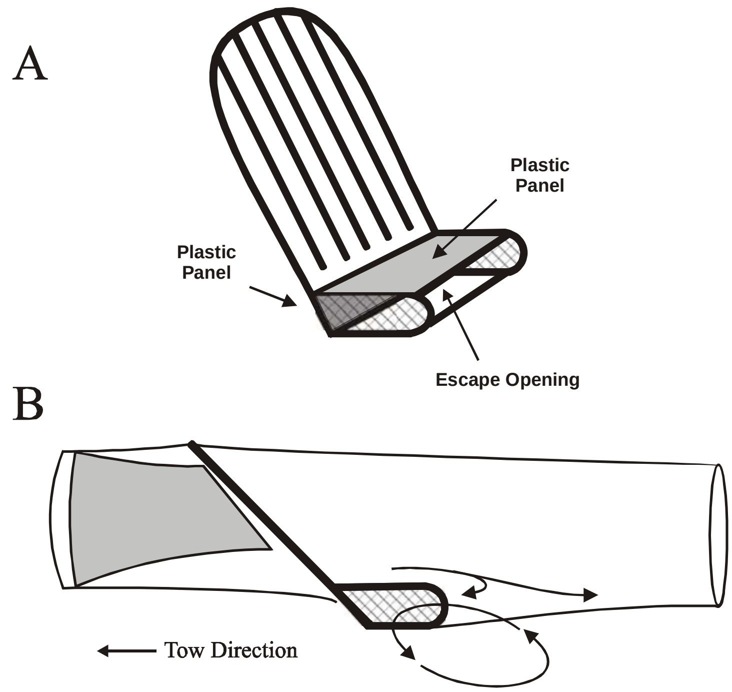


Figure 1: A) Schematic representation of prototype BRD. B) Water flow pattern observed.

To determine whether the frequent escapes observed in the prototype BRD were due to an inclined flow pattern, NOAA Fisheries and Norwegian research biologists conducted a study to evaluate the swimming performance of juvenile red snappers and juvenile pinfish in an inclined water flow (Engas and Foster, 2002). Using a clear acrylic tilting swimming tube with propeller-driven flow, swimming was studied at a swimming speed of three body lengths/s with the tube either horizontal or lowered to an angle of 45^{o} (Figure 2). Both species maintained a position between the visual reference points (bull's-eyes) using only the caudal fin for locomotion when the tube was horizontal. All the fish except one red snapper dropped out of the bull's-eye and fell back to the end of the tube when it was lowered to 45^{o}. An erratic swimming pattern, including the use of pectoral fins, was then observed in both species, but the tail-beat frequency was not changed. The erratic swimming and pectoral activity displayed when the tube was inclined indicated that the fish experienced destabilizing forces or that swimming within an inclined flow could be an "unnatural" situation. This suggests that the frequent escapes observed when fish experience an inclined water flow at a trawl escape opening may be because they tend to leave this area rather than take up a position swimming "up-hill" against the direction of flow.

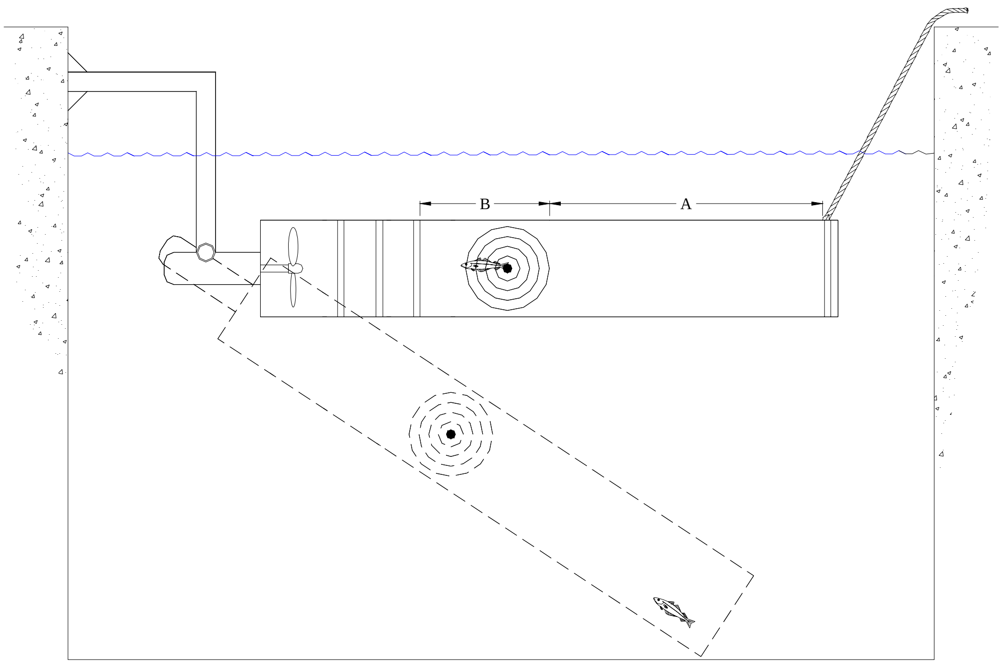


Figure 2: Diagram of experimental apparatus

The Fish Box

Based on the inclined water flow study, a prototype BRD design was developed similar to the prototype presented in Figure 1. The new design, called the Fish Box was constructed separate from the TED (Figure 3). Plastic panels are installed on the front and top of the box frame to generate the inclined water flow pattern. A mesh funnel was installed immediately behind the Fish Box to reduce the likelihood of shrimp loss.

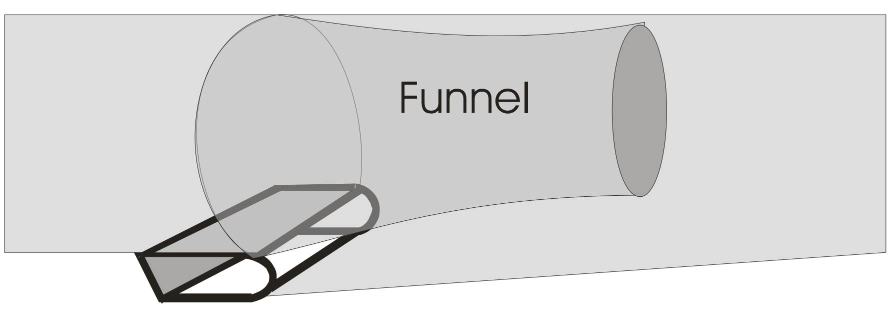


Figure 3: Fish Box bycatch reduction device

Daylight observations of finfish entering the area of inclined water flow were similar to that of the original prototype design. After passing through the funnel, fish dropped down in the extension into the slow flow area under the funnel. Fish then advanced forward into the vertical flow area. When entering the area of the inclined water flow, most fish quickly dropped down out of the escape opening. Snapper appeared to linger in the area slightly longer than most species. However, escapement of snapper occurred at a higher rate than had been observed with any other BRD concept.

Two Fish Box designs were tested on commercial vessels. The Modified Fish Box was based on the same design except the top panel contained a curvature to enhance the vortical flow pattern. During the Fish Box certification tests, 35 tows were completed that met the certification protocol (NMFS, 1999) for evaluation of red snapper reduction. The estimated red snapper reduction in fishing mortality was 23.8% with a 95 % confidence interval was 15.2% - 32.4%. Thirty six (36) tows were completed for the Modified Fish Box. The estimated reduction in red snapper mortality was 18.3% with a 95% confidence interval of 4.3% - 32.2% (Foster, 2004). The reduction rate for snapper and total finfish obtained during the certification tests were lower than what occurred during behavioral observations. These results indicate that the behavioral responses observed during daylight conditions are not likely the same as those occurring at night.

Side Opening Grids

Researchers at the Harvesting Systems and Engineering Division have also conducted research on the potential of using Turtle Excluder Devices (TEDs) as BRDS. A study conducted by Bates and Vinsonhaler (1956) gave indications of a technique that could be applied to a grid design to induce fish escapement. The focus of their study was to develop a means of diverting juvenile fish away from the water intake pipe in hydro-electric facilities. They found that by placing louvers diagonally across the intake canal, fish could be diverted horizontally across the canal into a bypass channel away from the intake pipe. This system was successful with fish much smaller than the spacing between the louvers and the effectiveness of the system was due to the behavioral response to the louver system rather than mechanical means. Based on this research, a study was conducted to evaluate the potential of side opening grids in reducing shrimp trawl finfish bycatch (Foster and Watson, 2003).

A double grid (Figure 4) was constructed in such a way as to reduce the amount of visible space between the bars while not restricting the passage of shrimp into the codend. The grid consisted of two rows of bars, offset so that a given bar lined up in the space between the bars of the opposing row. A turtle escape opening was created by removing a large rectangular piece of trawl webbing from side of the extension. The removed webbing was replaced by interchangeable flaps. Three flaps designs were constructed with finfish escape holes located in the bottom/side of the extension, the middle of the extension, and the top/side of the extension in order to determine the optimal escape opening location.

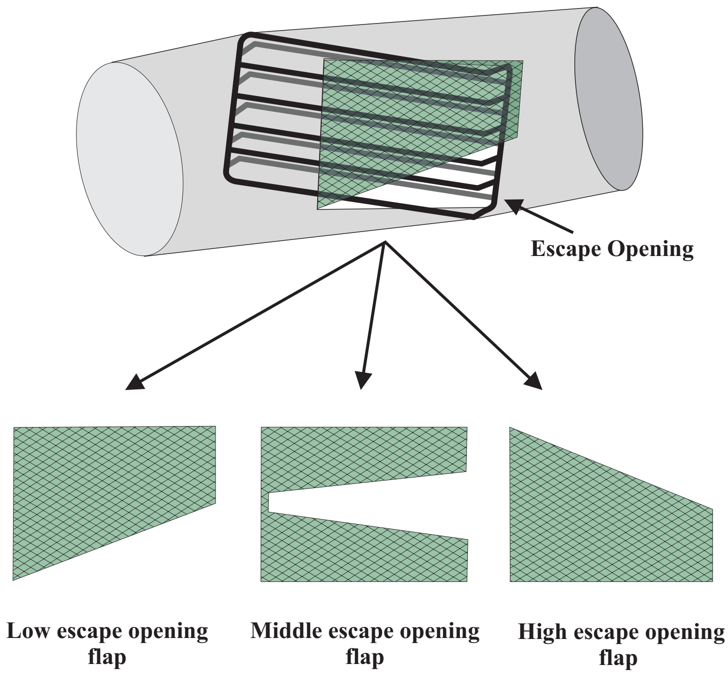


Figure 4: Side Opening Grid with flap configurations.

The grid was installed in the trawl just forward of the codend oriented as to exclude fish out of the side of the extension. The double grid was also rotated 90^{o} in a top opening configuration with the flap removed in order to compare the behavioral responses of fish to two different grid orientations. All observations of fish behavior were made under daytime ambient light conditions.

The behavioral responses described were based on observations of juvenile red snapper (*Lutjanus campechanus*) a demersal fish, and atlantic bumper (*Chlorscombrus chrysurus*), and the striped anchovy (*Anchoa hepsetus*), two small pelagic species. All fish in this study were small enough to pass between the bars of the grid, and escapement was a result of behavioral responses. The response of both pelagic and demersal fish to the side opening grid was found to be a typical predator avoidance response similar to the documented response of fish in the path of an otter board (for details see Wardle, 1986). When the fish had clear passage out of the escape opening, they turned at an angle to the water flow and passed down the face of the grid and out of the escape opening. With the top opening grid, pelagic fish exhibited a successful avoidance strategy and the escape rate was high. However, the overall escape rate for snapper in the top opening grid was much lower than with the grid opening out of the side. The results of this study suggest that while pelagic fish appear to be able to negotiate side or top opening grids equally well, the side opening grid offers a more natural avoidance route for demersal species such as red snapper. Observations of the side opening grid demonstrated great potential for use as a TED as well as a bycatch reduction device.

The side opening grid was subjected to and passed the small turtle certification test in 2000 in preparation for a BRD certification test on commercial vessels. BRD certification tests on a commercial vessel took place in 2001. A total of 19 tows were completed on the trip. At the beginning of the test, the observer and captain immediately noticed that the Side Opening Grid was not achieving the rate of fish reduction expected. During the trip, the grid was fished in four different configurations with similar results. After the trip, testing of the grid was discontinued due to poor performance.

Red Snapper Sensitivity to Infrared Light

The results of the Fish Box and Side Opening Grid BRDs underscored the need to develop an unobtrusive means by which to observe fish behavior in trawls under night conditions. Considering available technology, infra red lighting appears to be the most practical approach for this application.

Prior to developing an infrared camera and lighting system for use in BRD research, NOAA Fisheries scientists conducted research to test juvenile snapper sensitivity to infrared light. The optomotor response, an unconditioned motor reflex (Harden Jones, 1963), was used to measure red snapper sensitivity to infrared light. The apparatus was contained in a circular tank 1.22 m in diameter filled with 30 cm of sea water (Figure 5). Two clear lexan rings were placed in the tank enclosing a swim channel with an outside diameter of 91 cm and inside diameter of 25 cm. The clear rings prevented fish from detecting turbulence created by the rotating outer and inner striped backgrounds. The striped backgrounds were also constructed of lexan painted white with 2.5 cm wide vertical black stripes 5 cm apart. The patterned rings were suspended off of the bottom by a frame attached to an aluminum axis upon which the visual stimulus turned. An opaque white plexiglass disk placed over the top of the apparatus prevented fish from responding to visual stimulus from above.

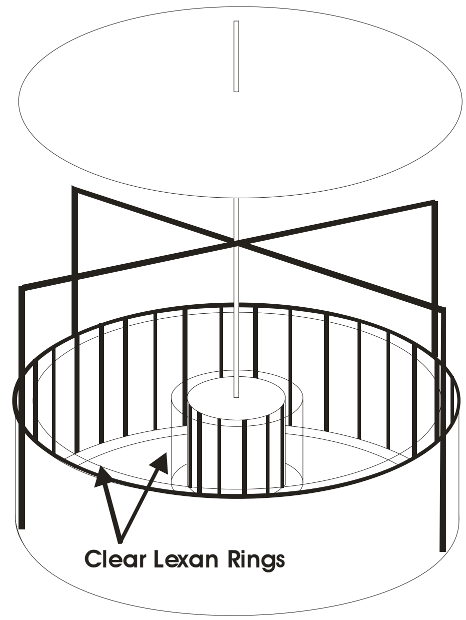
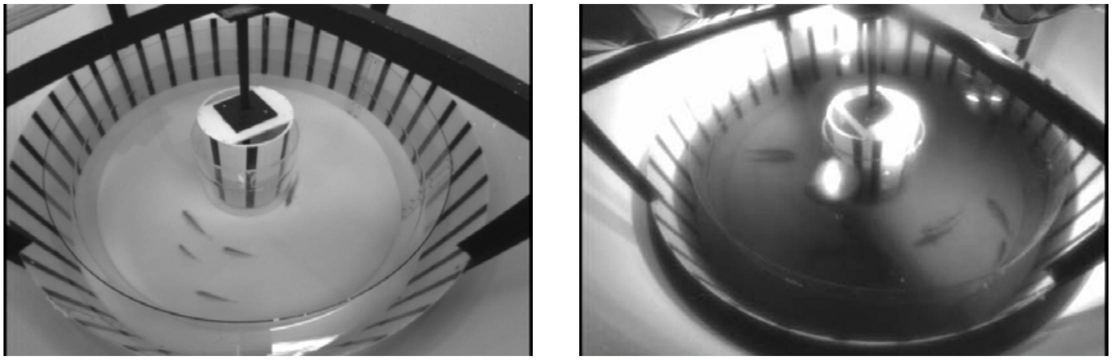


Figure 5: Diagram of Optomotor Apparatus

Experiments were carried out in April 2003 at the University of Mississippi and at the NOAA Fisheries laboratory in Pascagoula, MS. A total of 20 juvenile snapper between 80 cm and 120 cm (fork length) were used. Five snapper were used in each trial. Snapper were place in the tank in an enclosed room illuminated by fluorescent lighting. They were allowed to acclimate for one hour prior to testing. At the start of the test the visual pattern was rotated by hand at a rate of approximately 10 rpm. The test period lasted 5 minutes. At one minute intervals, the direction of rotation changed. After the initial treatment, the lights were turned off and snapper were allowed to visually adapt to the darkness. The tank was then illuminated with 60 LED lights with a peak wavelength of 880 nm. The treatment was then repeated as with the fluorescent lighting. All observations were made with a small CCD camera viewing through a 5 cm hole in the side of the tank.

Upon rotation of the visual pattern, all of the snapper illuminated by fluorescent lighting quickly began swimming around the swim channel in the direction of the pattern rotation, keeping pace with the pattern (Figure 6a). When the direction was reversed, snapper turned 180^{o} and again swam in the direction of rotation. When exposed to the rotating pattern illuminated by infrared light, all of the snapper exhibited random orientation and movement indicating that snapper failed to see the moving pattern illuminated by infrared lights (Figure 6b). The results of this experiment demonstrate the potential for the use of infrared lights for observing red snapper behavior in trawls under commercial trawling conditions.



A B

Figure 6: Response of juvenile red snapper when the optomotor apparatus is turned clockwise with a) fluorescent lighting and b) infrared illumination.

Night Observations using Infrared Lights

Trawl operations using infrared lights to observe fish behavior under dark conditions began in May of 2003 on the R/V HST1. The BRDs evaluated during the test period were fisheyes, Jones-Davis BRD, Fish Box, and Side Opening Grid.

Right away researchers were able to determine that the fish behavior under dark conditions differed greatly from daylight observations. Under light conditions, fish being overtaken by the trawl exhibit a strong optomotor response facing into the direction of the tow. Fish were able to maintain their spatial orientation to the trawl components rarely making contact with the webbing. Under dark conditions, the orientation of fish that are being overtaken is more random. There is some degree of optomotor response observed, possibly from the bioluminescence stirred from the webbing moving through the water. Fish appear more panicked darting back and forth often contacting the webbing and other components of the trawl. Night observations of fish encountering the Side Opening Grid indicate that fish are able to detect the grid bars, but under very low light conditions, fish are unable to be herded by the slope of the bars toward the escape openings. Fish encountering the slow flow areas of the other BRD designs seem even more reserved to maintain there position in the slow flow areas as compared to daylight conditions, relying heavily on crowding as the primary stimulus for escapement. Observations of the Fish Box under day vs. night condition indicate that escapement occurs at a much higher rate under daytime conditions. These observations give indication that the inclined water flow exhibited by this design stimulates fish rather than forces fish to leave when escapement occurs.

In August 2003, research was conducted on the R/V Caretta to study fish behavior in relation to placement of escape openings in the trawl extension. Three BRD designs were evaluated. All three designs were based on the fisheye BRD concept (Figure 7).

The Triangle Fisheyes are two BRDs in the shape of right triangles. The fisheyes were placed in the bottom of the extension with a triangular piece of webbing removed creating an escape opening on the bottom side of the extension. The Side Opening Half Moon Fisheyes (another double BRD design) was installed in the sides of the extension. The straight side of the escape opening was flush with the sides of the extension and the curved portion of the frame intruded inside of the extension. The Bottom Opening Half Moon Fisheyes had the same escape opening dimensions as the side opening design. However, with this design the curved portion of the escape openings faced outward. The BRDs were installed in the bottom of the extension, 17 meshes to either side of center. A 173cm x 25cm piece of black plastic (herculite) was attached to the bottom of the extension behind the escape openings to prevent shrimp from crawling out of the trawl.

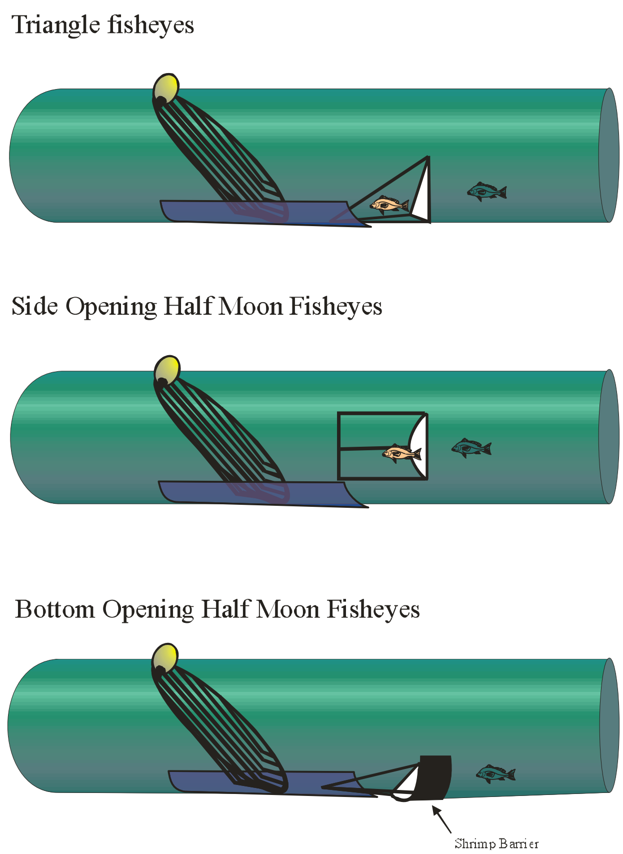


Figure 7: BRD Designs evaluated during the August, 2003 research cruise on the R/V Caretta.

Behavioral observations with the Triangle Fisheyes indicate demersal finfish such as juvenile red snapper, croaker and longspine porgy were observed reacting to the slow water flow areas created by the fisheyes. The fisheyes were observed to have a slight inward turn causing the inside corners of the triangles to ride lower in the extension than the rest of the fisheye frame. The fish tended to take up position in the lowest part of the extension behind the BRD and took the majority took up position behind the inside corners of the fisheyes, away from the escape opening (Figure 8). Shrimp were also observed taking up position in the slow flow areas behind the fisheyes.

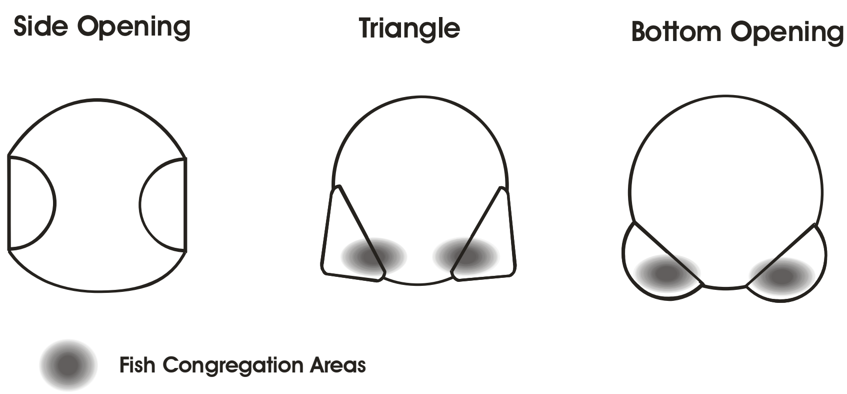


Figure 8: Fisheye configurations with fish congregation areas

Fish and shrimp observations were then obtained around the Side Opening Half Moon Fisheyes. There was around 8cm of clearance between the bottom of the escape openings and the bottom of the extension. The majority of the fish paid little or no attention to the fisheyes as they passed through the TED extension and passed into the codend. Fish that did take up positioning the slow flow areas behind the fisheyes did for only a short period of time before falling back. Shrimp also responded to the slow flow areas at a much lower rate than they did with the triangle fisheye. During haulback, fish and shrimp were observed advancing forward from the codend in the bottom of the extension and passing under the escape openings of the fisheyes with little or no response to the BRDs.

Based on these observations, a third fisheye design was constructed. The Bottom Opening Half Moon Fisheye was installed to allow the BRD escape openings to be the lowest part of the extension. A shrimp barrier was also installed due to the fact that the bottom of the extension is an area of high shrimp occurrence. Juvenile snapper as well as other demersal finfish responded well to the low opening fisheyes with many fish taking up position in the lowest part of the extension near the escape openings and many escapes were observed while towing. The water flow was observed to be very low immediately behind the escape opening and a small number of shrimp were observed swimming forward across the barrier.

After the behavioral observations were obtained, proof of concept evaluations were conducted with the Bottom Opening Half Moon Fisheyes on the R/V Caretta. Twenty three (23) paired tows were completed for this configuration. Sixteen (16) tows were analyzed as non-problem tows. The total bycatch reduction was 42.7% with a shrimp loss of 3.4%. The reduction for zero year class red snapper was 12.7 % while the reduction rate for age one red snapper was 56.0 %. The estimated red snapper F reduction was 43%. (Foster, 2003).

Certification tests were initiated in the fall of 2003 with the bottom opening fisheye design. However, operational problems were encountered with the design in that the fisheyes located on the bottom of the trawl had a tendency to scoop mud during the haulback causing the net to bog and rip between the fisheyes and TED. Testing has been discontinued on this design until the operational problems can be overcome.

Swimming Performance and Behavior

Understanding fish behavior in trawls is a key to developing effective bycatch reduction technology. However, the ability of fish to respond in a given environment is limited by performance thresholds. To better understand red snapper swimming performance and how it is affected by environmental factors, NOAA Fisheries has been assisting the University of Mississippi on a three year MARFIN project entitled "Behavior and Swimming Performance of Red Snapper, *Lutjanus campechanus*: Its Application to Bycatch Reduction".

The objectives of the laboratory experiments conducted during this three year project are: (1) Examine seasonal changes in red snapper swimming performance. (2) Examine how red snapper swimming performance changes with size. (3) To quantify the change in red snapper swimming performance with temperature and light levels (i.e. day vs. night swimming). (4) Examine the day vs. night behavioral responses of red snapper to changing water flow patterns using a vortex generating BRD.

Starting in January 2002, Harvesting System began collecting live snapper from trawlable webbing reefs for use in this study. Now in the third year, more than 800 live age 0 and age 1 juvenile snapper have been collected for the University in support of this ongoing project.

Industry Assistance

Researchers with the Harvesting Systems and Engineering Division continue to support the shrimping industry, state, and federal researchers and academia in efforts to develop bycatch reduction technology. Working cooperatively with the Gulf and South Atlantic Fisheries Foundation Inc., information on advancements in BRD technology and evaluation techniques are periodically disseminated to the shrimping industry through video productions, presentations and reports. Vessel sea time is provided annually to BRD developers for evaluation of prototype BRDs. During evaluations, Harvesting Systems divers obtain observations of fish behavior, video documentation of operational characteristics, water flow measurements, and delineation of water flow patterns associated with bycatch reduction designs. This information was provided along with consultation from Harvesting Systems gear technicians to modify and evaluate bycatch reduction devices. Fifty one (51) conceptual designs and design modifications for bycatch reduction contributed by fishers, net shops, gear technicians, and biologist were evaluated between 1999 and 2003.

Discussion

As documented by Broadhurst (2000), bycatch reduction technology developed for shrimp trawls can be broadly categorized into two categories; (1) those that separate species by difference in behavior; and (2) those that mechanically exclude unwanted organisms according to there size. Because of the similarity in size between bycatch species and shrimp in the Gulf of Mexico, bycatch reduction strategies have had to rely on behavioral differences. Because of technological limitations, most BRD development has been based on behavioral observations obtained during daylight conditions. However, the shrimp trawl fishery in the Gulf of Mexico is primarily a night fishery. Many BRD designs such as the Fish Box and Side Opening Grid have shown great promise in daylight only to fall short of expectations when tested in the fishery under commercial conditions. It is highly suspected that these shortcomings are a result in the differences between the behavior observed during the day and what actually occurs at night.

The implementation of ultra-bright infrared LEDs and low light CCD cameras as research tools has been a major breakthrough in our ability to understand fish behavior in trawls at night. Finfish observations using infrared illumination indicate that BRDs are most effective in releasing demersal finfish such as red snapper when the escape openings are near to the bottom of the trawl. Observations also indicate that fisheyes installed in the bottom of the trawl have a higher escape rate while towing than fisheyes installed in the top of the codend. These findings are consistent with previous studies which have shown that fisheyes are effective in excluding finfish bycatch when placed in the bottom of the trawl (Watson et al., 1993).

However, observations also indicate that the bottom of trawl is an area of high shrimp occurrence. BRDs placed in this area are at risk of substantial shrimp loss due to shrimp crawling out of the BRD escape openings. In order to address the shrimp loss, a shrimp crawl barrier was incorporated into the BRD design. The 3.4 % shrimp loss with the current design is an improvement over results achieved with similar BRD designs tested without shrimp barriers, which showed shrimp losses from 19% to 31% (Watson et al., 1993). However, more research is needed to redesign the device to reduce the vulnerability to bottom hangs and bogging with the bottom opening configuration.

We have been successful in developing BRDs that work in daytime conditions based on our understanding of fish behavior in trawls as observed under daytime conditions. It is our hope that this methodology will continue to be successful now that we have an effective way to observe fish under nighttime commercial trawling conditions.

Acknowledgments

The results presented in this report are a product of the dedicated fisheries biologists, gear specialists, and secretary at the Harvesting Systems and Engineering Division, NOAA Fisheries and Johnson Controls, Southeast Fisheries Science Center, Pascagoula, MS. Special thanks also goes to Arill Engaas, with the Institute of Marine Research, Bergen, Norway, and Glenn Parsons, with the University of Mississippi. The Harvesting Systems personnel are as follows:

James Barbour
Keith Bates
Charlie Bergmann
Jeff Gearhart
Kendall Falana
Jack Forrester
Dan Foster
Dominy Hataway
Wayne Hoggard
Nick Hopkins
Drew Hopper
Mariel Hughes
Lionell Laforce
John Mitchell
David Saksa
Lee Saxon
Dale Stevens
Charles (Wendy) Taylor
John Watson

References

Batty, R.S., 1983. Observations of fish larvae in the dark with television an IR illumination. Mar. Biol. 76, 105-107.

Broadhurst, M.K. 2000. Modifications to reduce bycatch in prawn trawls: A review and framework for development. Reviews in Fish Biology and Fisheries. 10: 27-60.

Engaas, A., Foster, D., Hataway, D., Watson, J. and Workman, I.K. 1999. The behavioral response of juvenile red snapper (*Lutjanus campechanus*) to shrimp trawls that utilize water flow modifications to induce escapement . Marine Technology Society Journal 33(2): 43-50.

Engaas, A., Foster, D., 2002. The response of red snapper (*Lutjanus campechanus*) and pinfish (*Lagodon rhombiodes*) to inclined water flow. Fisheries Research 58 (2002) 315 – 321.

Goodyear, C.P. Phares, P., 1990. Status of red snapper stocks of the Gulf of Mexico-Report for 1990. National Marine Fisheries Service, Southeast Fisheries Science Center, Miami, FL. Laboratory Report, Contribution # CRD 89/90-05, 72p.

Foster, D., Watson, J. 2003. The response of finfish to side opening grids. ICES Symposium on Fish Behaviour in Exploited Ecosystems. June 2003, Bergin, Norway.

Foster, D., 2003. R/V Caretta August 21 – September 18, 2003 Cruise Report. NOAA Fisheries, Southeast Fisheries Science Center, P.O. Drawer 1207, Pascagoula, MS, 30568

Foster, D., 2004. 1999 – 2003 North-Central and Western Gulf of Mexico BRD Performance, Report to SEDAR. NOAA Fisheries, Southeast Fisheries Science Center, P.O. Drawer 1207, Pascagoula, MS, 30568

Harden Jones, F.R. 1963.The Reaction of Fish to Moving Backgrounds. J. exp. Biol., 40, 437-46.

Masuoka, T., Ishizuka, S., Anaradu, K., Nakano, M., 1997. Assessment by underwater infrared video of the selectivity of an experimental Danish seine for deep-water prawn. In: Hancock, D.A., Smith, D.C., Grant, A., Beumer, J.P. (Eds.), Proceedings of the Second World Fisheries Congress: Developing and Sustaining World Fisheries Resources: The State of Science and Management. 1996, Quensland, Australia. CSIRO Publishing, Australia, pp. 551-557.

Nichols, S., Shah, A., Pellegrin, G.I., and Mullin, K., 1990. Updated estimates of shrimp fleet bycatch in the offshore waters of the US Gulf of Mexico. Report to the Gulf of Mexico Fishery Management Council. 1990. National Marine Fisheries Service, Southeast Fisheries Science Center, Pascagoula Laboratory, P.O. Drawer 1207, Pascagoula, MS 39568.

NMFS 1999. Gulf of Mexico Bycatch Reduction Device Testing Protocol Manual. National Marine Fisheries Service, Southeast Regional Office, 9721 Executive Center Drive, St. Petersburg, Florida 33702.

Olla, B.L., Davis, M.W., 1990. Effects of physical factors on vertical distribution of larval walleye Pollock *Theragra chalocogramma* under controlled laboratory conditions. Mar. Ecol. Prog. Ser. 63-105-112.

Olla, B.L., Davis, M.W., Rose, C., 2000. Differences in orientation and swimming of walleye Pollock *Theragra chalcomgramma* in trawl net under light and dark conditions: concordance between field and laboratory observations. Fisheries Research 44, 261-266.

Ruggles, C.P., Ryan, P., 1964. An investigation of louvers as a method of guiding juvenile pacific salmon. In: The Canadian Fish Culturist. Issue 33, November 1964, 67 p.

Ryer, C.H., Olla, B.L., 1998. Effect of light on juvenile walleye Pollock schooling and interaction with predators. Mar. Ecol. Prog. Ser. 167, 215-226.

Wardle, C.S., 1986. Fish behavior and fishing gear. In: T.J. Pitcher (Editor), The Behaviour of Teleost Fishes. Croom Helm, London/Sydney.

Warren, B. 1994. ed. Win-Win bycatch solutions. National Fisheries Conservation Center, 4055 21st Avenue West, Seattle, WA 98199. 112p.

Watson, J., Workman, I., Foster, D., Taylor, C., Shah, A., Barbour, J. and Hataway, D., 1993. Status report on the potiential of gear modifications to reduce finfish bycatch in shrimp trawls in the southeastern United States, 1990-1992. NOAA Tech. Memo., NMFS-SEFC-327.

Workman, I. K., and Foster D.G,. 1994. Occurrence and behavior of juvenile red snapper, *Lutjanus campechanus*, on commercial shrimp fishing grounds in the northeastern Gulf of Mexico. Marine Fisheries Review, 56(2): 9-11.

Workman, I., Foster, D., 2002. The Webbing Reef: A tool used in the study of juvenile red Snapper (*Lutjanus campechanus*). Proceedings of the Oceans 2002 IEEE/MTS Conference, 146–150.