REPORT TO CONGRESS

SOUTHEASTERN UNITED STATES SHRIMP TRAWL BYCATCH PROGRAM

PREPARED BY

NATIONAL MARINE FISHERIES SERVICE

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

U.S. DEPARTMENT OF COMMERCE

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Report on Southeastern United States Shrimp Trawl Bycatch Program

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1.0 EXECUTIVE SUMMARY

This report responds to Congressional requirements imposed pursuant to the Sustainable Fisheries Act of 1996. Section 405(e) of the Magnuson-Stevens Fishery Conservation and Management Act (Magnuson-Stevens Act) (16 U.S.C. 1881d(e)) requires the Secretary to complete the ongoing shrimp trawl bycatch program and submit a detailed report to Congress. Specifically, the law requires that "The Secretary shall, within one year of completing the programs required by this section, submit a detailed report on the results of such programs to the Committee on Commerce, Science, and Transportation of the Senate and the Committee on Resources of the House of Representatives."

NMFS, acting on behalf of the Secretary, has attempted to respond fully to the Congressional mandates to conclude and summarize the incidental harvest research program initiated in 1992 (Section 405 (a)-(d)), and to then prepare a detailed report on those activities (Section 405(e)). In doing so, it should be noted that three guiding principles have been consistently applied throughout this research program. First, priority attention has been given to ensure that the research program was scientifically sound in its design and implementation. To this end, NMFS' Southeastern Regional Office (SERO) and Fisheries Science Center (SEFSC) jointly developed and published a document entitled "Shrimp Trawl Bycatch Research Requirements." This document established scientific protocols for conducting onboard shrimp trawl bycatch characterization research, developing and testing bycatch reduction devices (BRDs), and evaluating various bycatch management options. These protocols were subjected to peer review by an industry-organized panel of researchers and statisticians and, upon approval, became the scientific foundation of the bycatch research program.

Second, because the shrimp trawl bycatch issues are complex, and have profound implications for numerous user groups, care was taken in the early development phases to involve all affected parties in the research program. To this end, NMFS entered into several cooperative agreements with the Gulf and South Atlantic Fisheries Development Foundation, Inc. (Foundation) to organize and utilize a 34-member Finfish Bycatch Steering Committee to guide the development and implementation of the bycatch research plan. Included on the Steering Committee were representatives of the commercial and sportfishing industries, the conservation community, state fishery management agencies, the Gulf and Atlantic States Marine Fisheries Commissions, the Gulf and South Atlantic Fisheries Management Councils, Sea Grant programs, universities, and NMFS. In addition, a 15-member Technical Review Panel and 8-member Gear Review Panel were established to advise the Steering Committee. Working together, these diverse groups developed and published "A Research Plan Addressing Finfish Bycatch in the Gulf of Mexico and South Atlantic Shrimp Fisheries." Throughout the bycatch research program, this document has been the keystone to the effort.

Third, following the implementation of the research plan, NMFS has not been working alone to collect and evaluate the scientific information provided in this report. Many diverse groups collected the onboard shrimp trawl bycatch data used for bycatch characterization and BRD evaluation. The stock assessment techniques and published conclusions have been peer-reviewed by Council stock assessment panels and many other national and local groups.

Ultimately, the goal of the finfish bycatch research program was to assess the impact of incidental shrimp trawl bycatch on federally managed fishery resources and thus provide fishery managers information needed to judiciously manage finfish bycatch in the Gulf and south Atlantic shrimp fisheries. Over the past five years (February 1992 through December 1996) a total of 4,215 sea days of sampling effort have been achieved by NMFS observers (1,405 days) and non-NMFS observers (2,810 days) in the Gulf of Mexico and along the east coast of the United States. Most of the effort occurred in waters off Texas (1,219 days) and Louisiana (1,096 days), followed by the Atlantic (920 days), Florida (841 days), and Alabama-Mississippi (139 days). These sea days were accomplished during 604 trips, varying in length from 1 to 54 days. From these sea days, bycatch data have been collected from 5,695 individual tows, with several hundred different species being documented from the trawls.

When all tows collected in the southeast Atlantic (east coast of the United States) were combined for analysis, the results by weight revealed that on the average about 27 kg of organisms per hour are taken during trawling operations. About 51% of the catch by weight is composed of finfish, 18% by commercial shrimp species, 13% by non-commercial shrimp crustaceans, and 18% by non-crustacean invertebrates. Analysis by number revealed that on the average about 1450 organisms per hour are taken during trawling operations. Analysis of the composition of the organisms showed that about 54% of the catch by number is composed of finfish, 23% by commercial shrimp species, 12% by non-commercial shrimp crustaceans, and 11% by non-crustacean invertebrates.

When all tows collected in the Gulf of Mexico were combined for analysis, the statistics by weight revealed that on the average about 28 kg of organisms per hour are taken during trawling operations (Figure 4). Analysis of the composition of the organisms showed that about 67% of the catch by weight is composed of finfish, 16% by commercial shrimp species (brown shrimp, white shrimp, pink shrimp, seabobs, sugar/blood shrimp, and rock shrimp), 13% by non-commercial shrimp crustaceans, and 4% by non-crustacean invertebrates. The analysis by number revealed that on the average, about 1350 organisms per hour are taken during trawling operations (Figure 4). Analysis of the composition of the organisms showed that about 50% of the catch by number is composed of finfish, 29% by commercial shrimp species, 17% by non-commercial shrimp crustaceans, and 4% by non-crustacean invertebrates.

Bycatch in the shrimp fishery, as a whole, can be estimated by multiplying the catch rates observed aboard the sampled vessels by the total effort. Thus, both an estimate of the catch rates per some unit of effort and an estimate of the total effort for the unit chosen are necessary for calculation of total bycatch. In stock assessments, these bycatch estimates have the same function as any other catch statistic - they are estimates of removals of individuals from the population that must be accounted for in the models used in assessment. As such, a continuous time series over several years is needed for dependable assessments. Bycatch estimates from the shrimp trawl fishery have been made for at least 30 species in the Gulf of Mexico, and at least 7 species in the south Atlantic.

Bycatch of non-targeted finfish does not occur just in the shrimp trawl fishery. Identifying other fishing activities (commercial and recreational) with associated bycatch, as well as non-fishing activities where stock removals occur, and quantifying the catch (mortality) resulting from such activities, are critical for accurately assessing the status of fishery stocks. Information regarding the type and quantity of bycatch associated with non-shrimp fisheries and non-fishery activities is often inadequate for stock assessment due to lack of time series estimates for bycatch and stock mortality. Most of the available information of this nature has been obtained through short-duration programs, many of which have been neither sustained over time nor conducted throughout the range of the fishery.

For those fisheries where bycatch exerts a significant impact on other stocks, estimating bycatch must be considered in the same light as estimating commercial and recreational catch and as such it must be an integral part of basic fishery statistics collections. Moreover, strategies must be developed to distribute observer capability among the various fisheries requiring coverage, in such a manner as to complete basic quantification of bycatch for all sizable fisheries and to provide continuing coverage in those fisheries deemed to exert significant impact on populations of species taken in bycatch. Other priority southeastern fisheries that require observer coverage to estimate bycatch either initially or on a continuing basis include the pelagic longline, menhaden, and reef fish fisheries.

Human activities, primarily urban and industrial expansion, have resulted in the loss of large areas of productive and commercially valuable fishery habitats in the southeast. Upland flood control and other measures that restrict freshwater and sediments to coastal areas, point and non-point source pollution, nutrient enrichment, dredge and fill or open disposal operations, hydroelectric power development, and oil and gas production and exploration activities have been identified as factors contributing to a reduction in the quality and quantity of fishery habitat. Documenting fish mortality from these types of activities is difficult, often speculative, and typically not included in traditional stock assessments. While federal and state agencies have been successful in offsetting some habitat loss through restoration and creation of wetlands, seagrass beds and other aquatic habitats, more emphasis should be directed at identifying sources and quantifying fishery mortality resulting from non-fishing human activities.

The basic purpose of stock assessment is to provide advice on the optimum exploitation of aquatic living resources. In stock assessments, bycatch estimates from shrimp trawls, bycatch estimates from non-shrimp fisheries, and impact estimates from non-fishing activities, all have the same function as any direct harvest statistics - they are estimates of removals of individuals from the population (stock) that must be accounted for in the population models used in assessment. Directed fishing pressure, habitat alteration/degradation, fish population declines resulting from climatic change, and predatory-prey interactions are all integral components for assessing the strength of a fishery stock. Biologists attempt to quantify total mortality with the highest degree of accuracy. Some sources of mortality can only be approximated. Overestimates typically lead to excessively restrictive management measures, while underestimates may result in management measures that fail to adequately protect fisheries stocks. Stock assessments with shrimp trawl bycatch estimates have been produced for red snapper, weakfish, king mackerel, Spanish mackerel, red drum, cobia, and sharks.

One of the objectives of the southeast bycatch research program was to identify, develop, and evaluate gear options for reducing bycatch in the Gulf and south Atlantic shrimp fisheries. The research program called for gear modification studies to be conducted in inshore, near shore, and offshore waters focusing on key FMP managed species (i.e., Gulf red snapper, Atlantic weakfish, king mackerel, and Spanish mackerel), and coordinated through a technical review panel. The technical review panel was responsible for selecting the best prototype gear modifications for commercial evaluation, monitoring testing in different shrimping areas, and prioritizing gear modification options for management consideration. The goal of the gear development project is to develop shrimp trawl gear modifications and or fishing tactics, which are capable of reducing the bycatch of finfish with minimum loss of shrimp production.

From 1990 to 1996 fishery researchers and commercial fishers working under the auspices of the southeast regional bycatch program developed and tested a total of one hundred and forty five (145) bycatch reduction device (BRD) designs. These evaluations were conducted under a research plan developed by the Foundation and a testing protocol developed by the National Marine Fisheries Service. Operational testing for sixteen (16) BRD designs was conducted on commercial shrimp vessels by the Foundation, Georgia Department of Natural Resources (GDNR), the NMFS Galveston and Mississippi Laboratories, NCDMF, Texas Shrimp Association, Texas A&M Sea Grant, and University of Georgia Sea Grant. These evaluations have produced an extensive database consisting of over 3,400 tows.

Shrimp trawl gear modifications have been successfully developed and evaluated under the southeast regional bycatch program for their potential as possible management options to reduce the bycatch mortality associated with shrimp trawling. The 12x5 fisheye, the extended funnel BRD and the expanded mesh BRD have been approved for use by the shrimp industry in the south Atlantic under Amendment 2 to the Fishery Management Plan for the shrimp fishery. The 12x5 fisheye have been approved for implementation in the Gulf of Mexico under Amendment 9 to the Fishery Management Plan for the shrimp fishery.

Several new designs currently being evaluated also appear to offer excellent potential. This program has demonstrated that new and improved sustainable fishery technology can be successfully developed through cooperative efforts between the commercial fishing industry, federal and state research agencies. These technologies can offer management options to restore overfished stocks and reduce environmental impacts while maintaining viable commercial fisheries.

Measures to reduce bycatch have been proposed to alleviate problems with incidental capture of living marine resources in the Gulf of Mexico shrimp trawl fishery. However, the mandated use of bycatch reduction devices may have the effect of releasing more shrimp predators or allowing small fish to grow larger and thus become predators on shrimp, possibly reducing shrimp fishery yield by increasing the incidence of predation by finfish. Although the interaction of shrimp and finfish predators in a Gulf of Mexico estuary has been described in detailed in the literature, limited information is available regarding shrimp predation in offshore waters, and its effect on shrimp stocks. An ecosystem-based model of the interactions among shrimp and finfish stocks in

the Gulf of Mexico was developed as an analytical tool to guide research and management with respect to bycatch. However, it is important to remember that predictive results of this (and other) models are based on assumptions and the quality of the information available. The current analysis is based on updating previous models that attempted to describe the interactions among fisheries, bycatch, and living marine resources in the Gulf.

Revision of the ecosystem-based bycatch model is enhanced through incorporation of new information on bycatch characterization, stock assessments, and efficiencies of bycatch reduction devices. The large number of variables in the model represent movement toward a realistic evaluation of ecosystem effects in the dynamics of the Gulf of Mexico shrimp fishery. The initial output, however, is of relatively low resolution due to aggregation of information within larger components (e.g., seatrout, snappers, etc. are described within the bottomfish group). Data used to parameterize the model include specific rates for individual components (e.g., sediment burial rates, respiration rates of shrimp) and general trends or average values for other components (e.g., species-directed effort patterns, respiration rates for benthic infauna, natural mortality rates for phytoplankton and zooplankton). The model is used to simulate several different hypothetical scenarios, which encompass possible changes in ecosystem dynamics with the implementation of bycatch management policy. Depending on bycatch exclusion rates and assumptions relative to predator selection of shrimp prey, simulated shrimp stock biomass could increase by 4.7% or decrease by 17%. The decrease in the shrimp stocks is primarily due to predation, but is also due to a reduction in the amount of nitrogen recycled from discards. However, nitrogen returned to the ecosystem through discards is minimal in comparison to the rather large input from riverine sources.

Fishermen discard catch for a number of reasons. These include harvest of prohibited species, harvest of a species with no market value, and harvest of fish that are the wrong size. There is a wide variation in the bycatch yield not only by region but also by season within specific areas. The volume and number of species comprising the bycatch in tropical fisheries are generally greater than found in more temperate regions. Many nations harvest shrimp and export it in exchange for hard currency that they in turn use to buy goods and services on the world market. In the past, with few exceptions, it has not proved to be economical to retain bycatch which is generally lower in value (sometimes as much as 15 times less valuable that the shrimp) and would generally occupy valuable storage space that could be used for shrimp. Today with the realization of the magnitude of the bycatch and impact on resources there is renewed emphasis on reducing or utilizing bycatch.

It is believed that economics and profitability are the major constraints to use of bycatch. The single most important constraint is the lack of methods to bring the catch to shore at a cost compatible with market end use. Further, the training of personnel in appropriate methods in harvesting and processing is much needed. Thus, education and training are essential to successful utilization of bycatch. Throughout the literature there has been a call for various activities to occur that are deemed necessary for the full utilization of bycatch to occur. These requests include such activities as development of methods to harvest and handle the bycatch, data collection on the bycatch, product development, profitability and market studies of the products developed, training and education regarding utilization of the bycatch, and new equipment development for handling and processing bycatch. Finally, the environmental impact of removing

large quantities of bycatch from the natural environment must be investigated to determine long term impacts of the environment to support these exploited populations.

The NMFS and others have determined that a number of finfish resources in the Gulf of Mexico and south Atlantic are depleted for several reasons, including the application of too much fishing effort by commercial and recreational fishermen and the incidental bycatch of the shrimp trawl fleet. The ensuing debate about how best to restore the stocks to desirable levels involves numerous technological, political, biological and economic factors. Among them are: 1) technological interaction in which shrimping gear inadvertently harvests finfish; 2) management interaction between the shrimp and other fishery management plans governing the harvest of finfish species; 3) competition between commercial and recreational fishermen and among fishermen with different gear types within each group; 4) economic trade-offs over time among various harvesting groups and between different groups of consumers; 5) the current uncertainty regarding whether or not the commercial management structure will allow for an ITQ or similar management system; 6) a lack of current biological information to determine the desirable size of some of the finfish stocks and future yields; and 7) whether or not effort controls will be placed on the recreational fishery. For all these reasons, the interaction between the shrimp and finfish fisheries of the U.S. Gulf of Mexico constitutes a management and economics problem that is controversial, challenging, and, as yet, unresolved in the case of most southeast finfish stocks.

2.0 FORWARD

The Fishery Conservation Amendments of 1990 (Public Law 101-627, Section 110 (c)) amended the Magnuson Fishery Conservation and Management Act (Magnuson Act) (16 U.S.C. 1801) to require the Secretary of Commerce (Secretary) to conduct a 3-year research program to determine the impact of incidental harvest by shrimp trawlers on federally managed fishery resources found along the Nation's south Atlantic and Gulf of Mexico coasts. The Secretary was also required to establish a cooperative program to design and evaluate approaches for reducing the mortality of these incidentally harvested fishery resources. Upon its completion, Congress required the Secretary to submit a detailed report on program findings.

The National Marine Fisheries Service (NMFS), acting on behalf of the Secretary, responded fully to these initial Congressional mandates by implementing a shrimp trawl bycatch research program that was scientifically valid and inclusive of affected and interested parties. February 1995 marked the completion of the third year of that intensive research effort - but not the completion of the entire research program. As mandated by The Fishery Conservation Amendments of 1990, an intermediate report was submitted in April 1995 to apprise Congress of progress made to date and plans for completing the program.

The Sustainable Fisheries Act of 1996 (Public Law 104-297, Section 405) amended the Magnuson-Stevens Fishery Conservation and Management Act (Magnuson – Stevens Act) (16 U.S.C. 1801) to require the Secretary to complete the ongoing shrimp trawl bycatch program and submit a detailed report to Congress. Specifically, Section 405(e) of the Magnuson-Stevens Act, 16 U.S.C. 1881d(e) requires that "The Secretary shall, within one year of completing the programs required by this section, submit a detailed report on the results of such programs to the Committee on Commerce, Science, and Transportation of the Senate and the Committee on Resources of the House of Representatives." This report is being submitted to meet these congressional requirements.

3.0 ABOUT THIS REPORT

This report deals with one of the most significant marine fisheries issues of the 1990s - shrimp trawl bycatch. Specifically, its purpose is to update members of Congress and other interested parties on the completion of this multi-year cooperative shrimp trawl bycatch research program for the southeastern United States. Congressional mandates for this regional research effort were outlined in the Magnuson-Stevens Act.

Significant progress has been made through this research program in addressing the complex bycatch issue. Excellent, cooperative working relationships have been established among the many and diverse government, industry, and public parties interested in resolving the shrimp trawl bycatch issue. The balance of this report describes the complex bycatch issue, reviews Congressional mandates for the conclusions of the program, and highlights the Secretary's response to these mandates, including a brief review of significant accomplishments relative to each.

3.1 The Problem

Since the late 1940s, technological advances have revolutionized fishing vessels, fishing gear, navigational equipment, and fishing techniques. These advancements have enabled commercial and recreational fisherman to catch effectively the fish they seek, thus placing tremendous harvest pressure on many stocks. Many of these fisheries target a single species or groups of species (e.g., shrimp) and employ the most efficient fishing methods and gear available, but they are seldom 100% selective. As a result, in most commercial and recreational fisheries worldwide, an incidental capture of non-target species and age groups occurs. This incidental harvest is termed bycatch.

In some fisheries, bycatch is commercially valuable and is landed along with the target species. In other fisheries, bycatch is non-marketable or illegal to land and is therefore discarded with high mortality rates after target species have been removed. While discarded bycatch is usually of little economic importance to these fisheries, the mortality of directly affected species is not without consequence. It can adversely affect the population size and structure of impacted stocks, reduce the availability of bycatch species to other fisherman that may target them in other fisheries, and result in fundamental changes in ecosystem energy flows.

Since the mid-1970s, concern over bycatch in the Gulf of Mexico and south Atlantic shrimp fisheries has intensified among state and federal fishery managers, conservationists, commercial and recreational fisherman, and the public. Concerns initially surfaced over the incidental capture of endangered or threatened sea turtles. Substantial progress, however, is being made to reduce sea turtle mortalities through the required use of certified turtle excluder devices (TEDs).

More recently, concern over shrimp trawl bycatch has broadened to include the incidental catch of finfish and other living marine resources. Concern over finfish bycatch is being expressed intensely and globally, and for several important reasons:

1) An increase world demand for protein, linked with a growing realization that coastal ocean resources are finite and under stress, has focused national attention on the need to minimize waste in all fisheries, including valuable shrimp fisheries.

2) Declining landings for many species of marine finfish, shellfish, and crustaceans have precipitated the imposition of state and federal catch restrictions to maintain or rebuild overfished fish stocks. As a matter of equity, sport and commercial fisherman are reluctant to accept regulation of their directed fishing activities if management measures are not also imposed to reduce significant incidental fishing mortality.

3) Research findings in the 1980s and 1990s revealed that bycatch discards in the Gulf of Mexico and southeastern Atlantic shrimp fisheries were indeed significant. While croaker, porgies, spot, and other non-federally managed groundfish species accounted for the larger share of bycatch, federally managed species such as red snapper, king mackerel, Spanish mackerel, and sharks were also represented.

4) Stock assessments in the early 1990s indicated some finfish species taken as bycatch in the shrimp fishery were under severe stress and would not recover quickly unless shrimp bycatch was reduced. Weakfish and Spanish mackerel in the south Atlantic, and red snapper in the Gulf of Mexico were three notable examples.

Concern over red snapper populations in the Gulf of Mexico brought the shrimp trawl bycatch issue into focus and precipitated the development and implementation of the cooperative bycatch program. In 1989, a red snapper stock assessment revealed that the Gulf stock was at a very low level and that directed and incidental harvest would have to be severely restricted to allow for stock rebuilding. Notably, data showed that over 90% of the fishing mortality on age 0 and age 1 red snapper was attributed to shrimp trawling (Goodyear and Phares, 1990). Managers agreed that this source of mortality would have to be significantly reduced in order to rebuild red snapper stocks within the time frame established by the Gulf of Mexico Fishery Management Council (Gulf Council) without halting all directed commercial and recreational red snapper fisheries.

In 1990, the Gulf Council considered a 3-month closure of the Gulf shrimp fishery to protect juvenile red snapper. This proposal responded to concerns expressed by commercial and recreational red snapper fisherman who believed shrimpers needed to share the burden of regulations required to rebuild red snapper populations. However, subsequent analysis of the proposed closure (Nichols et al., 1990) indicated that it would likely have little benefit, particularly if shrimping effort shifted to other periods. This realization motivated the Gulf Council to begin searching for other management approaches that might be effective in reducing the bycatch of small juvenile red snapper in shrimp trawls. During these discussions, many parties raised concerns about the adequacy of shrimp bycatch estimates and the potential economic impacts that would likely result from proposed management measures.

Much progress has been made toward addressing and resolving many of the complex issues brought to the meetings in the early 1990s. The intermediate report submitted to Congress in April 1995 outlined the initial formation, development, and subsequent implementation of the

shrimp trawl bycatch research program in the southeastern United States. That early report outlined the progress that had been completed up to that point. This new report to Congress is designed to provide an update of the program accomplishments, display the significant research achievements, and discuss important findings in light of complex management issues. The data summarized and contained in this report are complete through December 31, 1996. While there were additional data collected in 1997, only those data that have been edited and entered into the archived database also will be discussed in the report.

4.0 THE MANDATE FROM CONGRESS

During the 1996 reauthorization of the Magnuson-Stevens Fishery Conservation and Management Act, continued concerns over bycatch issues manifested themselves in an amendment mandating the Secretary to report on progress with regards to the Incidental Harvest Research Program initiated in 1992. Through Section 206 of the Sustainable Fisheries Act, Congress communicated the following charge to the Secretary:

4.1 Public Law 104-297, Section 206 INCIDENTAL HARVEST RESEARCH

(a) COLLECTION OF INFORMATION.--Within nine months after the date of enactment of the Sustainable Fisheries Act, the Secretary shall, after consultation with the Gulf Council and South Atlantic Council, conclude the collection of information in the program to assess the impact on fishery resources of incidental harvest by the shrimp trawl fishery within the authority of such Councils. Within the same time period, the Secretary shall make available to the public aggregated summaries of information collected prior to June 30, 1994, under such program.

(b) IDENTIFICATION OF STOCK.--The program concluded pursuant to subsection (a) shall provide for the identification of stocks of fish which are subject to significant incidental harvest in the course of normal shrimp trawl fishing activity.

(c) COLLECTION AND ASSESSMENT OF SPECIFIC STOCK INFORMATION.--For stocks of fish identified pursuant to subsection (b), with priority given to stocks which (based upon the best available scientific information) are considered to be overfished, the Secretary shall conduct--

> **(1) a program to collect and evaluate information on the nature and extent (including the spatial and temporal distribution) of incidental mortality of such stocks as a direct result of shrimp trawl fishing activities;**
>
> **(2) an assessment of the status and condition of such stocks, including collection of information which would allow the estimation of life history parameters with sufficient accuracy and precision to support sound scientific evaluation of the effects of various management alternatives on the status of such stocks; and**
>
> **(3) a program of information collection and evaluation for such stocks on the magnitude and distribution of fishing mortality and fishing effort by sources of fishing mortality other than shrimp trawl fishing activity.**

(d) BYCATCH REDUCTION PROGRAM.--Not later than 12 months after the enactment of the Sustainable Fisheries Act, the Secretary shall, in cooperation with affected interests, and based upon the best scientific information available, complete a program to--

> **(1) develop technological devices and other changes in fishing operations necessary and appropriate to minimize the incidental mortality of bycatch in the course of shrimp trawl activity to the extent practicable, taking into account the level of bycatch mortality in the fishery on November 28, 1990;**
>
> **(2) evaluate the ecological impacts and the benefits and costs of such devices and changes in fishing operations; and**

(3) assess whether it is practicable to utilize bycatch which is not avoidable.

(e) REPORT TO CONGRESS.--The Secretary shall, within one year of completing the programs required by this section, submit a detailed report on the results of such programs to the Committee on Commerce, Science, and Transportation of the Senate and the Committee on Resources of the House of Representatives.

(f) IMPLEMENTATION CRITERIA.--To the extent practicable, any conservation and management measure implemented under this Act to reduce the incidental mortality of bycatch in the course of shrimp trawl fishing shall be consistent with--

(1) measures applicable to fishing throughout the range in United States water of the bycatch species concerned; and

(2) the need to avoid any serious adverse environmental impacts on such bycatch species or the ecology of the affected area.

5.0 THE RESPONSE

NMFS, acting on behalf of the Secretary, has attempted to respond fully to the Congressional mandates to conclude and summarize the incidental harvest research program initiated in 1992 (Section 405 (a)-(d)), and to then prepare a detailed report on those activities (Section 405 (e)). In doing so, it should be noted that three guiding principles have been consistently applied throughout this research program. First, priority attention has been given to ensure that the research program was scientifically sound in its design and implementation. To this end, NMFS' Southeastern Regional Office (SERO) and Fisheries Science Center (SEFSC) jointly developed and published a document entitled "Shrimp Trawl Bycatch Research Requirements" (NMFS, 1991). This document established scientific protocols for conducting onboard shrimp trawl bycatch characterization research, developing and testing bycatch reduction devices (BRDs), and evaluating various bycatch management options. These protocols were subjected to peer review by an industry-organized panel of researchers and statisticians and, upon approval, became the scientific foundation of the bycatch research program.

Second, because the shrimp trawl bycatch issues are complex, and have profound implications for numerous user groups, care was taken in the early development phases to involve all affected parties in the research program. To this end, NMFS entered into several cooperative agreements with the Gulf and South Atlantic Fisheries Development Foundation, Inc. (Foundation) to organize and utilize a 34-member Finfish Bycatch Steering Committee to guide the development and implementation of the bycatch research plan. Included on the Steering Committee were representatives of the commercial and sportfishing industries, the conservation community, state fishery management agencies, the Gulf and Atlantic States Marine Fisheries Commissions, the Gulf and South Atlantic Fisheries Management Councils, Sea Grant programs, universities, and NMFS. In addition, a 15-member Technical Review Panel and 8-member Gear Review Panel were established to advise the Steering Committee. Working together, these diverse groups developed and published "A Research Plan Addressing Finfish Bycatch in the Gulf of Mexico and South Atlantic Shrimp Fisheries" (Hoar et al., 1992). Throughout the bycatch research program, this document has been the keystone to the effort.

Third, following the implementation of the research plan, NMFS has not been working alone to collect and evaluate the scientific information provided in this report. Many diverse groups collected the onboard shrimp trawl bycatch data used for bycatch characterization and BRD evaluation. The stock assessment techniques and published conclusions have been peer-reviewed by Council stock assessment panels and many other national and local groups.

6.0 PROGRAM ACCOMPLISHMENTS

Ultimately, the goal of the finfish bycatch research program was to assess the impact of incidental shrimp trawl bycatch on federally managed fishery resources and thus provide fishery managers information needed to judiciously manage finfish bycatch in the Gulf and south Atlantic shrimp fisheries. The following sections, as outlined in the mandate from Congress, provide a brief summary of the more significant accomplishments made during the research effort. Discussions under each section include a brief introduction, materials and methods (if necessary), results and general discussion with conclusions. The intent in this report is to demonstrate program responsiveness to Congressional mandates, note progress, and discuss significant findings, but not to provide an exhaustive discussion of detailed program findings. Technical reports and peer-reviewed publications, which are better suited for relaying detailed program finding, have been prepared as research was completed, and are listed in Appendix I.

6.1 Collection of Information

In February 1992, a joint commercial/government research program was initiated between NMFS SEFSC and the Foundation to collect species-specific bycatch data to characterize catch rates by number and weight taken by the shrimp fishery during commercial operations in the U.S. Gulf of Mexico and along the southeast Atlantic coast of the United States. The goals of this joint research program were to: 1) update bycatch estimates temporally and spatially, 2) manage and maintain bycatch characterization data sets, 3) analyze bycatch characterization data on the temporal and spatial catch rates of finfish and shrimp, 4) provide data to estimate total bycatch of selected species for stock assessment analysis, 5) develop and evaluate various bycatch reduction devices (BRD), 6) manage and maintain bycatch reduction device data sets, and 7) provide summary data set files and summaries to independent researchers for analyses. This research effort has and will continue to provide essential data to SERO, Gulf of Mexico Fishery Management Council (GMFMC) and South Atlantic Fishery Management Council (SAFMC), fish and wildlife departments of Gulf and south Atlantic states, associations of commercial shrimpers and recreational fishermen, as well as legislators and elected officials at all levels of government.

The sampling design used in this research effort followed the guidelines as set forth in the Research Plan Addressing Finfish Bycatch in the Gulf of Mexico and South Atlantic Shrimp Fisheries, prepared by the Foundation, under the direction of a Steering Committee composed of individuals representing industry, environmental, state, and Federal interests (Hoar et al., 1992). The intent of the sampling design was to survey the shrimp fishery during commercial operation and not to simply establish a research survey study of the bycatch or the finfish populations.

Over the past five years (February 1992 through December 1996) a total of 4,215 sea days of sampling effort have been achieved by NMFS observers (1,405 days) and non-NMFS observers (2,810 days) in the Gulf of Mexico and along the east coast of the United States. Most of the effort occurred in waters off Texas (1,219 days) and Louisiana (1,096 days), followed by the Atlantic (920 days), Florida (841 days), and Alabama-Mississippi (139 days). These sea days were accomplished during 604 trips, varying in length from 1 to 54 days. From these sea days, bycatch

data have been collected from 5,695 individual tows, with several hundred different species being documented from the trawls.

6.2 Identification of Stocks: Bycatch Characterization

Analysis of characterization data reveals important insights about the bycatch in the south Atlantic and the Gulf of Mexico shrimp fisheries. For presentation purposes, the data have been summarized into selected area, depth, and season categories. These stratification cells were created using three seasons (Pre-Summer: January through April, Summer: May through August, and Post-Summer: September through December), seven locations (Atlantic >34°N latitude, Atlantic between 30°-34°N latitude, Atlantic <30°N latitude, West Florida, Alabama-Mississippi, Louisiana, and Texas), and two depth zones in the Gulf of Mexico (nearshore, ≤10 fm; and offshore, >10 fm). In the Atlantic >34°N area only the inshore area was sampled, while in the other two Atlantic coastal areas only the offshore was sampled in this research.

The sample unit in each cell consisted of a single subsample from a trawl haul. NMFS-trained observers were used to collect the trawl haul subsamples and record the data from the fishery. A subsample was obtained from a randomly selected net after each tow. The data collected consisted of tow weight, species composition, species abundance, species weight, and length measurements by species groups. Preliminary research tows indicated that a subsample of 13 kg per towing hour was adequate to ensure that most species taken in the catch were adequately represented in the subsample. A detailed description of the onboard sampling procedures is contained in the NMFS Bycatch Characterization Sampling Protocol (NMFS, 1992a). All observers, whether funded by NMFS, the Foundation, or other agencies, were required to collect data following this protocol.

6.2.1 Results

6.2.1.1 Atlantic (General Trends)

When all tows collected in the southeast Atlantic (east coast of the United States) were combined for analysis, the results by weight revealed that on the average about 27 kg of organisms per hour are taken during trawling operations (Figure 1). About 51% of the catch by weight is composed of finfish (FISH), 18% by commercial shrimp species (SHRIMP) (brown shrimp, *Penaeus aztecus;* **white shrimp,** *P. setiferus;* **pink shrimp,** *P. duorarum;* **seabobs,** *Xiphopenaeus kroyeri;* **sugar/blood shrimp,** *Trachypenaeus* **spp; and rock shrimp,** *Sicyonia brevirostris***), 13% by non-commercial shrimp crustaceans (CRUSTACEA), and 18% by non-crustacean invertebrates (INVERTEBRATES). Analysis by number revealed that on the average about 1450 organisms per hour are taken during trawling operations (Figure 1). Analysis of the composition of the organisms showed that about 54% of the catch by number is composed of finfish, 23% by commercial shrimp species (brown shrimp, white shrimp, pink shrimp, seabobs, sugar/blood shrimp, and rock shrimp), 12% by non-commercial shrimp crustaceans, and 11% by non-crustacean invertebrates.**

Shrimp trawl catch per hour averages for each of the different seasons were examined. Analysis by weight revealed that the pre-summer season had the lowest overall catch rates at 12 kg per hour, while the summer and post-summer seasons had very similar catch rates at around 30 kg per hour (Figure 2). Finfish catch rates always comprised more than 44% of the catch, while shrimp catch rates were approximately 15% to 18% in the summer and post-summer periods, respectively, but 37% in the pre-summer season. Analysis by number showed that the pre-summer season had the lowest overall catch rates with 850 individual organisms per hour, followed by the summer period with around 1350 organisms per hour (Figure 2). The greatest rates were in the post-summer period with 1800 organisms per hour taken in the trawls. Finfish catch rates always comprised more than 44% of the catch, while shrimp catch rates were 17% to 26% in the post-summer and summer periods, respectively, and 11% in the pre-summer season.

Shrimp trawl catch per hour averages for each of the different locations were also reviewed during the analysis (Figure 3). By weight, the northern area (>34°N) had the highest overall catch rates (37 kg per hour), while the other two areas were similar in catch rates at around 25 kg per hour. On the average, about 8 kg of finfish are taken as bycatch for every one kg of commercial shrimp harvested in a trawl in the northern area (>34°N), with about 2.5 to 3 kg of finfish taken as bycatch for every one kg of commercial shrimp harvested in the middle (30°-34°N) and southern (<30°N) Atlantic areas. By number, the middle area (30°-34°N) had the highest overall catch rates (1550 individual organisms per hour), while the other two areas were similar in catch rates with approximately 1050 organisms per hour. On the average, 1.3 finfish are taken as bycatch for every one commercial shrimp harvested in a trawl in the northern area (>34°N), with about 2.2 to 2.8 finfish taken as bycatch for every one commercial shrimp harvested in the southern (<30°N) and middle (30°-34°N) Atlantic areas, respectively.

With regards to weight, in the Atlantic northern area (>34°N) blue crab (*Callinectes sapidus***) made up 19% of the average weight of a typical trawl, followed by pink shrimp at 16%, and spot (***Leiostomus xanthurus***) at 12%. In the Atlantic middle area (30°-34°N) cannonball jellyfish (***Stomolophus meleagris***) made up the greatest average weight at 11%, followed by both Atlantic menhaden (***Brevoortia tyrannus***) and white shrimp at 10%. In the Atlantic southern area (<30°N) brown shrimp made up the greatest percentage of the catch in a typical trawl at 16%, followed by star drum (***Stellifer lanceolatus***) at 14%, and southern kingfish (***Menticirrhus anericanus***) at 9%.**

With regards to number, in the Atlantic northern area (>34°N) the pink shrimp made up 23% of the average by number from a typical trawl, followed by spot at 20%, and the brown shrimp at 14%. In the Atlantic middle area (30°-34°N) star drum made up the greatest average number at 16%, followed by both brown and white shrimp at 10%. In the Atlantic southern area (<30°N) the brown shrimp made up the greatest percentage of the catch from a typical trawl at 22%, followed by the star drum at 21%, and the northern searobin (*Prionotus carolinus***) at 7%.**

6.2.1.2 Gulf of Mexico (General Trends)

When all tows collected in the Gulf of Mexico were combined for analysis, the statistics by weight revealed that on the average about 28 kg of organisms per hour are taken during trawling operations (Figure 4). Analysis of the composition of the organisms showed that about 67% of the

catch by weight is composed of finfish, 16% by commercial shrimp species (brown shrimp, white shrimp, pink shrimp, seabobs, sugar/blood shrimp, and rock shrimp), 13% by non-commercial shrimp crustaceans, and 4% by non-crustacean invertebrates. The analysis by number revealed that on the average, about 1350 organisms per hour are taken during trawling operations (Figure 4). Analysis of the composition of the organisms showed that about 50% of the catch by number is composed of finfish, 29% by commercial shrimp species (brown shrimp, white shrimp, pink shrimp, seabobs, sugar/blood shrimp, and rock shrimp), 17% by non-commercial shrimp crustaceans, and 4% by non-crustacean invertebrates.

Shrimp trawl catch per hour averages for each of the different seasons were examined during the analysis (Figure 5). By weight, the pre-summer season had the lowest overall catch rates at 20 kg per hour, while the summer and post-summer seasons had very similar catch rates at above 30 kg per hour. Finfish catch rates were above 60% of the catch, while shrimp catch rates were around 15% to 18% in the post-summer and summer periods, respectively, and 16% in the pre-summer season. Analysis by number revealed that the pre-summer season had the lowest overall catch rates at 800 individual organisms per hour, followed by the post-summer period at around 1300 organisms per hour. The greatest rates were in the summer period at around 2100 organisms per hour taken in the trawls. Finfish catch rates were always above 46% of the catch, while shrimp catch rates were about 29% to 30% in the summer and post-summer periods, respectively, and 28% in the pre-summer season.

Shrimp trawl catch per hour averages for each of the different locations and depth zones was also examined during the analysis (Figure 6). Analysis by weight revealed that in all but one case (Alabama/Mississippi) the offshore zone had a lower catch rate than the nearshore area for the same location. The Alabama-Mississippi area had the highest overall combined (nearshore + offshore) catch rates, while the Louisiana nearshore area had the greatest catch rate for a single area. Offshore Florida had the lowest single area catch rate. In each area, the lowest catch rates were for non-crustacean invertebrates, followed by non-shrimp crustaceans and commercial shrimp, with finfish comprising the highest catch rates. On the average, about 4 kg of finfish are taken as bycatch for every one kg of commercial shrimp harvested in the trawl in the Gulf of Mexico. Analysis by number showed that in all but one case (Alabama/Mississippi) the offshore zone had a lower catch rate than the nearshore area for the same location. The Alabama-Mississippi area had the highest overall combined (nearshore + offshore) catch rates, while the Alabama-Mississippi offshore area had the greatest catch rate for a single area. Offshore Florida had the lowest single area catch rate. In each area the lowest catch rates were for non-crustacean invertebrates, followed by non-shrimp crustaceans, then commercial shrimp, and finally finfish with the highest catch rates. On the average, about 1.8 finfish were taken as bycatch for every one commercial shrimp harvested in the trawl.

With regards to weight, in the Florida nearshore area pink shrimp made up 18% of the average weight of a typical trawl, followed by iridescent swimming crab (*Portunus gibbesii***) at 9%, and leopard searobin (***Prionotus scitulus***) at 6%. In the Florida offshore area the pink shrimp made up the greatest average weight at 19% followed by blotched swimming crab (***Portunus spinimanus***) at 8%, and shoal flounder (***Syacium gunteri***) at 7%. In the Alabama-Mississippi nearshore area the Atlantic croaker (***Micropogonias undulatus***) made up the greatest percentage of the catch in a typical trawl at 34%, followed by the brown shrimp at 11%, and the sand seatrout (***Cynoscion* *arenarius*) at 7%. In the Alabama-Mississippi offshore area the longspine porgy (*Stenotomus caprinus*) represented the species with the greatest overall average weight percentage in the catch at 16%, followed by inshore lizardfish (*Synodus foetens*) at 5%, and Atlantic croaker at 5%. In Louisiana, the Atlantic croaker represented the greatest percentage of the nearshore catch at 19%, with white shrimp next at 12%, followed by Gulf menhaden (*Brevoortia patronus*) at 9%. In the offshore waters, longspine porgy was greatest at 15%, followed by inshore lizardfish at 10% and Atlantic croaker at 9%. The Texas area was very similar to Louisiana. Atlantic croaker dominated the nearshore catch at 14%, followed by Gulf butterfish (*Peprilus burti*) at 13% and brown shrimp at 7%. In the offshore area the longspine porgy represented the greatest component of the catch at 16%, followed by brown shrimp at 16%, and Atlantic croaker at 9%. It can be seen from the data that the Atlantic croaker was the bycatch species that was represented the most frequently in the nearshore trawls for most areas, while the longspine porgy typically dominated the offshore trawls.

With regards to number, in the Florida nearshore area, pink shrimp made up 27% of the average number of a typical trawl, followed by the iridescent swimming crab at 12%, and the leopard searobin at 11%. In the Florida offshore area, pink shrimp made up the greatest average number at 28%, followed by the longspine swimming crab (*Portunus spinicarpus*) at 9%, and the shoal flounder (*Syacium gunteri*) at 7%. In the Alabama-Mississippi nearshore area, Atlantic croaker made up the greatest percentage of the catch by number in a typical trawl at 18%, followed by the brown shrimp at 17%, and the lesser blue crab (*Callinectes similis*) at 10%. In the Alabama-Mississippi offshore area the longspine porgy represented the species with the greatest overall average number percentage in the catch at 19%, followed by the longspine swimming crab at 10%, and the sugar/blood shrimp at 7%. In Louisiana, Atlantic croaker represented the greatest percentage of the nearshore catch by number at 17%, with white shrimp next at 14%, followed by brown shrimp at 12%. In the offshore waters longspine porgy was greatest at 18%, followed by sugar/blood shrimp at 10%, and the longspine swimming crab at 8%. The Texas area was again quite similar to Louisiana. The nearshore catch was dominated by the Gulf butterfish at 13%, followed by the longspine porgy at 12%, and the Atlantic croaker at 11%. In the offshore area the longspine porgy represented the greatest component of the catch by number at 20%, followed by the brown shrimp at 14%, and the sugar/blood shrimp at 10%.

6.2.1.3 Selected Finfish Species

Although groundfish species makeup the majority of the bycatch taken in shrimp trawls, several species that represent major or even minor components of the total bycatch have received a great deal of attention because of their commercial and recreational importance, and the potential for significant impacts on their population abundance. Five species (2 dominant and 3 less dominant) from the Gulf of Mexico and five species (2 dominant and 3 less dominant) from the east coast of the United States area are presented in this report. In the southeast Atlantic the two dominant species included Atlantic croaker (Figure 7) and spot (Figure 8), while the less dominant caught species included king mackerel (*Scomberomorus cavalla*) (Figure 9), Spanish mackerel (*Scomberomorus maculatus*) (Figure 10), and weakfish (*Cynoscion regalis*) (Figure 11). In the Gulf of Mexico the two dominant species included Atlantic croaker (Figure 12) and longspine

porgy (Figure 13), while the less dominant caught species included king mackerel (Figure 14), Spanish mackerel (Figure 15), and red snapper (*Lutjanus campechanus*) (Figure 16).

In the southeastern Atlantic, the Atlantic croaker had its highest catch rates by weight in the northern area (>34°N) at the end of 1993 and the beginning of 1994. A high catch rate also occurred in the post-summer 1993 period in the southern area (<30°N). Catch rates by numbers showed similar peaks to those noted above. The average size of Atlantic croaker in the southeastern Atlantic was 134 mm total length. The catch of spot by both weight and number was greatest in the northern area (>34°N) and less in the southern area (<30°N). Summer and post-summer seasons seemed to have the highest rates. The average length of spot in the southeastern Atlantic was 110 mm total length. The catch of king mackerel by both weight and number was very low throughout the most areas. The greatest catch by weight (about 0.16 kg per hour) and number (about 0.6 individuals per hour) was during the post-summer 1992 period in the middle area (30°-34°N). The average length was 168 mm fork length. Spanish mackerel were more abundant than king mackerel, but still represented a less dominant caught species. Highest catch rates by both weight and number were in the northern area (>34°N) in the summer 1992 period and by weight in the summer 1993 period in the southern area (<30°N). Average size was 173 mm fork length. Weakfish catch by both weight and number was greatest in the northern area (>34°N) during the 1993 and 1994 periods, with post-summer or summer periods in the southern area (<30°N) also with high weight and number catch rates. Weakfish were also found in the trawls in the middle area (30°-34°N) with greatest weights in the pre-summer and summer periods. The average length of weakfish was 127 mm total length.

In the Gulf of Mexico, the Atlantic croaker had the highest catch rates by weight and in the nearshore area off Alabama-Mississippi and Louisiana. Average length was around 161 mm total length. Longspine porgy had its highest catch rates by both number and weight in the offshore waters of Alabama-Mississippi, Louisiana, and Texas. Two very large catch rates by weight were noted in the post-summer 1993 and summer 1994 periods off the Alabama-Mississippi area. Average size for longspine porgy in the Gulf of Mexico was only 90 mm fork length. The highest catch rates by weight for king mackerel have been observed in the Texas area, typically during the summer seasons nearshore and the post-summer seasons offshore. One very high catch rate by weight was noted in the nearshore area of Louisiana in the post-summer 1993 period. Average catch by number had several peaks, however, with none above about 6 individuals per hour. King mackerel had a average length of 230 mm fork length. Red snapper were rarely caught in the Florida and Alabama-Mississippi areas. Highest catch rates by both weight and number occurred in the offshore waters of Texas and Louisiana. Red snapper had a mean length of 117 mm fork length. Spanish mackerel had their highest catch rates by weight in the nearshore waters off Texas, Louisiana, and Alabama-Mississippi. A very high catch rate (for Spanish mackerel) was noted during the summer season in 1993 off Louisiana, but most values are below 0.5 kilograms per hour. Catch rates by number had similar trends to those noted for weight. Spanish mackerel had an average length of 205 mm fork length.

6.3 Collection and Assessment of Specific Stock Information

Man's activities are having an increasingly serious effect on natural populations of animals - either deliberately, through direct exploitation, or accidentally through pollution or changes in the environment. It is also recognized that if the harmful effects are to be dealt with efficiently, a better knowledge is needed on how the abundance of natural stocks is controlled. Estimating the amount of finfish bycatch in the shrimp trawl fishery starts with identifying, counting, and weighing catches on commercial fishing vessels. As described above, trained observers placed aboard cooperating vessels have done this work. Yet, this is only the beginning of the analyses necessary to determine the status of a specific finfish stock. First, catch per unit effort values must be calculated to estimate total catch of a particular finfish species in the shrimp trawl fishery. Next, from these total shrimp trawl bycatch estimates (bycatch mortality), age specific mortality estimates must be developed. Finally, these age specific mortalities are incorporated with other sources of mortalities (i.e., bycatch from other fisheries, non-fishing mortalities, etc.) to estimate the total mortality levels for the species. It is only after the incorporation of all these sources of mortality into the complete stock assessment context that the consequences of these shrimp trawl bycatch mortalities can be determined for the stock.

6.3.1 Nature and Extent of Incidental Mortality in Shrimp Trawls (Spatial and Temporal)

Bycatch in the shrimp fishery, as a whole, can be estimated by multiplying the catch rates observed aboard the sampled vessels by the total effort. Thus, both an estimate of the catch rates per some unit of effort and an estimate of the total effort for the unit chosen are necessary for calculation of total bycatch. In stock assessments, these bycatch estimates have the same function as any other catch statistic - they are estimates of removals of individuals from the population that must be accounted for in the models used in assessment. As such, a continuous time series over several years is needed for dependable assessments.

6.3.1.1 Gulf of Mexico

In the Gulf of Mexico estimates of total shrimping effort, in hours fished, have been calculated for the entire period with observer programs. These effort estimates are based on interviews with fishing vessel captains (shrimp catch per hour) and then expanded to fill the temporal and spatial strata (Nance, 1994).

Observer sampling programs in the Gulf have not been continuous over time. Three separate programs provided observer data in the 1972-82 period. The regional research program provided extensive observer data from 1992 through 1996.

Observer data from the 1970's and 1980's was sparse, and statistically "unbalanced" in the sense that in one year observers might cover one geographic area in one season, moving to another area and season the following year. The 1990's data were much improved, with higher sampling rates, and much broader coverage each year, but there were still many significant gaps in coverage. Data from both periods have been criticized for "non-random" selection of vessels and trips to be sampled -- only vessels willing to carry an observer could be considered, and very few volunteered.

Because of this non-randomness, it is impossible to evaluate just how well the sample represents the entire fleet using objective, statistical means.

There is no analytical way to remedy the problems presented by non-random sampling; those problems remain as weaknesses of the program. There are ways to work around the sparse, unbalanced, and discontinuous nature of the observer data. One way is to incorporate supplemental information on variation in abundance of bycatch species into one analysis. A large data base on abundance variation is available from the research vessel sampling conducted by NMFS Pascagoula and the cooperative Southeast Area Monitoring and Assessment Program (SEAMAP). These data are sometimes termed "fishery-independent," or "resource surveys" data. These data are in no way expected to mimic the catch rates of commercial shrimp vessels. Rather, the only underpinning needed is that the ratio of catch rates of research vessels to commercial shrimpers be reasonably constant. The formal name for the technique used is General Linear Modeling (GLM). Estimates based on this technique have been used by NMFS since 1987. The NMFS realizes that direct estimates of bycatch would be the preferred method. However, this would involve a mandatory observer program (for randomization of vessel selection) to sample the over 6,000,000 hours of annual fishing effort.

For many years, there was little scientific controversy about the estimation procedures or the bycatch estimates, despite repeated examination by the stock assessment panels. The procedures and estimates were viewed as the most reasonable, given the nature of the available data. Once the estimates led to a clear management impact regarding red snapper, controversy arose quickly. There have been three formal reviews that included review of bycatch data collection and estimation. All have been critical of the bycatch estimates, centering on three areas: 1) the non-random data collection is not scientifically appropriate, 2) the estimates of statistical uncertainty about the existing estimates have not been well defined, and 3) many other possible choices of indirect methods (like the GLM) exist, with no objective way to choose among them. Lacking an objective way of choosing among proposed methods, there is no scientific way of coming to closure on the choice of a "best" method.

However, the range of remaining uncertainty about the true level of shrimp bycatch has little impact on the assessment of the red snapper stock, or the need to reduce shrimp fleet bycatch to eliminate red snapper overfishing. Many of the alternatives suggested by outside reviewers have now been tried. Most led to estimates of red snapper bycatch above the NMFS estimates currently used. The lowest estimates extant, provided by consultants to the shrimp fishery, were considered in stock assessment models run at the September 1997 Science and Management Peer Review in New Orleans. The assessment conclusions were unchanged even when the lowest estimates were used. Red snapper are currently overfished, and substantial reduction in shrimp trawl bycatch of red snapper is needed to recover the stock.

Bycatch estimates for over 30 species have been made and provided to appropriate stock assessment teams. Annual estimates for several key species are collected in Table 1.

6.3.1.2 South Atlantic

Bycatch estimates from the south Atlantic are more problematic than those obtained from the Gulf of Mexico because of inadequate observer coverage and total shrimp effort estimations. With regards to total shrimp effort estimations, the calculation of total trawling hours, is not possible because of lack of interviews at the docks by state port agents. The only possible units that can be used for expansion of bycatch rates to a total are trips and weight of shrimp landed (Peuser, 1996). Shrimp landings have always been collected for each strata, but trip data are missing during some spatial and temporal periods when observers were collecting data. Both these expansion parameters (shrimp landings and trips) are absolute values (no variance associated with the units), but each have problems. On the one hand, trip duration varies, but in the expansion process a one day trip has the same value as a 5 day trip. Also, since information by tow must be summed over the entire trip, degrees of freedom for each strata are greatly reduced during statistical analysis. On the other hand, if pounds of shrimp are used tow by tow information can be retained (finfish per shrimp for each tow), but some researchers question the relationship of finfish catch with shrimp catch. Using shrimp as the expansion variable implies that the catch of shrimp and the catch of finfish are correlated. For example, large catches of finfish occur during large catches of shrimp, which may not be the case.

With regards to observer coverage, bycatch sampling programs in the south Atlantic have not been continuous over time. Although there may have been some smaller efforts to collect bycatch data from the shrimp trawl fishery along the east coast of the United States, the first integrated observer program was the one developed through cooperative efforts between the Foundation and NMFS in 1992. However, even this observer program did not have enough resources to provide adequate coverage to fill all the temporal and spatial strata outlined in the bycatch research plan. In addition, the data, similar to the Gulf, has been criticized for "non-random" selection of vessels and trips to be sampled. Again, because of this non-randomness, it is impossible to evaluate just how well the sample represents the entire fleet using objective, statistical means.

Even with these general weaknesses, bycatch estimates, in numbers at age, have been calculated for each strata with both observer coverage and expansion data (Peuser, 1996). Catch-at-age tables from the shrimp trawl fishery have been estimated for weakfish (Peuser, 1996), as well as king mackerel, Spanish mackerel, and cobia (*Rachycentron canadum***) (Vaughan and Nance, 1998). However, to make these estimates useful in the stock assessment context, somehow bycatch estimates in numbers at age for known strata need to be applied to unknown strata (e.g., no bycatch estimate available), both within and between years. In the south Atlantic this has been left to the individual species assessment groups to decide what assumptions they are willing to make to accomplish this final step. Once this step is complete, the species-specific assessment groups can include bycatch estimates in numbers at age from the shrimp trawl fishery into the catch-at-age matrix for use in analysis.**

Discarding of young weakfish in the south Atlantic shrimp trawl fishery however was recognized as a problem in early weakfish management plans (Mercer, 1985). She noted that estimated discards often approached or exceeded directed landings in south Atlantic states. Subsequent assessments of Atlantic coast weakfish showed that discard loss in shrimp trawlers reduced yield per recruit (YPR) and spawning stock biomass per recruit (SSB) (Vaughan et al., 1991). Amendment 1 of the Atlantic States Marine Fisheries Commission (ASMFC) management plan called for the states

from Florida to North Carolina to reduce discard loss of weakfish in shrimp trawls by 50% (Seagraves, 1991). This measure was retained in Amendment 2 which is enforceable under the Atlantic Coast Fisheries Cooperative Management Act (ACFCMA). Fishing technology innovations such as bycatch reduction devices (BRDs) have been shown to be effective in reducing discards of weakfish (Rulifson et al., 1992). For this assessment, weakfish discards were estimated as a function of weakfish abundance and shrimp fishing effort (Gibson, 1994). Shrimp fishery effort data were provided by the NMFS/SEFSC. Weakfish abundance was indexed from young of the year (YOY) catch in the North Carolina Department of Marine Fisheries (NCDMF) and SEAMAP surveys (Z-score composite index).

Estimation of discards was a two stage process. First, a direct expansion of weakfish discards was made by multiplying annual shrimp landings by a year specific discard ratio. Sea samples came from a variety of sources and the ratio was assumed to apply across the entire south Atlantic region for that year. These estimates were available for years 1985-86, 1988, 1990, and 1992-93. The direct estimates, along with weakfish relative abundance and shrimp trawl effort in the south Atlantic, allow for estimation of catchability coefficients. The geometric mean catchability coefficient was then used with shrimping effort and weakfish relative abundance to estimate discards loss across all years (1982-1996).

6.3.2 Magnitude and Distribution of Non-Shrimping Mortality

Bycatch of non-targeted finfish does not occur just in the shrimp trawl fishery. Identifying other fishing activities (commercial and recreational) with associated bycatch, as well as non-fishing activities where stock removals occur, and quantifying the catch (mortality) resulting from such activities, are critical for accurately assessing the status of fishery stocks. Information regarding the type and quantity of bycatch associated with non-shrimp fisheries and non-fishery activities is often inadequate for stock assessment due to lack of time series estimates for bycatch and stock mortality. Most of the available information of this nature has been obtained through short-duration programs, many of which have been neither sustained over time nor conducted throughout the range of the fishery.

For those fisheries where bycatch exerts a significant impact on other stocks, estimating bycatch must be considered in the same light as estimating commercial and recreational catch and as such it must be an integral part of basic fishery statistics collections. Moreover, strategies must be developed to distribute observer capability among the various fisheries requiring coverage, in such a manner as to complete basic quantification of bycatch for all sizable fisheries and to provide continuing coverage in those fisheries deemed to exert significant impact on populations of species taken in bycatch. Other priority southeastern fisheries that require observer coverage to estimate bycatch either initially or on a continuing basis include the pelagic longline, menhaden, and reef fish fisheries.

Human activities, primarily urban and industrial expansion, have resulted in the loss of large areas of productive and commercially valuable fishery habitats in the southeast. Upland flood control and other measures that restrict freshwater and sediments to coastal areas, point and non-point source pollution, nutrient enrichment, dredge and fill or open disposal operations, hydroelectric

power development, and oil and gas production and exploration activities have been identified as factors contributing to a reduction in the quality and quantity of fishery habitat. Documenting fish mortality from these types of activities is difficult, often speculative, and typically not included in traditional stock assessments. While federal and state agencies have been successful in offsetting some habitat loss through restoration and creation of wetlands, seagrass beds and other aquatic habitats, more emphasis should be directed at identifying sources and quantifying fishery mortality resulting from non-fishing human activities.

6.3.2.1 Fishing Mortality

In the southeast, gear type and target species or target species group has defined 29 distinct fisheries. In 1996, the southeastern commercial fishing industry caught an estimated 1.8 billion pounds of seafood with an ex-vessel value of $904 million. Recreational landing for the south Atlantic and Gulf of Mexico (excluding Texas) were estimated at 108 million pounds in 1996. Most of these fisheries are regulated under Magnuson-Stevens Act statutes, by coastal states, or under interjurisdictional plans. In recent years federal research grants have been awarded for bycatch characterization of some southeastern fisheries on a short-term basis. EPA recently funded Mississippi State University (MSU) to conduct a comprehensive assessment of fisheries bycatch monitoring in the Gulf of Mexico. The publication contains a review of past and present bycatch research not only for the Gulf of Mexico but also for other regions as well (Burrage et al., 1997). It also discusses recent research on fisheries identified as the priority fisheries or fisheries that may have a significant impact on other fishery stocks other than the shrimp fishery in the southeast region.

6.3.2.1.1 Menhaden Fishery

The purse-seine menhaden (*Brevoortia* **spp) fishery is the largest fishery by volume in the southeast and the second largest fishery on a national level. In 1996, menhaden landings in the southeast were estimated at 1.1 billion pounds. On a percentage basis (i.e., pounds bycatch per pounds target) the menhaden bycatch appears low in comparison to the shrimp fishery, but a few percent of a billion pounds a year might have considerable impact on the bycatch species. Several short-duration studies have characterized the bycatch of the menhaden purse-seine fishery since the 1950's, but the high variability of bycatch among sets has made analysis problematic. Bycatch percentages (number of fish in comparison to estimated menhaden catch) have ranged from 0.06% to 3.90%. Recently, federal research grants enabled scientists at Louisiana State University to examine the species composition and fate of released bycatch from samples of 235 sets aboard commercial menhaden boats during 1994 and 1995 (Condrey and De Silva, 1997). Mean bycatch percentages (percentage of released bycatch by number to estimated menhaden catch) were 0.04 % in 1994 and 0.17% in 1995. While 58 species were recorded, 12 species accounted for 90% of released bycatch in 1994: Atlantic croaker, scaled sardine (***Harengula jaguana***), sand seatrout, crevalle jack (***Caranx hippos***), gafftopsail catfish (***Bagre marinus***), Spanish mackerel, striped mullet (***Mugil cephalus***), Atlantic cutlassfish (***Trichiurus lepturus***), unidentified sharks, silver seatrout (***Cynoscion nothus***), Gulf butterfish and red drum (***Sciaenops ocellatus***). Sixty-two species were documented in 1995, with Atlantic croaker, Spanish mackerel, sand seatrout, and gafftopsail catfish accounting for 71% of the released bycatch. Of the fish observed in this study, approximately 66% were gilled, 17% were caught and retained, 5% were kept by the crew, 9% were released dead or disoriented, 2% were released alive, and less than 1% released with an undetermined fate. Note that all species, except for scaled sardine, are used by the commercial and recreational fishing sectors, including Atlantic cutlassfish for bait. Four Atlantic bottlenose dolphins (***Tursiops truncatus***) and 4 sea turtles (two loggerhead (***Caretta caretta***), one green (***Chelonia mydas***) and one hawksbill (***Eretmochelys imbricata***) were released during this time period. All sea turtles and three Atlantic bottlenose dolphins were released alive, with one dolphin being released dead.**

6.3.2.1.2 Pelagic Longline Fishery

Since 1992 scientific observers from or contracted by the National Marine Fisheries Service have been placed on longline vessels targeting large pelagic species in the northwest Atlantic, Caribbean, and the Gulf of Mexico. Each year, vessels were randomly selected within each area and quarter, based upon their reported fishing activity in the previous year. The objective of this program was to achieve observer coverage of 5% of the sets made per year, with coverage in each area and quarter in proportion to the relative effort in the previous year. Due to variability in funding, actual coverage varied from about 2% to 5% of the total longline sets per year. A total of 2,857 sets were recorded observed by personnel from the SEFSC and NEFSC programs from May of 1992 to December of 1996. Observers from the SEFSC region recorded over 50,000 individuals (primarily swordfish, tunas, and sharks), marine mammals, turtles, and seabirds during this time period.

Observer data have been used in estimation of by catch of marine mammals, turtles, billfish, swordfish, and sharks. Samples obtained by observers contributed to studies of the swordfish reproductive biology, swordfish age and growth, and tuna, swordfish and shark genetics.

One of the more recent observer studies to characterize the commercial shark longline fishery was conducted during 1994 and 1995 by the Foundation. Observers collected data from 96 trips aboard commercial shark longline vessels. Of the 7,836 large coastal sharks caught, 76% were retained, 17% discarded and 17% released alive. Of the 3,037 small coastal sharks, 58% were harvested, 40% discarded (primarily used for bait) and 1% released alive. Other groups captured included 7,688 sharks (non-classified), 317 fishes and 15 sea turtles. A total of 104 marketable fish of 6 species were landed; all other bycatch was released or discarded, and all sea turtles were released alive.

6.3.2.1.3 Florida East Coast Gill Net Fishery

During 1994, NMFS and the Florida Department of Environmental Protection implemented an observer program to collect data from the Florida east coast gill net fishery. The objectives of the research were to document and quantify sea turtle mortality and to quantify bycatch during gill netting activity in nearshore waters from Cape Canaveral to Jupiter Inlet, Florida. NMFS observers collected data from 42 sets and several test sets in depths from 0.5 to 7.0 fathoms. No sea turtles were captured. The target species for eleven trips was bluefish (_Pomatomus saltatrix_**), nine trips were for Spanish mackerel, and six trips sought Florida pompano (**_Trachinotus carolinus_**), two trips sought spot, and one trip was for whiting (Menticirrhus spp). A total of 2,065 fish, composed of 51 species, was discarded. Approximately 81% of these individuals were released alive. Sixty-one percent of the live individuals and 51% of the dead were yellowfin menhaden (**_Brevoortia smithi_**). Thirty-four species of fish weighing approximately 10,689 pounds were landed during this survey. By weight, 68% were Spanish mackerel, and 21% were bluefish.**

6.3.2.1.4 Reef Fish Fisheries

Observer coverage of the commercial reef fish fishery operating primarily off the west coast of Florida, and to a lesser extent off Louisiana was conducted between 1993 through 1995, during 289 days at sea. NMFS observers collected data from 576 sets aboard fish trap vessels, 317 sets from bottom longline, and 580 sets from bandit reel vessels. Based on surface release observations of under-sized target and unwanted species, the majority of fish were released alive with release mortality ranging from approximately 2% to 5% for all gear types.

Thirteen trips were made during 1993 through 1995 aboard six fish trap vessels with 36% of the 11,999 traps set being processed. A total of 16,943 fish of 64 taxa were sampled. Approximately 58% of the individuals were released alive, 44% were kept, 2% were released dead, 7% retained for bait, and less than 1% were released with an unknown fate.

Twelve trips were made aboard nine bottom longline vessels in 1994 and 1995. Two hundred forty-two sets targeted red grouper (_Epinephelus morio_**) with the remaining 75 sets seeking yellowedge grouper (**_Epinephelus flavolimbatus_**) and blueline tilefish (**_Caulolatilus microps_**) in**

deeper waters. From the 229,467 hooks processed (100%), a total of 5,224 fish of 89 taxa were caught. Approximately 56% of the individuals were kept, 28% released alive, 5% released dead, 10% retained for bait, and 2% released with an unknown fate.

Sixteen trips were made aboard bandit-rigged vessels during 81 sea days of observations from January through July 1995. Nine trips targeted red grouper and vermilion snapper (*Rhomboplites aurorubens*) off Florida and seven trips were for red snapper off Louisiana. Of the 2,806 fish (45 taxa) processed off Florida, 55% were kept, 37% were released alive, 2% were released dead, 7% retained for bait and less than 1% released with an unknown fate. Off Louisiana, a total of 716 fish comprised of 16 species were sampled during March 1995. Of these, 46% of the individuals were kept, 47% were released alive, 2% were released dead, 2% retained for bait, and 2% were released with an unknown fate.

6.3.2.1.5 Recreational Fishing

Estimates of fish caught but not retained in recreational fisheries are made through the national Marine Recreational Fishery Statistics Survey program (MRFSS) for much of the southeast region. There have been Salton-Kennedy (SK) awards for short duration projects assessing recreational bycatch in some geographic areas not covered by MRFSS. A number of federal grants have been awarded to examine mortality of hooked and released fish, addressing red snapper, red grouper, king and Spanish mackerel, and sharks. There have been other federal research grants directed at bycatch of sturgeon in coastal shad fisheries. Recently published comprehensive reviews (Muoneke and Childress, 1994; Burrage et al., 1997) report on the mortality of hooked and released fish by bait type, number and types of hooks, water temperature and depth of capture. US marine recreational fish catch was estimated at 313 million fish, with over 50% of the catch released alive. The Gulf of Mexico accounted for the highest number of fish caught (42%). An additional 2.3 million fish were landed in Texas (P. Phares, NMFS Miami Laboratory, personal communication).

6.3.2.2 Non-Fishing Mortality

Fish mortality resulting from non-fishing activities including coastal development, industrial waste water, and oil and gas production and exploration have been found to impose major negative impacts on estuaries and fish stocks. This section documents fish mortality from known sources.

6.3.2.2.1 Fish Kills

Human activities are the most common reason behind the 100-200 fish kills documented in Texas each year. Based on data from approximately 4,600 fish kills from 1958 to present, Texas Parks and Wildlife Department (TPWD) estimates fish mortality at more than 250 million. The cause of 60% of the fish kills has been attributed to low dissolved oxygen with the majority resulting from human activities such as coastal development, dead-end canals and nutrient enrichment (W. Denton, Texas Parks and Wildlife Departmetn, personal communication).

6.3.2.2.2 Hydroelectric Generation

In comparing non-fishing human induced fish mortality in Galveston Bay, Texas A&M Sea Grant ranked mortality (number of organisms) from highest to lowest by source: bay shrimpers, Cedar Bayou Power Plant, recreational shrimping, fish kills, and recreational fishing (Palafox and Wolford, 1993). Cedar Bayou plant is one of five hydroelectric generating stations on Galveston Bay, with at least one chemical plant having similar operations. These types of facilities have high pumping rates and intake velocities. Cooling water operations associated with these plants effect fish and shellfish through impingement, entrainment and by increasing surrounding water temperatures. The species most affected are those most abundant in the bays: white and brown shrimp, blue crab, Gulf menhaden, bay anchovy (*Anchoa mitchilli***), sand seatrout, spot and Atlantic croaker.**

6.3.2.2.3 Oil and Gas Structures

More than 4,000 oil and gas structures are located in the Gulf of Mexico. Current regulations require the removal of structures that are no longer in operation. More than one hundred removals occur each year, with 66% salvaged by explosives. NMFS scientists are currently assessing the extent of fish mortality caused by use of these underwater explosives using underwater and surface surveys. Various field techniques including underwater and surface transects beneath and around the platforms, as well as tag and release methods, are used to estimate fish mortality. Preliminary results obtained from seven platform removals in water depths ranging from 45 to 92 feet during summer months indicate average mortality per structure of 3,300 fish. This yields an average estimated fish kill of 221,000 per year, assuming 66% of the platforms are removed by explosives. Dominant species killed by explosives included Atlantic spadefish (*Chaetodipterus faber*** **), bluefish, red snapper and sheepshead (***Archosargus probatocephalus***).**

6.3.3 Assessment of Status and Condition of Stocks

The basic purpose of stock assessment is to provide advice on the optimum exploitation of aquatic living resources. In stock assessments, bycatch estimates from shrimp trawls, bycatch estimates from non-shrimp fisheries, and impact estimates from non-fishing activities, all have the same function as any direct harvest statistics - they are estimates of removals of individuals from the population (stock) that must be accounted for in the population models used in assessment. Directed fishing pressure, habitat alteration/degradation, fish population declines resulting from climatic changes, and predatory-prey interactions are all integral components for assessing the strength of a fishery stock. Biologists attempt to quantify total mortality with the highest degree of accuracy. Some sources of mortality can only be approximated. Overestimates typically lead to excessively restrictive management measures, while underestimates may result in management measures that fail to adequately protect fisheries stocks. Each of the stocks listed below have a Council Stock Assessment Panel and a Council Standing Statistical Committee that reviews the assessment.

6.3.3.1 Red Snapper

6.3.3.1.1 Gulf of Mexico

Current management of red snapper in the US Gulf of Mexico involves a reduction in shrimp bycatch mortality from historical levels. The baseline adopted for measuring the change is the average bycatch fishing mortality on the 1983-1988 year classes which were most vulnerable to the shrimp trawl fishery from 1984-1989. The annual effort in the areas with significant bycatch relative to that in the baseline period increased after the baseline period and has been higher than the baseline in all but the most recent year. Inspection of these data indicate that the absolute magnitude of the bycatch estimates is more variable than the effort. This suggests that variations in year class strength influence the number of red snapper killed in shrimp trawls more than recent variations in shrimp effort.

Nichols and Pellegrin (1992) estimated the monthly mean percentages of the annual bycatch. The age composition of the bycatch by month was estimated from the length frequencies in the resource survey and bycatch characterization trawl samples. The resulting estimates indicate that young of the year begin to recruit to the bycatch in June and July, and become the dominant part of the bycatch by September. Age-1 red snapper constitute an important part of the bycatch each month.

Shrimp bycatch mortalities for the 1982-1991 year classes were estimated by backward iterative solution of the Baranov catch equation (Ricker, 1975). The method starts with the Sequential Population Analysis (SPA) estimate of the number of individuals of a year class alive at the beginning of January at model age 2. Thus, the SPA estimate of N at age 2 in 1984 is the estimate for the 1982 year class. The bycatch estimates were available at a temporal resolution of 1/3 year (January-April, May-August, and September-December). The probable age composition of the bycatch in each trimester was evaluated from the observed age composition from bycatch characterization and research survey samples by year. For years where insufficient observations were available to partition the bycatch into ages, the catches were partitioned using the mean monthly fractions at age for each trimester. Instantaneous natural mortality (M) was assumed to be 0.5 for age 0 and 0.3 for age 1. With post-bycatch M of 0.1, the cumulative instantaneous annual fishing mortality (F) estimates for the 1984-1989 base period was 2.12. If M was 0.15 or 0.20, the corresponding F was 1.96 and 1.80, respectively. These values imply conditional survival probabilities of surviving the shrimp bycatch of 0.12 for M=0.1, 0.14 for M=0.15 and 0.17 for M=0.20.

6.3.3.2 Weakfish

6.3.3.2.1 Atlantic Ocean

Age 0 losses of weakfish have averaged 9.8 million fish and are highly variable depending on the abundance of weakfish and amount of shrimping effort. Peak losses of 21.2 and 26.9 million occurred in 1986 and 1995 respectively. Because the sea sample data are sparse, discard estimates for the shrimp fishery are recognized as the most uncertain component of the catch-at-age matrix. A delta method variance approximation, accounting for uncertainty in the catchability scaler and weakfish abundance, produced Coefficient's of Variation (CV) on the discard estimates

averaging 51%. Variance of the discard estimates is likely understated since it does not account for uncertainty in the shrimp effort data. Further, recent estimates may be biased high since the sea samples of discards may require a catchability adjustment factor based on BRD effectiveness and temporal-spatial deployment. However, historical VPA runs (both SVPA and CAGEAN) have demonstrated a significant increase in fishing mortality (primarily on age 0 and to a much lesser extent on age 1) with bycatch verses without bycatch.

6.3.3.3 King Mackerel

The impact of shrimp bycatch on king and Spanish mackerel spawning potential was evaluated by comparing the estimated static Spawning Potential Ratio (SPR) with bycatch mortality to the estimated static SPR without bycatch mortality.

6.3.3.3.1 Atlantic Ocean

Using the current estimate of fishing mortality of F = 0.234, and a bycatch mortality of F = 0.118 for age 0 fish, the estimated static SPR for king mackerel in the Atlantic is approximately 31.3%. If the fishing mortality associated with shrimp bycatch is removed, the estimated static SPR is approximately 35.3%, a difference of approximately 4 %.

6.3.3.3.2 Gulf of Mexico

Using the current estimate of fishing mortality of F = 0.648, and a bycatch mortality of F = 0.579 for age 0 fish, the estimated static SPR for king mackerel in the Gulf of Mexico is approximately 2.7 %. If the fishing mortality associated with shrimp bycatch is removed, the estimated static SPR is approximately 4.8%, a difference of approximately 2.1 %.

6.3.3.4 Spanish Mackerel

6.3.3.4.1 Atlantic Ocean

Using the current estimate of fishing mortality of F = 0.885, and a bycatch mortality of F = 0.184 for age 0 fish and F = 0.070 for age 1, the estimated static SPR for Spanish mackerel in the Atlantic is approximately 18.3%. If the fishing mortality associated with shrimp bycatch is removed, the estimated static SPR is approximately 23.7%, a difference of approximately 5.5%.

6.3.3.4.2 Gulf of Mexico

Using the current estimate of fishing mortality of F = 0.650, and a bycatch mortality of F = 0.209 for age 0 fish and F = 0.142 for age 1, the estimated static SPR for Spanish mackerel in the Gulf is approximately 20.3%. If the fishing mortality associated with shrimp bycatch is removed, the estimated static SPR is approximately 28.8%, a difference of approximately 8.5%.

6.3.3.5 Red Drum

6.3.3.5.1 Gulf of Mexico

The estimated numbers taken as a part of the bycatch in the shrimp fishery have gradually increased since 1972, but the annual estimates are quite variable. Because recreational landing statistics are available only since 1979, the combined harvest can only be estimated since then. During the period 1979-1987 the catch in numbers fluctuated around a mean of about 4.5 million fish. The numbers caught declined from 3.7 to 1.4 million fish from 1987 to 1988 as a result of conservation measures that essentially eliminated the commercial fishery and sharply curtailed the recreational harvest. As a result, the bycatch of the shrimp fishery which was not affected by the conservation measures increased from about 3.5% before 1988 to 9% of the total numbers taken by the combined fisheries thereafter. The total number of red drum taken in 1995 was about 3.4 million, nearly 75% of the 1979-1987 average.

The catch-at-age estimated from each of the strata each year were summed to provide an estimate of the total catch-at-age for the fishery each year. Because the age distribution of the shrimp bycatch is unknown it was not possible to include this source of mortality appropriately in the catch-at-age matrix. For analytical reasons all of the red drum caught as shrimp bycatch were assumed to be age 0 and were added to that age in final catch-at-age matrix.

6.3.3.6 Cobia

6.3.3.6.1 Atlantic Ocean

While cobia are a part of the shrimp trawl bycatch in the Atlantic, no analysis has been done to quantify the actual impact of this bycatch on the cobia stocks of the Atlantic. Estimates of total cobia bycatch have been made and presented in Vaughan and Nance (1998).

6.3.3.6.2 Gulf of Mexico

The bycatch data from the commercial shrimp trawl fishery in the Gulf of Mexico that were utilized in the previous assessments were updated for the 1998 assessment. As before, groundfish survey size samples were used to apportion the bycatch by age based on the age-length key of Franks and McBee (1991). Bycatch was split 70% age 0 and 30% age 1 based on size samples. These bycatch estimates are included in the annual catch-at-age estimates and in all analyses. To date, there has been no work done to quantify the impact of shrimp trawl bycatch on the cobia stocks.

6.3.3.7 Sharks

While sharks are a part of the shrimp trawl bycatch in both the Atlantic and Gulf of Mexico, the actual impact of this bycatch on the various shark stocks has not been evaluated. Observations show that large sharks are released through the TEDs, but several species of small sharks, and the young of larger shark species are taken in shrimp trawl bycatch.

6.4 Bycatch Reduction Program

6.4.1 Technological Devices to Minimize Bycatch (BRDs)

One of the objectives of the southeast bycatch research program was to identify, develop, and evaluate gear options for reducing bycatch in the Gulf and south Atlantic shrimp fisheries (NMFS, 1991). The research program called for gear modification studies to be conducted in inshore, near shore, and offshore waters focusing on key FMP managed species (i.e., Gulf red snapper, Atlantic weakfish, king mackerel, and Spanish mackerel), and coordinated through a technical review panel (TRP). The technical review panel (Branstetter, 1997) was responsible for selecting the best prototype gear modifications for commercial evaluation, monitoring testing in different shrimping areas, and prioritizing gear modification options for management consideration. The goal of the gear development project is to develop shrimp trawl gear modifications and or fishing tactics, which are capable of reducing the bycatch of finfish with minimum loss of shrimp production.

From 1990 to 1996 fishery researchers and commercial fishers working under the auspices of the southeast regional bycatch program developed and tested a total of one hundred and forty five (145) bycatch reduction device (BRD) designs. These evaluations were conducted under a research plan developed by the Foundation (Hoar et al., 1992) and a testing protocol developed by the National Marine Fisheries Service (NMFS, 1992b). Operational testing for sixteen (16) BRD designs was conducted on commercial shrimp vessels by the Foundation, Georgia Department of Natural Resources (GDNR), the NMFS Galveston and Mississippi Laboratories, NCDMF, Texas Shrimp Association, Texas A&M Sea Grant, and University of Georgia Sea Grant. These evaluations have produced an extensive data base consisting of over 3,400 tows, which have been compiled by the NMFS Galveston Laboratory.
In June, 1997 analyses of this data base were conducted by the NMFS Mississippi Laboratories and a report submitted to the NMFS SEFSC and the NMFS SERO (Watson et al., 1997a). In

August, 1997 a peer review of the available science on the status and management of red snapper in the Gulf of Mexico was conducted. The review process identified possible sources of bias in bycatch reduction and shrimp retention estimates for BRDs tested in the Gulf of Mexico. As a result of the peer review the data were re-analyzed in October, 1997 using criteria which addressed these concerns (Watson et al., 1997b). The present report represents the most recent analyses and estimates of the bycatch reduction potential for shrimp trawl bycatch reduction devices (BRDs) evaluated as of December 1996.

6.4.1.1 Methods

The research plan (Hoar et al., 1992) identified a four phase gear development program that included:

1. Initial Design and Prototype Development - The full technical range of trawl design and modification approaches were identified. Industry techniques, ideas solicited from fishers, net shop designs, and research studies conducted by various research groups were evaluated. Fish behavior, gear instrumentation, and gear performance studies were conducted on each design using SCUBA, remote video cameras, and other techniques. This work evaluated fish behavior and feasibility of prototype concepts. The results of this phase were subjectively evaluated based on the experience and expertise of the gear designer and research team. Operational data were collected on the modified net, and preliminary catch performance data obtained during comparative gear trials. The second phase of development was initiated once a design was determined to offer bycatch reduction potential and integrated into the construction of a net.

2. Proof of concept - Objectives during this phase were to evaluate prototype devices on key species, determine total finfish reduction rates, and establish shrimp catch rates. Proof of concept testing evaluated adequacy of design for safety and for problems with operational use. Proof of concept testing was conducted under a specific scientific protocol developed under the "Shrimp Trawl Bycatch Research Requirements (NMFS, 1991). The most successful designs were prioritized based on proportional bycatch reduction and shrimp retention and reviewed by a technical review panel for inclusion in operational evaluation by the commercial shrimping industry throughout the southeast.

3. Operational evaluation - The objective in this phase was to test the BRD/TED gear combination against a standard TED net under conditions encountered during commercial shrimping operations. Trained observers were placed aboard cooperating commercial vessels to collect data on both shrimp and finfish catch rates as well as species composition. BRD/TED combinations were tested on trawlers using the same TED employed in both the test and control gear. Testing was conducted over a wide range of geographic areas, seasons, and conditions.

4. Industry evaluation - Widespread commercial evaluations of approved BRD designs. Analyses of the data collected under the research plan were conducted to calculate reduction rate estimates for the different BRD designs for key species which are under existing or proposed management plans including; shrimp (weight), red snapper (number), Spanish mackerel (number), king mackerel (number), and weakfish (number). Reduction rate estimates were also calculated for total fish (weight), croaker (weight), spot (weight), and southern flounder (*Paralichthys lethostigma*) (number) which are predominant species or are considered economically important. Ratio estimation and testing procedures were used for statistical analyses (SAFMC, 1997). Data were partitioned by geographical area, south Atlantic statistical zones 29-36 and Gulf of Mexico statistical zones 8-21. A minimum of 30 tows was required for a gear design to be considered for analyses under the BRD certification protocol.

For BRDs that demonstrated a statistically significant overall reduction in red snapper bycatch, analyses were conducted to determine estimates of reduction in fishing mortality (F) for red snapper based on reduction rate estimates by length frequency categories. Ratio estimates of reductions by 20 mm size classes were calculated.

Estimates of reduction of F for each gear were calculated from the VPA analyses and the monthly size composition data of Goodyear (1995), using software that Goodyear provided. Ranges of reduction estimates of F reported in the tables of this document are based on M values at age 0 of 0.4 to 2 per year.

6.4.1.2 Results

The operational test results for sixteen (16) BRD designs (Table 2) are presented. These designs include three different size fisheye BRDs which were evaluated in five different positions (Figure 17), three funnel designs (Figure 18), a modified funnel design (Figure 19), a modified TED design and a "snake eye" design. The modified TED design was a Supershooter TED (trademark name) with holes cut in the side of the extension behind the TED; the "snake eye" design had diamond shaped holes cut in the extension ahead of a Parrish TED.

Reduction data are summarized using point estimates and 95% confidence. Upper and lower confidence limits are presented as shaded bars above and below the point estimate, reduction rates, which were not significant (p>0.05), are presented as point estimates without shaded bars. Note that non significant negative values are not shown to scale in any of the figures.

Estimated reduction rates for the 12x5 fisheye (30 mesh) for the Gulf of Mexico are presented in Figure 20. The estimated shrimp reduction rate for the 12x5 fisheye in the 30 mesh position was 4% with a p-value of 0.17. Total fish reduction estimate was 44% with a 95% confidence interval of 38% - 49%. Red snapper reduction estimate was 59% with a 95% confidence interval of 40% - 79%. Significant reduction rates were also shown for Spanish mackerel, king mackerel, croaker, spot, and southern flounder.

Estimated reduction rates for the 12x5 fisheye (5 mesh) for the Gulf of Mexico are presented in Figure 21. The estimated shrimp reduction for this device was -1%(increase) with a p-value of

0.78. Total fish reduction estimate was 31% with a 95% confidence interval of 24% - 37%. Red snapper reduction estimate was 44% with a 95% confidence interval of 24% - 63%. A significant reduction rate was also demonstrated for croaker.

Estimated reduction rates for the 12x5 fisheye (offset) for the Gulf of Mexico are presented in Figure 22 Shrimp reduction estimate was 8% for this device with a 95% confidence interval of 5% - 12%. Total fish reduction was 33% with a 95% confidence interval of 25% - 41%. Red snapper reduction was 25% with a 95% confidence interval of 8% - 43%. Significant reductions were also achieved for croaker and spot.

Estimated reduction rates for the 4x7 fisheye for the Gulf of Mexico are presented in Figure 23. Shrimp reduction was 7% with a 96% confidence interval of 4% - 11%. No significant reduction rates were achieved for any other species.

Estimated reduction rates for the extended funnel for the Gulf of Mexico are presented in Figure 24. The estimated shrimp reduction rate for the extended funnel BRD was 1% with a p-value of 0.74. Total fish reduction estimate was 32% with a 95% confidence interval of 26% - 38%. Red snapper reduction rate estimate was not significant. Significant reduction rates were demonstrated for Spanish mackerel, croaker, and spot.

Estimated reduction rates for the 3/5 extended funnel for the Gulf of Mexico are presented in Figure 25. The estimated shrimp reduction rate was 2% with a p-value of 0.46. Total fish reduction was 24% with a 95% confidence interval of 16% - 32%. The red snapper reduction estimate was 27% with a p-value of 0.08. Significant reduction rates were shown for croaker and spot.

Estimated reduction rates for the Jones/Davis device for the Gulf of Mexico are presented in Figure 26. The estimated shrimp reduction rate for the Jones/Davis BRD was 4% with a p-value of 0.07. Total fish reduction estimate was 58% with a 95% confidence interval of 53% - 63%. Reduction estimate for red snapper was 40% with a 95% confidence interval of 30% - 50%. The Jones/Davis device also had significant reduction rates for croaker and spot.

Estimated reduction rates for the side opening Supershooter TED (trademark name) for the Gulf of Mexico are presented in Figure 27. Shrimp reduction estimate for this device was 0% with a p-value of 0.86. Total fish reduction was 22% with a 95% confidence interval of 17% - 27%. The red snapper reduction estimate was 6% with a p-value of 0.78. Significant reduction rates were achieved for croaker and spot.

Estimated reduction rates for the 12x5 (30 mesh) fisheye for the south Atlantic are presented in Figure 28. Shrimp reduction estimate for this device was -4% (increase) with a p-value of 0.17. Total fish reduction was 14% with a 95% confidence interval of 8% - 20%. Weakfish reduction was 25% with a p-value of 0.08. Significant reduction rates were achieved for Spanish mackerel (53%, C.I. = 27% - 80%) and spot (36%, C.I. = 20% - 53%).

Estimated reduction rates for the 12x5 (offset) fisheye for the south Atlantic are presented in Figure 29. Shrimp reduction estimate for the offset fisheye was 1% with a p-value of 0.07. Total fish reduction was 26% with a 95% confidence interval of 11% - 42%. The weakfish reduction rate estimate was 37% with a 95% confidence interval of 31% -43%. Significant reduction rates were also demonstrated for croaker, spot, and southern flounder.

Estimated reduction rates for the 4x7 fisheye for the south Atlantic are presented in Figure 30. Shrimp reduction estimate for the 4x7 fisheye was 2% with a p-value of 0.77. The only significant reduction rates achieved by the 4x7 fisheye was for total fish (18%, 95% C.I.= 5% - 31%) and spot (32%, 95% C.I. = 14% - 50%).

The 6x6 fisheye in the south Atlantic (Figure 31) had a shrimp reduction estimate of 11% with a p-value of 0.24 and a total fish reduction estimate of 14% with a p-value of 0.28. Weakfish reduction rates estimate was 29% with a 95% confidence interval of 7% - 50%. Significant reduction rates were also demonstrated for croaker, spot, and southern flounder.

The extended funnel in combination with a Georgia TED in the south Atlantic (Figure 32) demonstrated a negative shrimp reduction rate (nominal increase) of -9% with a 95% confidence interval of -15% to -3%. Total fish reduction was 41% with a confidence interval of 29% - 53%. Spanish mackerel reduction estimate was 57% with a 95% confidence interval of 12% - 100%. Significant reduction rates were also demonstrated for croaker and spot.

The extended funnel in combination with a Burbank TED in the south Atlantic (Figure 33) had a shrimp reduction estimate of 1% with a 95% confidence interval of .4% - 2%. Total fish reduction was 11% with a 95% confidence interval of 7% - 15%. Weakfish reduction rate estimate was 39% with a 95% confidence interval of 32% - 46%. Reduction estimate for Spanish mackerel was 40% with a 95% confidence interval of 38% - 42%. Significant reduction rates were also demonstrated for croaker, spot, and southern flounder.

The extended funnel in combination with the Supershooter TED (trademark name) in the south Atlantic (Figure 34) demonstrated no loss in shrimp catch (0%) and had a total fish reduction rate of 58% with a 95% confidence interval of 51% - 64%. Weakfish reduction rate estimate for this design was 55% with a 95% confidence interval of 47% - 62%. Reduction for Spanish mackerel was 84% with a 95% confidence interval of 54% - 100%. Significant reduction rates were also demonstrated for croaker, and spot.

The snake eye design (Figure 35S) did not demonstrate significant reduction rates for any of the species evaluated.

Among the BRD designs evaluated, the reduction rates estimates for bycatch varied by species. The best overall reduction rates were demonstrated by the top position, 12x5 (30 mesh) fisheye (Figures 36 and 20), the extended funnel (Figures 37 and 34), and the Jones/Davis device (Figures 19 and 26). Among these designs the greatest total fish reduction was demonstrated by the Jones/Davis device (58%), the extended funnel (58%) and the 12x5 (30 mesh) fisheye (44%).

There was no reduction in shrimp catch with the extended funnel, the 12x5 (5 mesh) fisheye (Figure 21), and the side opening TED (Figure 27). Shrimp loss varied from 1 - 11% with the other designs. Greatest loss demonstrated by the 6x6 fisheye (Figure 31) with 11% loss and the 12x5 offset (Figure 22) and the 4x7 fisheye (Figure 23) with 8% and 7% loss respectively.

Reduction rates for the key FMP species, red snapper in the Gulf of Mexico and weakfish in the south Atlantic varied between the designs evaluated. The best overall reduction rates for red snapper were demonstrated by the 12x5 (30 mesh) fisheye (59%), the 12x5 (5 mesh) fisheye (44%), the Jones/Davis (40%), and the 12x5 (offset) fisheye (25%). Calculated estimates of reduction in fishing mortality (F) for red snapper based on reduction rate estimates by length frequency categories for these designs are presented in Table 3. Reduction in red snapper fishing mortality estimates (F) were 52%-67% for the Jones/Davis design, 59%-60% for the fisheye (30 mesh), 66%-70% for the 12x5 fisheye (5 mesh), and 66%-77% for the 12x5 fisheye (offset). The best reduction rates for weakfish were demonstrated by the extended funnel (55%) and the 12x5 offset fisheye (37%). For Spanish mackerel the best reduction rates were demonstrated by the extended funnel (84%), the 12x5 (30 mesh) fisheye (53%), and the Jones/Davis design (53%). For king mackerel the highest reduction rates were demonstrated by the 12x5 (30 mesh) fisheye (80%) and the Jones/Davis design (34%).

All of the BRD designs demonstrated good reduction rates for croaker except the 4x7 fisheye. Reduction rates for the other designs ranged from 61% to 91% with the best rates demonstrated by the Jones/Davis design (91%), the side opening TED (75%), and the 12x5 (5 mesh) fisheye (74%). The best reduction rates for spot were demonstrated by the Jones/Davis design (87%), the extended funnel (74%), and the 3/5 extended funnel (62%). The best reduction rates for southern flounder were demonstrated by the 12x5 (30 mesh) fisheye (57%), the extended funnel (57%), and the 3/5 extended funnel (54%).

In addition to the BRD designs presented in the current report there are several new BRD designs developed in 1997 currently being evaluated or proposed for evaluations in 1998. These new designs which have excellent bycatch reduction potential include the expanded mesh with cone stimulator (Figure 38), the Parker TED (Figure 39), and the 4x8 Andrews TED (DIHN TED) (Figure 40).

6.4.1.3 Discussion

Shrimp trawl gear modifications have been successfully developed and evaluated under the southeast regional bycatch program for their potential as possible management options to reduce the bycatch mortality associated with shrimp trawling. The 12x5 fisheye, the extended funnel BRD and the expanded mesh BRD have been approved for use by the shrimp industry in the south Atlantic under Amendment 2 to the Fishery Management Plan for the shrimp fishery (SAFMC, 1996). The 12x5 fisheye have been approved for implementation in the Gulf of Mexico under Amendment 9 to the Fishery Management Plan for the shrimp fishery (FMP).

Several new designs currently being evaluated also appear to offer excellent potential. This program has demonstrated that new and improved sustainable fishery technology can be

successfully developed through cooperative efforts between the commercial fishing industry, federal and state research agencies. These technologies can offer management options to restore overfished stocks and reduce environmental impacts while maintaining viable commercial fisheries.

6.4.2 Evaluation of Ecological Impacts of BRDs

Measures to reduce bycatch (bycatch reduction devices) have been proposed to alleviate problems with incidental capture of living marine resources in the Gulf of Mexico shrimp trawl fishery. However, the mandated use of bycatch reduction devices may have the effect of releasing more shrimp predators or allowing small fish to grow larger and thus become predators on shrimp, possibly reducing shrimp fishery yield by increasing the incidence of predation by finfish. Although the interaction of shrimp and finfish predators in a Gulf of Mexico estuary has been described in detail (Minello et al., 1989), limited information is available regarding shrimp predation in offshore waters, and its effect on shrimp stocks. An ecosystem-based model of the interactions among shrimp and finfish stocks in the Gulf of Mexico was developed as an analytical tool to guide research and management with respect to bycatch. However, it is important to remember that predictive results of this (and other) models are based on assumptions and the quality of the information available. The current analysis is based on updating previous models that attempted to describe the interactions among fisheries, bycatch, and living marine resources in the Gulf.

Research completed in the early 1980's resulted in the development of several models to examine potential fish predation on shrimp stocks in offshore waters (Browder, 1983; Sheridan et al., 1984a). The premise of the models was that reduction of shrimp trawl bycatch affected shrimp stock dynamics and, ultimately, shrimp fishery yield. The models were used to simulate dynamics of living resources in the ecosystem subsequent to bycatch reduction (perturbation). Initially, quantitative data which specified *Penaeus* **as a prey item was minimal and indicated a low incidence of finfish predation on shrimp (Browder, 1983; Sheridan et al., 1984a). Information regarding competition among fish species was even more limited. One model utilized traditional population dynamics techniques (matrix operations); the other was an ecosystem simulation model with numerous compartments representing different trophic groups linked by energy flow and nitrogen cycling within the system.**

The population dynamics model indicated that even the most favorable discard practices could increase shrimp harvest by only 8% (Sheridan et al,. 1984a). This assumes no discards of shrimp and a high rate of discards for bottomfish. Furthermore, a major assumption was that reassimilation of fish discards would "be directly translated into shrimp yield" (Sheridan et al., 1984a). However, the authors indicated that the actual benefit would probably be less since assimilation rates in the model were overestimated; therefore, results from the population dynamics model were not considered to be very accurate. The trophic model provided greater flexibility for inclusion of biotic and abiotic factors such as riverine input of nitrogen, solar radiation, plankton and benthic components, fishing effort, and stocks of shrimp, bottomfish, migratory and pelagic finfish, large predators (dolphins), scavengers (sharks), and utilization of bycatch by fishermen. Results from this model suggested that shrimp production (biomass) would

decline approximately 25% if discards were reduced by 50% through utilization (i.e., removal of biomass from the ecosystem). Model results also indicated that only an 8% reduction in shrimp production would be observed with the introduction of trawls which reduced bycatch, assuming that excluded finfish do not exhibit selective predation against shrimp as a prey item. Consequently, the authors concluded that using bycatch reduction devices (BRD'S) or similar techniques to reduce finfish capture would result in no long term effect on shrimp harvest if finfish exhibited even moderate selectivity against shrimp as prey. Shrimp biomass would decrease initially, but shrimp stocks would rebound and stabilize after the first or second year following implementation of BRD'S (Browder, 1983; Sheridan et al., 1984a). The trophic model of Browder has been generally accepted in evaluating predator-prey interactions in the shrimp fishery since data from many different research efforts up to that time were used to parameterize and quantify the model.

Since 1980, when the Browder models were developed, new research has provided additional information on predator-prey interactions between shrimp and finfish stocks in the Gulf of Mexico. Scientists of the SEFSC and other investigators have continued to examine foods of trawl-susceptible and coastal pelagic fishes and consequently identified the dominant shrimp predators and their frequency of predation on penaeid shrimp (Divita et al., 1983; Manooch and Haimovici, 1983; Manooch and Hogarth, 1983; Manooch et al., 1983; Naughton, 1981; Saloman and Naughton, 1983a, 1983b; Sheridan and Trimm, 1983; Sheridan et al., 1984b). Of 161 fish species examined, only 14 fish species have been identified as predators on shrimp of the genus *Penaeus*. **These include Atlantic croaker, sand seatrout, spotted seatrout (***Cynoscion nebulosus***), silver seatrout, ocellated flounder (***Ancylopsetta quadrocellata***), inshore lizardfish, bighead searobin (***Prionotus tribulus***), smooth puffer (***Lagocephalus laevigatus***), red snapper, lane snapper (***Lutjanus synagris***), Spanish mackerel, rock sea bass (***Centropristis philadelphica***), dwarf sand perch (***Diplectrum bivittatum***), and Atlantic sharpnose shark (***Rhizoprionodon terraenovae***). The relative importance of shrimp predation by each of these species is presented in Table 4. Sand seatrout represent the dominant predator of shrimp in Gulf waters, despite the low occurrence of** *Penaeus* **in their stomachs. This is attributed to the abundance of the sand seatrout population in the Gulf of Mexico (NMFS, unpublished data).**

Since 1990 research on bycatch characterization and bycatch reduction devices (BRDs) have produced data on the magnitude, composition, and distribution of bycatch species captured in trawls and on effectiveness of trawls equipped with BRDs. Bycatch characterization studies (>450 trips, >4, 000 observer days) have recorded >250 species of finfish. Characterization data include size and weight characteristics of fish as well as catch per unit effort (CPUE) by area, season, and depth fished (NMFS, unpublished data). BRD evaluations indicate that certain gear types can release up to 79% of a given species (biomass; NMFS, unpublished data). Seven species of known shrimp predators were evaluated with respect to exclusion from trawls using BRDs. CPUE was reduced for Atlantic croaker, Spanish mackerel, lane snapper, and red snapper. CPUE remained unchanged for rock sea bass, smooth puffer and inshore lizardfish.

A review panel of scientists from NMFS and academic institutions was assembled to examine areas for improvement of the existing models. This working group identified the need for inclusion of additional functional relationships in the model. In addition, new parameters were

identified for components describing stocks of phytoplankton, zooplankton, bycatch, discards, shrimp and several finfish groups (reef fish, pelagics, etc.).

6.4.2.1 Model Development and Revision

6.4.2.1.1 Model Design

The design of the new model follows Browder (1983) and Sheridan et al. (1984a). A generalized version of the model is shown in Figure 41. Nitrogen is used as the common currency of material flow within the model since it can quantitatively describe biotic (stocks) and abiotic (environmental) components of the model. Therefore, nitrogen substitutes for biomass of living marine resources through simple conversion of biomass (kg) to nitrogen units (mg N_2/m^2). The model is programmed using the Stella/iThink simulation software for Macintosh computer platforms. The model contains 110 variables including:

1. *Abiotic components*: **river runoff, sedimentation rates, water temperature, and photoperiod.**

2. *Biological components*: **N_2 pools (inorganic and organic) planktons, benthos (infauna and epifauna), crustaceans, finfish, (bottomfish, pelagics, migratory fish), dolphins, sharks and birds.**

3. *Ecological components*: **predation, excretion, respiration, natural mortality, assimilation, and denitrification rates.**

4. *Fishery components*: **species-directed effort, catch, discards, and bycatch reduction rates.**

The bottomfish component of the model includes reef fish species such as red snapper, which are susceptible to incidental, capture in trawls at young age stages.

6.4.2.1.2 Data Input and Model Parameterization

Examples of the inputs and outflows of nitrogen for individual stocks of living marine resources are shown in Figure 42. The nitrogen inputs for each component in the model are detailed in Table 5. Removal of material in nitrogen components is achieved through burial (sedimentation), denitrification, or uptake by resources. In stocks of living marine resources, removal of nitrogen from the stock is achieved through respiration, decomposition, harvest, and predation by other resources. The majority of the data used to parameterize the model was taken from published reports on life history and ecological requirements of individual species. Data on river flow into the Gulf of Mexico (Atchafalaya and Mississippi rivers) were obtained from the U.S. Army Corps of Engineers, New Orleans District. Data from NMFS statistical surveys were used to quantify fishing effort and landings for commercial species of shrimp and fish. Due to the lack of quantitative information, the components describing dolphins, sharks, and sea birds were not utilized in the simulations despite anecdotal reports that these stocks could have significant impacts on other resources, especially through predation of discards. Because these components

were closed off (i.e., no predation on other components), the simulations results presented in this report must be viewed as preliminary, but probably represent the upper bounds of the effects on the shrimp stocks.

6.4.2.1.3 Results of Simulations

Output of the model is contingent upon the assumptions and data constraints imposed on the parameters and simulations. The model was parameterized using data for the Gulf of Mexico offshore waters, from Alabama to Brownsville (NMFS statistical areas 11-21). Mortality of discards from bycatch was assumed to be 100% for simulation purposes. This implies the worst-case scenario with regard to the fate of the discards. Bycatch that is not scavenged or consumed by predators returns to the general stock of organic nitrogen in the ecosystem. The model was used to simulate the ecosystem for a one year period under four hypothetical perturbations. Results of these scenarios were compared against baseline simulations to examine the effect of bycatch management (i.e., BRDs) on shrimp stocks. The baseline conditions considered are before BRD-implementation into the fishery. It is important to note that <u>the results reflect differences in production within the stock of shrimp, and not fishery yield</u>. Results as they may affect shrimp stocks are reported below and summarized in Figures 43-46. No similar analyses were completed for other resources or stocks in the model.

Scenario 1: BRD effect - equivalent release of finfish.

The first simulation is a general overview of the effects of bycatch reduction policy on shrimp stocks. It was run for comparative purposes with the other simulations and demonstrates the BRD effect <u>if all finfish were released at an equivalent rate</u>. This scenario examines reduction in biomass of all bottomfish by 10, 25, & 50%, without selective BRD effects. Values for stocks of shrimp (biomass represented by nitrogen) with each simulation were compared to the baseline values. Results indicate a general decrease in shrimp stocks by reduction of finfish biomass. Over a one year period, shrimp stocks declined by 0.8% with 10% bycatch reduction, by 5.5% with bycatch reduction of 25%, and by 10.7% with 50% decrease in bycatch (Figure 43). The decline in shrimp stocks is attributed to an increase in the abundance of bottomfish predators and a reduction in the organic nitrogen pool (which is augmented by discards in the baseline simulation). However predation on shrimp is the primary reason for the differences because bottomfish nitrogen stock increased 4-9% due to bycatch reduction.

Scenario 2: BRD effects - selective release of finfish.

In actuality, BRDs do not release all finfish at equivalent rates. Some finfish are released at higher rates than others, and others are not released at all. However, because restoration of red snapper stocks is a major component behind the bycatch reduction policy, BRDs have been tested with the goal of achieving a 50% reduction in mortality of juvenile red snapper. Three gear types tested by NMFS and evaluated through the bycatch research program approach or attain this goal. These BRDs include a front position fisheye (30 mesh location) on top of the trawl, a middle position fisheye (45 mesh location), and the extended funnel design. However, each of these gear types exhibits variable exclusion rates with respect to different finfish species. Analysis of this

information reveals that exclusion of these species accounts for a reduction in CPUE (by weight) of 30.6% (front fisheye), 29.6% (middle fisheye), and 34% (extended funnel) of nitrogen in the bottomfish component of the model. This amount is returned to the sea alive and augments the stock of fish, which may prey on shrimp. Incorporating these data into the model yields a reduction in shrimp stocks of 6.7% for the front position fisheye, 5.9% for the middle position fisheye, and 8.2% for the extended funnel design (Figure 44). The release of finfish by BRDs will allow more larger sized fish in the population. An important assumption is that finfish predation on shrimp is expected to change as fish increase in size (i.e., depending on food habits of larger fish, predation on shrimp may either increase or decrease).

Scenario 3: Finfish size effect - increase in shrimp predation.

Finfish excluded from trawls will continue to grow, possibly leading to increased consumption rates on shrimp prey. Ecologically, consumption of prey types by finfish is largely dependent on the size structure of both predator and prey populations. Smaller fish, which could not prey on the large shrimp in the Gulf of Mexico may be able to do so if given the opportunity to grow larger. Data, which describe changes in predation or growth rates of finfish, are not currently adequate for use in the model developed here. Consequently, a sensitivity analysis of variable predation rates was undertaken to provide some insight as to the impacts on shrimp stocks. An average bottom fish exclusion rate (31.4%; CPUE by weight) for the three gear types described in Scenario 2 was used for this sensitivity analysis. This yields a decrease in shrimp stocks by 6.2% over baseline conditions. Finfish predation rates on shrimp were then increased by 10, 25, and 50%, and results from one year simulations were compared with the baseline values. A 10% increase in the predation rate on shrimp by excluded bycatch results in an 8.2% decline in shrimp stocks. Shrimp stocks declined by 10.8% with a 25% increase in predation rates, and by 16.7% with a 50% increase in predation rates by excluded finfish (Figure 45). The relationship between finfish predation rates and shrimp stocks appears to be linear and is discussed below.

Scenario 4: Finfish size effect - decrease in shrimp predation.

As fish grow they may change dietary habits. Under this assumption, fish of larger size will decrease predation on shrimp due to preference for alternate prey. Optimal foraging theory and research on predator-prey interactions of fish provide evidence of such occurrences in estuarine and oceanic ecosystems. Using our model, a series of simulations (similar to scenario 3 above) were conducted to examine the effect of decreasing predation rates by excluded fish on shrimp stocks. As in the previous simulation scenario, the baseline conditions reflect general bottomfish exclusion rates of 31.4% (CPUE by weight). In this set of sensitivity analyses, predation rates were decreased by levels of 10, 25, and 50%. Generally, a reduction in the predation rates by excluded fish has smaller impacts on the shrimp stocks. A 10% decrease in predation on shrimp by excluded by catch results in a 4.1% decline in shrimp stocks, and a 25% decrease in predation rates reduced shrimp stocks by 1.3%. As predation rates continue to decrease, there could be some benefit to the shrimp stocks; a 50% decrease in predation rates by excluded finfish resulted in a 4.7% increase in the amount of nitrogen in the shrimp stock (Figure 46).

6.4.2.1.3.1 Sensitivity Analysis

An extensive analysis was conducted to determine the sensitivity of model output to changes in input parameters. This type of analysis identifies the variables that affect model behavior the most and also provides a measure of confidence in the model parameters and output. Generally, input parameters were increased or decreased by ±10-100%, relative to baseline conditions, to determine which variable has the greatest effect on model output. Ecological parameters for individual stocks or species such as mortality, respiration, excretion, or assimilation rates were not evaluated as part of the sensitivity analysis, since input values for these represent the knowledge of actual conditions as reported in published literature. Biological components such as size of nitrogen stocks for individual groups of living resources were only evaluated to within 25% of baseline conditions, since the input values also represent status quo. Variables which were tested include predation rates, and those for abiotic (riverine inputs of organic and inorganic nitrogen), and fishery components (fishing/harvest, and discard rates). With respect to predation rates, by combining the output from simulation scenarios 3 and 4 above, we can observe the impacts of varying predation rates on shrimp stocks and production. The interaction between finfish predation rates and shrimp production is represented by a linear relationship (Figure 47). For every percent change in predation rate, there is 0.21% change in shrimp stock size. Of all the other variables evaluated, only riverine input of nitrogen and fishing effort/intensity showed significant impact on model output and behavior. The model was highly sensitive to riverine nitrogen inputs; increases in riverine nitrogen caused logistic growth in the stocks of benthic infauna and macrocrustaceans, including commercial shrimp. Logistic growth of these parameters during simulations resulted in output, which far exceeded reasonable conditions for most of the components in the model. Likewise, in the case of fishing intensity, changes in fishing effort by more than ± 25% caused a collapse of numerous resources stocks due to excessive harvest or unrealistic growth of all components.

6.4.2.1.3.2 Conclusions and Recommendations

Revision of the ecosystem-based bycatch model is enhanced through incorporation of new information on bycatch characterization, stock assessments, and efficiencies of bycatch reduction devices. The large number of variables in the model represent movement toward a realistic evaluation of ecosystem effects in the dynamics of the Gulf of Mexico shrimp fishery. The initial output, however, is of relatively low resolution due to aggregation of information within larger components (e.g., seatrout, snappers, etc. are described within the bottomfish group). Data used to parameterize the model include specific rates for individual components (e.g., sediment burial rates, respiration rates of shrimp) and general trends or average values for other components (e.g., species-directed effort patterns, respiration rates for benthic infauna, natural mortality rates for phytoplankton and zooplankton). The model is used to simulate several different hypothetical scenarios, which encompass possible changes in ecosystem dynamics with the implementation of bycatch management policy. Depending on bycatch exclusion rates and assumptions relative to predator selection of shrimp prey, simulated shrimp stock biomass could increase by 4.7% or decrease by 17%. The decrease in the shrimp stocks is primarily due to predation, but is also due to a reduction in the amount of nitrogen recycled from discards. However, nitrogen returned to the ecosystem through discards is minimal in comparison to the rather large input from riverine sources.

These model simulations indicate possible outcomes within the fishery and the ecosystem. A number of factors, some remaining unmeasured, may have profound effects on the actual response of the ecosystem to changes in resources. The fate of discards from the Gulf of Mexico trawl fishery is not fully understood. Generally, scientific data are lacking to adequately address the scope of the ecosystem, its inhabitants, and their interactions. This is especially evident with respect to stock size, predator-prey interactions, and competition among individual groups such as bottomfish, sharks, birds, and dolphins. Our assumption of 100% mortality of discards has not been investigated or documented. Other assumptions with inadequate information include: changes in fishing effort due to variability in size or mobility of the shrimp fleet, variability in recruitment or survivability for living resources, changes in life history within stocks, loss of habitat, selection of alternate prey, and competition among species. Sensitivity analyses indicate that the model is not robust with respect to changes in fishing intensity and riverine nitrogen input. While these factors could lead to some uncertainty in the model behavior and predictions, it also demonstrates the interactions and relationships of the driving forces in the ecosystem. The fact that the model is relatively unstable with respect to changes in fishing intensity may be an indication of the status of the fishery and might support claims that the shrimp fishery is quite near maximum sustainable yield. Finally, over the past 5 years, the natural variability of production in the shrimp fishery has approached 12% of average landings. When considering the potential decrease in shrimp stocks due to bycatch reduction and higher predation, it is likely that changes in, or impacts on, production will be within the natural annual variability and may therefore be difficult to detect. The actual effects of bycatch management on the shrimp resources will remain undetermined until bycatch reduction is implemented and follow-up observation are completed.

6.4.3 Evaluation of Economic Impacts (Cost / Benefit Analysis) of BRDs

One of the more challenging fishery economic issues in the southeast concerns the incidental bycatch of finfish by shrimp trawlers. While some of the bycatch has market value, most of it has little or no value to shrimpers and is discarded. The capture and discard of juvenile red snapper is one example that has been specifically addressed and has been the subject of considerable research and management efforts. Although a large number of other finfish stocks are affected by shrimp trawling, these other stocks have not been studied extensively either in terms of the biology or the economics of reducing bycatch associated with shrimp trawling. Accordingly, this section of the report deals mainly with the economic lessons to be learned from the examination of reducing the bycatch mortality of red snapper by regulating the shrimp harvesting industry. Other finfish stocks are referenced, but only casually since neither the biological nor economics information is available for such inquiries. This section is not intended to be an exhaustive review of all the economics inquiries into the shrimp and red snapper bycatch situation. Instead, the section provides a summary of the major findings in the shrimp and red snapper example, explores the general economic considerations that apply to bycatch issues and reports on lessons to be learned from the shrimp and red snapper inquiries that should have a much wider application than in the specific case examined.

As will be explored in the discussions to follow, the management regimes for the fishery creating the bycatch and the fisheries subject to bycatch are both critically important in terms of the nature

of the bycatch "problem" and the solutions to the problem. For example, in the case of shrimp fisheries it is known that the fishery is "overcapitalized" in the sense that shrimp harvesting effort could be reduced by a significant amount without a comparable decline in shrimp catches but with an increase in net national benefits. Since the magnitude of shrimp bycatch is positively related to the amount of shrimp trawling effort, it is rather straightforward that management resulting in a reduction in overall shrimp effort will lead to a reduction in the overall level of bycatch. This is a primary indicator that a portion, perhaps a major portion, of the bycatch problem is related to the open access nature of the southeast shrimp fishery; hence, the introduction of a management regime to resolve the open access problem will lead to a reduction in shrimp trawling effort and a reduction in bycatch. For the directed fisheries that utilize finfish species subject to shrimp bycatch, economic theory and empirical observations both indicate that potential increases in net national benefits resulting from the future harvest of the bycatch species will not be fully realized unless these fisheries are also managed in a way that resolves open access problems.

The economic determinations to assess the costs and benefits of bycatch reduction require knowledge of the current harvest sector costs for shrimp and finfish species and knowledge of the demand for these species. In addition to this baseline economics information, knowledge is required about the current level of bycatch, the degree of bycatch reduction that is possible under various bycatch reduction alternatives and the biological stock response to bycatch reduction. Finally, knowledge about changes in fishing effort for shrimp and finfish as a result of bycatch reduction is needed to determine the longer term economic outcome of bycatch reduction. Quite a lot of research and reports to provide the information has been completed (Greene, Moss and Thunberg, 1994; Hendrickson and Griffin, 1993; Holiman, 1998; Holiman, 1997; Keithly, Roberts and Ward, 1993; Thomas, et. al, 1993; Thomas, et. al, 1995; Ward, 1994, Ward and Macinko, 1996; Ward and Sutinen, 1994; Ward, Ozuna and Griffin, 1995; Waters, 1997; Waters, 1996; and, Waters, 1995). In addition, there is an ongoing effort to update the existing information and to provide new information. Examples include refinements to the Ward dynamic shrimp model, refinements to the Griffin bioeconomic simulation model, two new studies to investigate the economics of the for-hire fisheries, analyses of recently collected economics data pertaining to the private recreational fisheries, updates of existing shrimp import and supply models and updates and refinements to existing reef fish demand models.

6.4.3.1 Basic Economics of Bycatch Reduction

One of the analytical findings in the 1996 Regulatory Impact Review (RIR) of alternatives to reduce bycatch mortality of red snapper created by shrimp trawling concerned the change in the net present value (NPV) of benefits derived from shrimp trawling activities. The basic outcome was that the least costly of several alternatives designed to reduce red snapper bycatch by a minimum of 44% would result in economic losses totaling $117 million in terms of NPV. It should be noted that although alternatives of seasonal and area shrimp closures were in the official set of alternatives, the alternative of managing the shrimp fishery via individual transferable quotas (ITQs) was not possible because of the Congressional ban on implementing new ITQ programs for fisheries under Federal jurisdiction. In addition, it was pointed out during the red snapper peer review (MARAG Americas, 1997) that other alternatives such as economic incentive alternatives were likewise not considered by the Council. Nonetheless, of the alternatives

investigated, the alternative that would meet the criterion of a 44% reduction in red snapper bycatch mortality with the least cost to the shrimp industry was the mandated use of bycatch reduction devices (BRDs). For BRDs to be "practicable" from the standpoint of leading to an increase in net benefits to society, it is clear that the estimated loss in net economic benefits to the shrimp harvesting industry would have to be offset by an equal or greater increase in net benefits accruing to the red snapper and other finfish stocks that are subject to incidental harvest via shrimp trawling activities. In the case of red snapper it was determined that the full economic benefits from bycatch reduction would not be realized unless the commercial red snapper fishery was managed in an optimal fashion and unless the recreational catches of red snapper could be constrained to the level of the recreational allocation. This finding emphasizes the fact that the economics of bycatch must include a full accounting of the benefits as well as the costs of bycatch reduction for the fishery creating the bycatch and the fisheries impacted by the bycatch.
An important consideration is that only by pure coincidence will a bycatch reduction target for biological purposes turn out to be the appropriate target from the standpoint of maximizing net benefits to society. At the extreme, even though a large reduction based purely on the status of the bycatch stocks might be indicated, the economic target could be for a zero reduction if the economic considerations showed that the costs of any degree of bycatch reduction would not be matched by an equal or greater increase in benefits. This potential outcome derives from the basic economic principle that the correct level of bycatch reduction occurs at that point where the costs associated with the last increment of bycatch reduction are equal to the benefits derived from the last increment of bycatch reduction. Stated in terms that economists use, the governing economic principle that determines the correct level of bycatch reduction is "the marginal costs of bycatch reduction are equal to the marginal benefits from bycatch reduction." It is also important to note that the benefits have to be calculated in the context of the management structure for the bycatch species. For example, if the bycatch species is managed under an open access system that controls neither total effort nor total catch, then the increased size of the recovering bycatch stock will induce additional fishing effort and the increased effort will eventually drive the stock size back down, costs will rise and the potential benefits of the initial reduction in bycatch will be reduced or totally eliminated.

The important lesson to be learned from the standpoint of economics is that the correct level of bycatch reduction is not straightforward and depends on factors in addition to biological considerations. As a corollary, overall bycatch targets are typically based on projected stock increases related to bycatch reduction and the technical feasibility of different bycatch reduction levels. However, this combination of biological and technical considerations can easily lead to undesired consequences regarding net benefits to the nation if the basic concept of equating marginal costs and benefits is ignored. In addition, the hypothesized increase in the size of the bycatch stocks will not occur unless the potential increases in fishing effort on the bycatch stocks are recognized and resolved through an appropriate management system.

6.4.3.1.1 Impacts on Shrimp Fishery

Amendment 9 to the Gulf shrimp FMP considered several management alternatives designed to reduce the catch of juvenile red snapper by shrimp trawling. The alternatives included area closures, seasonal closures and the use of bycatch reduction devices (BRDs) in shrimp trawls and

all of these alternatives were addressed by the RIR for the amendment. While similar economic analyses have not been conducted for other species or for finfish in aggregate, there are useful lessons to be learned by examining some of the basic results of the example RIR. For example, all the alternatives were examined in terms of a target bycatch reduction of 44% and it would only be a coincidence that this target level is the appropriate target from an optimal yield standpoint. Nonetheless, the target was taken as a mandated reduction and the analysis attempted to determine the economic outcome without regard to differing degrees of bycatch reduction. It is important to recognize that while the target in this example case was based strictly on biological grounds, that there was evidence to support a conclusion that the biological target was technically achievable under one or more of the alternatives.

The basic outcome of the RIR analysis was that BRDs were the least cost alternative that could be employed to reach the objective of a specified reduction in red snapper bycatch mortality. This outcome was based on a finding that the alternative of requiring BRDs was superior to the alternatives of area or seasonal closures in terms of the costs to shrimpers and that the BRD alternative was technically feasible in terms of meeting the 44% bycatch reduction criterion. The RIR also noted that the biological effect on red snapper stocks would be similar regardless of the alternative chosen because all alternatives had to reach the same reduction goal to be considered feasible. Once it was determined that the BRD alternative was superior to other alternatives in economic terms, the balance of the economic analysis focused on the BRD alternative. The RIR proceeded to examine the economic effects of choosing different styles of BRDs that were capable of meeting the criterion of reducing the bycatch mortality of red snapper by at least 44%. Although different BRDs might be capable of meeting the 44% criterion, it was known from the outset that the different types of BRDs would have different performance characteristics in terms of the economics of shrimp harvesting. The analysis of the economic performance of several BRDs clearly indicated that the major factor providing for an economic differentiation among the BRDs is that they lose differing amounts of shrimp. The variability of shrimp losses among BRDs created significantly different outcomes in terms of the short term effects on shrimp harvest, the resources used to harvest shrimp, the cost of harvesting shrimp, the long term level of shrimp harvesting effort and therefore, on shrimp harvesting profitability and changes in net benefits to society. Explanations of the long term effects proved to be complex, partly because the long term outcomes depend largely on the reaction of overall shrimp harvesting effort in response to the short term effects of management. Understanding that the shrimp harvesting industry is open access, and further understanding that the year to year variation in the shrimp resource is independent of previous harvesting effort, a perhaps unanticipated result is that short term losses tend to lead to overall long term effort reductions. The reduction in effort eventually results in long term industry benefits that tend to offset part of the short term losses. It should be noted that this finding does not imply an absence of "losers" when shrimp effort declines. Indeed, the offsetting long term benefits are attributed partially to the exit of marginal firms.

Considering the estimated shrimp losses and the costs of purchasing the BRDs, and the fact that profits as a percent of revenues are small for shrimp harvesting firms, it was determined that the average shrimp vessel would incur an annual short term profit loss of significantly over three percent. The economic models also considered the reaction of the effort response of the shrimp harvesting industry to the loss in short term profits. This information came from an entry-exit model and an indirect cost model that allowed per vessel effort to change from season to season.

The resulting effects of the change in fleet size in conjunction with expected changes in annual effort per vessel allowed a calculation of the expected level of overall shrimp effort. The result was that estimated total effort declined in response to the decreased shrimp catches and increased costs of purchasing and maintaining BRDs. The model indicated that when a new harvesting equilibrium was reached, then the overall reduction in effort tended to reduce overall costs and hence tended to produce long term economic gains that offset, to some degree, the short term costs to shrimpers.

The results described above were the subject of a Congressionally mandated peer review and while the review tended to agree with the economic outcomes described in the RIR, the review also suggested refinements to the models and data currently utilized to analyze economic effects on the shrimp industry and strongly recommended that the red snapper fishery be analyzed in a manner similar to that done for the shrimp industry. The reviewers also recognized a virtual absence of economics information on the for-hire and private recreational fisheries and recommended that NMFS proceed with all dispatch to begin and complete the analyses noted to be missing. The review also indicated that the Council and NMFS should have considered additional alternatives to technical solutions and season/area closures. In general, the reviewers suggested that future considerations of alternatives include those that contain economic incentives. Specifically, they suggested looking at (1) individual bycatch allowances whereby shrimping ceases when the bycatch allowance is reached, (2) a system to determine "hot spots" of bycatch that shrimpers may be able to avoid and also suggested (3) analyzing a system of taxes whereby shrimpers are charged for each unit of bycatch and thus encouraged to minimize their personal bycatch. They also suggested that a management strategy to limit effort in the shrimp fishery would automatically reduce bycatch while maintaining the historical level of shrimp catches and providing for substantial increases in shrimp benefits. In response to the peer review, NMFS analysts, in cooperation with other economists in academia, will continue planned efforts to fill in the analytical gaps and will investigate other types of alternatives designed to meet bycatch reduction objectives.

6.4.3.1.2 Impacts on Finfish Fisheries

While the only finfish fishery studied to date is the red snapper fishery examined in the RIR for Amendment 9 to the Gulf Shrimp FMP, the basic economic concepts and analyses would apply for other fisheries that are subject to bycatch related to shrimp trawling. While similarities exist, different finfish species tend to have different management systems in place, there are differences in the demand and supply structures and there are complications related to the multi species nature of the fisheries. As a result of these differences, it is not possible simply to transfer the results pertaining to red snapper to other species and an economic analyses has to be conducted for each fishery impacted by shrimp bycatch. The basic similarity is that given the result regarding potential losses to the shrimp harvesting industry, economic feasibility requires an equal or larger positive change in net benefits resulting from the commercial and recreational use of these other finfish fisheries. In the RIR described above, it was concluded that benefits to red snapper stocks could approach the level of the estimated shrimp losses, but only if the red snapper stocks were managed under the approved Individual Transferable Quota (ITQ) program or some other management regime that would produce the same results. The peer review noted this result and

acknowledged that Congressional action to impose a moratorium on ITQs until the year 2000 means that the potential gains will be delayed because equally effective management regimes have not yet been discovered or implemented.

A problematical issue regarding potential benefits deriving from the commercial harvest of red snapper is that the fishery is managed on a constant catch basis, versus a constant fishing mortality rate basis. In practical terms, this means that some potential gains cannot begin accruing until the stocks are recovered and the total allowable catches (TAC) increased. Under the current management scenario, which is being revisited, the constant TAC would increase several fold at the point when the rebuilding schedule has been met. However, the new TAC has not been estimated via the biological models presently available, so the incorporation of the impact of a greatly enlarged TAC for the years following stock rebuilding could not be investigated. This result for red snapper probably applies to other fisheries that need to be restored to some mandated level of biological stock size, equilibrium yield or reproductive potential and the unknowns associated with future stock sizes and allowable harvests will continue to be an impediment to an economic investigation of appropriate management alternatives.

The red snapper stocks also support a large recreational fishery. Under current management there is a quota for the recreational users and the recreational fishery is to be closed when the quota is reached. From an economics standpoint, a closure of the recreational fishery would create short term losses in the red snapper recreational fishery and likely would create additional problems as the recreational effort not targeted on red snapper is transferred to other species. Furthermore, red snapper and most other species are part of a mixed catch and a continuing mortality from the discarded recreational bycatch of red snapper will be present for the balance of the fishing year following the closure of the recreational red snapper fishery. The possibility of a recreational closure would also likely create something like a derby recreational fishery, especially since red snapper is a highly sought species and is pursued in particular by the for-hire recreational sector. The Council could elect to reduce bag limits or take other actions in an attempt to ensure that the recreational fishery does not close during any given season, but such actions would also tend to decrease the short term values obtained from recreational fishing. Hence, short term benefits to recreational users are likely to be reduced in the case of the red snapper fishery. This finding may not apply to all finfish species and the peer reviewers mentioned that NMFS does not have good information on the value of recreational fisheries. Accordingly, general statements about economic outcomes related to recreational fishing are not possible and will not substitute for defensible quantitative analyses. NMFS recognized the problem of inadequate analyses of the recreational fisheries even before the peer review results were known and had initiated steps to conduct studies of the economic value of private recreational fishing as well as the value of commercial for-hire fishing activities. When the results of the data collections and subsequent analyses become available over the next one to three years, the analyses of potential economic benefits to recreational users of the enhanced finfish resources will be conducted. These analyses can then be applied in future RIRs that analyze the economic outcome of alternatives designed to reduce the bycatch from shrimp trawling.

As noted elsewhere in this report, NMFS is planning to extend the shrimp/red snapper analyses to cover other important finfish. In terms of the necessary economic analyses required, the general

thrust of the analyses can be described as follows. For king mackerel, a perfect world would envision new cost and earnings information that currently does not exist and NMFS is exploring 3 options to gather the data. The options include describing the need as a priority for the MARFIN and S-K programs, requesting that NMFS headquarters fund the work via an account set up for such purposes or gathering the information via the southeast's catch and effort logbook system. Recreational private and rental boat mode data were recently acquired via an add-on survey to the MRFSS and information related to the for-hire fisheries is being secured under a MARFIN project. The addition of biological information that provides information on the effect of shrimping activities on king mackerel mortality and the effect of recreational catch and release fishing (either intentional or regulatory discards) on king mackerel mortality could be used to modify existing mackerel VPA models. The modifications could make it possible to incorporate the interactive effects of stock sizes, directed effort changes and bycatch rates to provide a complete bioeconomic model of the king mackerel fishery. However, in a more realistic, shorter-term scenario, quite a lot of information should be available without taking the last step of creating and estimating the full scope model envisioned. Similar models for other finfish fisheries are at a very early stage of planning, and although it has clearly been demonstrated that sea trout and a number of other finfish species are subject to shrimp bycatch, plans for economic analyses for these species have not been formulated because these species are currently of lesser priority. The southeastern menhaden fisheries are also of lesser current priority, and pose somewhat unique economics and biological challenges because those fisheries are not only impacted by shrimp trawl bycatch, but they have a certain level of bycatch themselves. Extending the menhaden fisheries scenario, a refinement to the red snapper analyses could focus on the bycatch of that fishery because the species is only one component of a multi species fishery and effort changes in the directed red snapper fishery could have bycatch implications on other finfish. While no work has been done to characterize the importance of that type of situation, it could become rather important, especially as fisheries that have been sequentially overfished become sequentially managed for to meet stock rebuilding objectives.

6.4.3.2 Importance of Management Regime

A number of the basic results from the case of red snapper and shrimp in the Gulf of Mexico, as well as the discussion of potential outcomes for other finfish fisheries, strongly emphasizes that the management regime in place will have a dominant role to play in the overall, long term economic changes that will result from reductions in bycatch for any fishery. For example, theory and empirical evidence support the notion that if a fishery operates with no management controls, then attempts to rebuild stocks via such devices as bycatch reduction, habitat restoration, or other means designed to enhance stocks will not be successful. This outcome is predicated on conditions whereby total effort will increase such that the fishery reaches a long term equilibrium that stabilizes catches at some level which is lower than maximum economic yield and at effort levels that are greater than necessary to achieve maximum sustainable yield. This outcome can be predicted in all cases where the market demand for the species in question is strong enough to encourage the additional effort. Under other scenarios, there can be an open access management regime that features quotas and a variety of other restrictions like trip and size limits, area closures and gear restrictions. This situation helps preserve the biological status of the stocks, but problems of bycatch mortality and inefficient production methods will still preclude the attainment

of all the potential economic benefits. A third class of management features market driven effort controls such as individual transferable quotas for the commercial sector. In this case there is a possibility to forecast an increase in overall benefits even without a great deal of information for management purposes. The management regime for the fishery that has a bycatch is likewise of critical importance. For example, in the case of shrimp fisheries one estimate indicates that finfish bycatch may be reduced by as much as 60% if the shrimp fishery is managed under an ITQ system (Ward, personal communication). By any account it is recognized that the shrimp fishery is "overcapitalized" in the sense that more effort is expended than is necessary to catch the annual shrimp crop. Since the magnitude of shrimp bycatch is positively related to the amount of shrimp trawling effort, it is rather straightforward that management resulting in a reduction in overall shrimp effort automatically reduces the overall level of bycatch. This is a primary indicator that a portion of the bycatch problem is related to the open access nature of the southeast shrimp fishery. Hence, it is clear that the introduction of a management regime that resolves the open access problem will lead to a reduction in shrimp trawling effort and thereby to a reduction in bycatch. By logical extension to other fisheries that have a bycatch and that are managed under some form of open access or even partial limited access such as a license limitation and quota management system, then the general idea that at least a portion of the bycatch problem is the result of imperfect management structures is straightforward.

One of the underlying reasons for the need to manage the fisheries by means other than open access is the role of what economists call externalities. In the case of the shrimp and red snapper fisheries, there exists a "Coase externality" (Coase, 1960). In this type of externality situation, the production of goods by some firms, say shrimp trawlers, can decrease the benefits accruing to other firms, say red snapper harvesters. In such a case, and under certain conditions, it might be possible that the firms being impacted could pay the other firms to reduce their production. In this case we would say that red snapper producers might band together to pay shrimpers to reduce shrimping effort. This could theoretically occur if the required payments to the shrimpers were less than the resulting benefits to the red snapper producers. Alternatively, the shrimpers might be induced to use BRDs as a way to resolve the externality problem. In either case, the Coase externality exists and provides a possible way of looking at alternatives to the bycatch problem. Going a bit further with the discussion, it could be true that the management alternative to require the use of BRDs could be the appropriate method of resolving the Coase externality and thus resolving the bycatch problem in the case of the shrimp and red snapper fisheries.

The current and future management regime has particularly important consequences in the case of the red snapper and shrimp fisheries and indeed on a number of other target/bycatch fishery combinations throughout the southeast and the United States in general. As indicated earlier, at about the time it became clear that an amendment to reduce shrimp bycatch was imminent, Congress indicated the intent to impose a moratorium on new ITQ or similar management approaches until the year 2000. Subsequently, this intent was written into law in the form of the Magnuson-Stevens Act. As a direct result, the benefits that would have resulted from the simultaneous implementation of bycatch reduction and effective management of the red snapper resource for commercial purposes have largely been put off at least until the year 2001. Under certain circumstances, benefits could still accrue to recreational fishermen, but such benefits are not guaranteed because the for-hire and private recreational fisheries also operate in an open

access management environment. The current recreational management regime features regulation whereby the management system attempts to limit recreational catches by bag and limits and a closure of the recreational fishery when the quota is reached. Since effort is not controlled and since the rate of catch tends to rise with larger stock sizes, the fact that the recreational fisheries operate under a fixed quota is increasingly leading to a derby fishery that is beginning to have some of the same characteristics as the existing derby fishery for the commercial sector. An additional complication for the recreational fishery is that it is composed of a commercial for-hire sector and a private recreational sector and the two sectors would be expected to place different values on access to the fishery. However, the two sectors compete for the fixed quota and since the for-hire sector is taking a larger amount of the quota over time, it is probably necessary to implement a new management regime for the recreational sector. The Gulf of Mexico Fishery Management Council's Socioeconomic Panel has made a strong recommendation that would provide differential management rules for the two distinct recreational sectors.

6.4.3.3 How Much Should Bycatch Be Reduced?

If bycatch is to be approached as an economics issue or problem, then in those cases where it is economically rational to reduce bycatch to some degree, the optimum reduction in bycatch would be determined by comparing the marginal benefits and marginal costs of each additional reduction in bycatch. Using this approach, bycatch should be reduced as long as the marginal benefit exceeds the marginal cost of doing so. One must be careful to consider the management regimes that are in place at the time the marginal costs and benefits are calculated to ensure that the real costs and benefits are calculated correctly. In particular, it is important to take into consideration the long term changes in effort that are induced by the bycatch control mechanism. Importantly, it would be a mistake to calculate benefits that appear to be available in the very short term and stop at that point. Recalling the concept of the Coase externality introduced earlier, it is critical that all analyses fully address the implications of this type of externality along with the externality created when fishermen are competing for a common property resource. If either externality is ignored, the calculations of the level of marginal benefits and costs will be incorrectly determined and the result will be poor economics advice to fishery managers. Note that these basic economic principles were not fully considered in the case of shrimp and red snapper because the original bycatch reduction target was determined solely on biological and technical considerations. If it could be assumed that fishery managers, shrimpers and red snapper fishermen think in economically rational terms, the reduction target would not be determined in advance. Instead, the easiest, least-cost methods of reducing bycatch would be addressed first and it would be determined whether or not this first increment of bycatch reduction met the benefits equal costs criterion. Then, additional reductions in bycatch that could be achieved technically, but only with increasingly restrictive regulations on shrimping activity and concurrent increases in the cost of shrimping, would be adopted next if the increased benefits still exceeded the costs. It should be recognized that even if the first units of bycatch reduction are expected to increase marginal benefits to commercial and recreational red snapper fishermen, marginal benefits from successive increments of bycatch reduction would decline for several reasons. For example, each additional 10% reduction in bycatch probably would yield successively smaller additions to adult red snapper stocks due to the existence of other environmental factors that tend to limit stock growth. Additions to adult red snapper stocks also would probably yield successively smaller additions to profits of commercial fishermen as they increase their investments in fishing effort to harvest additional quantities, and would yield successively smaller additions in the level of consumer surplus associated with recreational fishing. For example, the first five fish caught per trip by recreational fishermen would yield more consumer surplus than the second five. Hence, as a general rule, the first increments of bycatch reduction would come at the lowest unit cost, while the first increment of benefits would be expected to be relatively high. Then, as additional increments of bycatch reduction are taken, the usual case will be for the next increment of costs to be higher while the next increment of benefits would usually be lower. Once again assuming that the first increment of bycatch reduction creates costs but also creates equal or higher benefits, then successive increments of bycatch reduction should be taken undertaken until the costs and benefits from the last incremental reduction in bycatch are equal.

6.4.4 Bycatch Utilization

Fishermen discard catch for a number of reasons. These include harvest of prohibited species, harvest of a species with no market value and harvest of fish that are the wrong size. There is a wide variation in the bycatch yield not only by region but also by season within specific areas. The volume and number of species comprising the bycatch in tropical fisheries are generally greater than found in more temperate regions. Many nations harvest shrimp and export it in exchange for hard currency that they in turn use to buy goods and services on the world market. In the past, with few exceptions, it has not proven to be economically feasible to retain bycatch which is generally much less valuable and would generally occupy storage space that could be used for shrimp. Regardless of these historical impediments that tend to make it unprofitable to retain and utilize bycatch, the realization of the magnitude of the bycatch and impact on the biological health of the stocks of those resources constituting bycatch has created a renewed emphasis on utilizing bycatch when it is not practicable to reduce bycatch.

Current NMFS policy indicates that the avoidance of bycatch is the preferred solution to the bycatch problem. In some or most cases, a portion or perhaps virtually all the bycatch from selected fisheries can be avoided through development of fishing gear, the introduction of management regimes that result in a reduction in overall fishing effort, the use of rights based management, or, in some cases, management regulations that limit fishing to times and places when the bycatch species are not so abundant. Since these alternatives cannot always be selected for a variety of reasons, there will undoubtedly be some instances whereby the bycatch issue cannot be resolved by avoiding the bycatch. Once the optimum level of bycatch avoidance has been achieved, a secondary question relates to the economic feasibility of retaining and utilizing the incidentally caught species versus discarding the incidentally caught species. Again referring to current NMFS policy and definitions, species that are caught incidentally while harvesting a target species but not sold or returned for personal use are considered as bycatch.

There appear to be only two workable alternatives available to deal with that portion of the bycatch which cannot be avoided. These include reducing the mortality of the species being discarded and using a greater spectrum of the species or sizes of species caught and discarded (Alverson et al., 1994). The Code of Conduct for Responsible Fisheries put forward by the FAO in 1995 also advocates a strategy for reducing the negative impact of bycatch. The Code includes:

1) emphasis on decreasing bycatch of stocks reduced below their optimum levels, and 2) better disposal of bycatch or utilization of bycatch for human consumption or other purposes benefiting people, especially if the stocks remain above optimal levels.

Many authors (Alverson, 1992a; Andrew and Pepperell, 1992; Gulland and Rothschild, 1984; Morrissey and Robles, 1992; Murawski, 1994; Saila, 1983; Thornburg, 1992) support the idea that the discard problem can be resolved, at least in part through broader use of the species being discarded. The solution to many world shrimp discard problems has focused on broader utilization of the discarded species (Barratt, 1986; Elsy, 1986; Herzberg and Shapira, 1978; ; Luna, 1981; Mocking and Machava, 1985; Musuishi, 1982; Peterson, 1982; Snell, 1978). Considerable attention to this approach has occurred in tropical ports of Asia, South America, North America (Mexico) (Blake and Bostock, 1991; Bung-Orn, 1982; Gordon, 1988, 1991; Gordon and Blake, 1991; Lemoine, 1982; Ordonez, 1985; Pauly and Neil, 1992; Suwanrangsi, 1986, 1988), and historically in the fisheries of Asia Most of these studies have met with some successes in specific areas under specific circumstances such as in day fisheries in developing nations. Following is a discussion of the methods that have been considered and some of the positive and negative aspects of each methodology.

6.4.4.1 Recovery, Handling, And Preservation Aboard Vessels

Recovery, handling, and preservation aboard vessels are the most critical aspects of the bycatch problem when one considers the potential for utilizing the resource for human use. The sheer volume of the bycatch, species variability, low value of most of the bycatch and the marketability of the bycatch fish combine to make collection at sea generally unprofitable. Until these problems are resolved, there will be no incentive for commercial recovery of the fish available constituting the bycatch. Recovery is only part of the process and the fish must be kept in a suitable condition for processing onboard the catcher vessel or for delivery ashore. Although a variety of high value products have been developed from bycatch species, commercial practicality of using the resource also depends on the cost of production, including efficient recovery at sea. According to Allsopp (1982), there are three options for handling the bycatch. These are as follows: 1) presorting of the fish and shrimp during harvesting by means of a separator trawl or excluder trawl; 2) total collection of the catch with sorting done aboard the trawler for stowage or transfer at sea to collector vessels; and 3) partial processing of selected fish of the bycatch at sea. Total processing of the bycatch at sea could be added to the list as a fourth option.

Over the past thirty years a number of excluder or separator trawls have been developed. However, the industry has been slow to adopt the use of this gear because of the shrimp loss associated with this gear. In recent years, in response to the need to comply with the Endangered Species Act and the need to reduce bycatch of fishes, the development of separator or excluder trawls has been advanced at a rapid rate. Currently there are several bycatch separator or excluder devices available to the shrimp fleet. Since these devices indeed avoid a substantial portion of the bycatch, the application of this gear should significantly reduce the bulk of fish harvested and the workload of the crew. However, the efficiency of these devices appears to be such that many of the desirable species of marketable size are separated or excluded and the remaining bycatch will be composed largely of small fish with low market value. Thus, the use of separator or excluder

trawls may be counterproductive in our quest for utilization of the bycatch, particularly for harvest of larger fish to be delivered to the usual markets.

The second two choices are applicable to areas where the fish/shrimp ratio is particularly high and it is impractical to stow on board even the large marketable species of the harvest. Both of these options require additional crew so that the harvesting of shrimp can continue unhindered. Motion and time studies on the quantities of catch, sorting, and stowage aboard vessels in Mexico indicated that, in most cases, the cold-storage space on the trawlers operating in the shrimp fishery was adequate and time available was sufficient for the crew to sort and stow the fish in the hold. However, without additional crew, time was not available to gut all the fish, a procedure necessary to insure a quality product for the market. In other shrimp fisheries such as in Thailand, fish are recovered during the last days of the trips to sea, thus filling any available fish hole space. These species are generally selected for their high market value. In Sri Lanka where they have a day fishery, the shrimp are sorted on board and the bycatch is held in a net and towed ashore and then sorted. In other areas, the fish are transferred at sea to a freight boat or a processor vessel. To date, these methods have not proved to be viable for a variety of reasons including the seasonality of the catch, the volume and composition of the bycatch, and the economics of these type operations.

The fourth option of total processing of the bycatch at sea is one that has been considered in the past, but generally has failed because of the space and storage capacity of the typical shrimp vessel. In recent years with the construction of larger shrimp vessels, it is possible to adopt gear and processing techniques that are being tried in the other fisheries (Ostervold, 1998) to produce a stabilized silage slurry. Once the fish oil and most of the water is removed, the resulting pulp has proved to be about 30% protein. The final product has been used as a protein additive to animal feeds to increase their nutritional value.

Incentives that will motivate the shrimp industry to recover and handle the bycatch need to be studied. The first step, however, is a realistic assessment of the operational costs for utilizing the bycatch. The recovery of those costs plus some incentive may prove attractive. To address this problem, one must recover the bycatch. In many places, this is being done already or is being considered.

A concern of captains and owners appears to be that the valuable shrimp catch could be spoiled by rising temperatures in their fish holds provoked by the bulk storage of fish. One way to alleviate this concern is to rationalize the current fleet into vessels specifically for shrimp or fish. Other means are to separate the shrimp and fish in stowage, or reduce the bulk of the fish by partial processing such as mincing. The costs of operating collector vessels, and of refrigerating or icing the bulk of the fish, make use of collecting systems impractical in many places because the market value of the bycatch is low.

Mechanical separation of fish from shrimp and partial processing of fish to reduce bulk and convert them to mince, silage, etc., would permit stowage aboard the vessels in current use. The replacement of old vessels with those of new design, with larger hold capacity, would also alleviate handling and recovery problems. A combination of such solutions will probably be the most

appropriate approach for different fisheries. No standard design for vessels is likely to be applicable worldwide because of the problems peculiar to each region.

6.4.4.2 Processing On Shore

Industrial research in the field of fish processing and product development has resulted in many innovative methods and formulations using fish as an ingredient for human food. It is essential to take into account various food habits in regions where bycatch is available and to select suitable and profitable processing techniques on the basis of market information. Differences in the nature of bycatch in different regions may also dictate the types of process required. For example, in regions where bycatch comprises many commercial fish, ways of extending traditional processing schemes to include bycatch should be sought. Where the bycatch is predominately small, non-commercial fish, less-conventional techniques that yield new products or simulate existing items are normally required.

Minced, deboned fish muscle is the basic, most versatile and easily produced material from small species in the bycatch. However, efficient evisceration and deboning of small fish are major problems. Gutting fish by hand produces appreciable quantities of waste and is time consuming. Further development work on equipment design is essential.

Acceptability tests have shown that minced products developed from bycatch are well received by people in several regions. Efforts to promote the production of these products warrant further investigation and promotion. Areas to be considered should include: 1) improvements in the texture of minced products; 2) the design of improved and less expensive equipment for bycatch processing, particularly efficient evisceration and deboning machinery for small fish species; 3) the possibilities of simulating more of the products currently on the market; 4) comprehensive evaluation of the flesh characteristics, including biochemical and functional properties, of bycatch fish harvested in different regions; 5) development of techniques for manufacturing acceptable infant foods incorporating minced fish; 6) development of techniques for use of fatty fish as minces and products for direct consumption; and 7) more detailed consideration of the economics of processing and marketing the bycatch products.

6.4.4.3 Actual And Potential Markets

One way to view the markets for bycatch species is to segregate them into markets that do not require subsidy versus markets that cannot operate in the absence of subsidies. Private competitive markets can be sustained without subsidy if the consumers have sufficient income to purchase the bycatch species or products made from the species and if their individual demand for the products of bycatch are sufficiently large. Markets that require subsidies could exist if the social benefits derived from feeding a population are thought to exceed the cost of the required subsidies. If these notions of different types of markets are to be addressed, it is essential to obtain profiles of the consumers within both types of markets in different regions. Further, these profiles should incorporate information on food habits so that they can serve as the basis for development, packaging, cost characteristics, and distribution techniques for products from the bycatch.

A number of marketable products have already been formulated at the laboratory, pilot and industrial production scales. These products can be classed as food (for direct consumption), livestock feeds, and industrial by products. Processed forms that are a mix of traditional products and that can be readily incorporated into customary food preparation, as well as small amounts of new, convenience products are especially promising. For a profitable mix in industrial manufacture of fish products, it is desirable to introduce higher-cost specialty products intended for high-income urban populations. The processed byproducts from deboning machines and trimmings from traditional processes have been made into fishmeal and bone meal for livestock feeds, as well as fertilizers. Less capital-intensive processes such as the production of fish silage have also been well promoted in Asia for small-scale livestock-meal preparation. It appears that increasing local demand for such feeds can be satisfied by the residues form food processing, even though this source would not be competitive in international fishmeal markets.

Other products from bycatch species for which markets are growing include specialty items such as small cocktail shrimp, for mixtures of species to make soups and for smoked and pickled products of lesser-known seafood.

Maintaining standard quality, strict hygiene, and attractive presentation for all new products is essential, but not sufficient, to ensure good market acceptance. According to Allsopp (1982), there are a number of steps required before new products are launched into the market. These include: 1) acceptability studies for urban and rural consumers; 2) product promotion through the media; and 3) product demonstrations that show the value of the product to the consumer. At present, lack of adequate market infrastructures and of marketing expertise is inhibiting progress in many regions. Thus, there is a need to improve and intensify market studies for both the privately sustained markets as well as the subsidized markets.

6.4.4.4 Economic Aspects

The major obstacle to the utilization of bycatch for human needs continues to be the profitability of the operation, both for individual boats that furnish their catch to processing plants and for totally integrated activities involving a fleet, processing, and marketing operations. Therefore, assessment of the potential and actual quantities of bycatch available as well as the methods of handling and processing has to be known if one is to determine procedures that will make operations profitable. It is clear that suitable techniques for recovery and processing will become established industrially only when they are proven to be profitable or when some entity is willing to subsidize the operations.

To achieve economically viable use of bycatch, processors must pay prices to shrimpers that are sufficiently high for landing the raw material and delivering it to shore. The processors must also manufacture acceptable products at a competitive price. These requirements may conflict in some regions, and government intervention, such as legislation and initial price subsidies, may be necessary to facilitate bycatch utilization. This is the case in the Gulf of Mexico where there are conflicting regulations regarding bycatch and where a substantial effort is underway to reduce bycatch and its impact on the red snapper and mackerel fisheries. Although one outcome of the

bycatch reduction effort may be to reduce the number of marketable food fish available in the bycatch, the general outcome will be that bycatch not avoided will consist largely of small fish. These would only be suitable for reduction into fishmeal or silage, and such products tend to command low prices; hence, it is questionable whether there is an economically viable process for utilizing that portion of the bycatch which cannot be avoided.

Nevertheless, the potential economic feasibility of processing bycatch into human food is attested to by the growing interest on the part of private sector investors (Ostervold, 1998). Allsopp (1982) summarized a number of actions that were necessary to evaluate the economic feasibility of bycatch utilization. They are as follows: 1) comparison of operational costs of boats and bycatch recovery systems in different areas under actual working conditions of shrimp vessels to determine the costs and benefits of processing different by catch species and mixtures for specific target markets; 2) more detailed consideration of the socioeconomic aspects of bycatch utilization; 3) further examination of the energy requirements for bycatch recovery and processing systems; 4) development of viable institutional schemes to distribute foods in markets that need to be subsidized; and 5) implementation of a broad scope of action to include financing, investment, and market analysis as well as technical assistance and industrial training of personnel for processing plants.

6.4.4.5 National And Regional Development

Activities on bycatch utilization are progressing in diverse regions of the world. Much of that activity is taking place in the Gulf of Mexico and Latin American countries. Some countries have established forms of industrial exploitation of bycatch, whereas others have not yet developed viable solutions. A few countries have established centers for research and development studies on bycatch for their regions. Practical recovery of bycatch appears to be more problematic in some countries that in others because of the complexity of the organization of the shrimping industry.

There is urgent need for cooperation and a much wider exchange of information on experiences for the different regions. Furthermore, regions and international organizations with expertise in the field should increase their training input to countries requiring assistance.

6.4.4.6 Conclusions And Recommendations

It is believed that economics and profitability are the major constraints to use of bycatch. The single most important constraint is the lack of methods to bring the catch to shore at a cost compatible with market end use. Further, the training of personnel in appropriate methods in harvesting and processing is much needed. Thus, education and training are essential to successful utilization of bycatch. Throughout the literature there has been a call for various activities to occur that are deemed necessary for the full utilization of bycatch to occur. These requests include such activities as development of methods to harvest and handle the bycatch, data collection on the bycatch, product development, profitability and market studies of the products developed, training and education regarding utilization of the bycatch, and new equipment development for handling and processing bycatch. Finally, the environmental impact of removing

large quantities of bycatch from the natural environment must be investigated to determine long term impacts of the environment to support these exploited populations.

7.0 PROGRAM CONCLUSIONS

The NMFS and others have determined that a number of finfish resources in the Gulf of Mexico and south Atlantic are depleted for several reasons, including the application of too much fishing effort by commercial and recreational fishermen and the incidental bycatch of the shrimp trawl fleet. The ensuing debate about how best to restore the stocks to desirable levels involves numerous technological, political, biological and economic factors. Among them are: 1) technological interaction in which shrimping gear inadvertently harvests finfish; 2) management interaction between the Shrimp and other FMPs governing the harvest of finfish species; 3) competition between commercial and recreational fishermen and among fishermen with different gear types within each group; 4) economic trade-offs over time among various harvesting groups and between different groups of consumers; 5) the current uncertainty regarding whether or not the commercial management structure will allow for an ITQ or similar management system; 6) a lack of current biological information to determine the desirable size of some of the finfish stocks and future yields; and 7) whether or not effort controls will be placed on the recreational fishery. For all these reasons, the interaction between the shrimp and finfish fisheries of the U.S. Gulf of Mexico constitutes a management and economics problem that is controversial, challenging, and, as yet, unresolved in the case of most southeast finfish stocks.

LITERATURE CITED

Allsopp, W. H. L. 1982. Introduction and Summary, pp. 7-19. In: Fish Bycatch; A Bonus From the Sea. Report of a Technical Consultation on Shrimp Bycatch Utilization held in Georgetown, Guyana, 27-30 October 1981. Jointly sponsored by: The Food and Agriculture Organization of the United Nations and International Development Research Centre, 163 p.

Alverson, D. L. 1992. An industry perspective on addressing the bycatch problem, pp. 191-196. In: R. W., R. W. Jacobson, D. L. Alverson, T. G. Gentle, and J. Auyong (eds.). Proceedings of the National Industry Bycatch Workshop, February 4-6, 1992, Newport, Oregon.. Natural Resources Consultants, Inc., Seattle, Washington, 485 p.

Alverson, D. L., M. H. Freeberg, S. A. Murawski, and J. G. Pope. 1994. A global assessment of fisheries bycatch and discards. FAO Technical Series Paper, No. 339. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy, 233 p.

Andrew, N. L. and J. G. Pepperell. 1992. The by-catch of shrimp trawl fisheries, pp. 527-565. In: M. Barnes, A. D. Ansell, and R. N. Gibson (eds.). Oceanography and Marine Biology Annual Review, 30, UCL Press, United Kingdom, 698 p.

Barratt, F. 1986. A study on the feasibility of utilizing prawn bycatch for human consumption. FAO FI RAS/85/004. UN/FAO, South Pacific Fisheries Development Programme, Rome, Italy, 23 p.

Blake, D. and T. Bostock. 1991. Shrimp bycatch: a problem in the Bay that has as yet found no viable solution. Bay of Bengal News. Issue No. 44. Bay of Bengal Programme, pp. 5-11.

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

Browder, J. 1983. A simulation model of a near-shore marine ecosystem of the north central Gulf of Mexico, pp. 179-222. In: Turgeon, K.W. (ed.), Marine Ecosystem Modeling. NOAA/National Environmental Satellite, Data and Information Service, Washington, D.C., 375 p.

Bung-Orn, S. 1982. Thailand, pp. 143-146. In: Fish Bycatch; A Bonus From the Sea. Report of a Technical Consultation on Shrimp Bycatch Utilization held in Georgetown, Guyana, 27-30 October 1981. Jointly sponsored by: The Food and Agriculture Organization of the United Nations and International Development Research Centre, 163 p.

Burrage, D. D., S. G. Branstetter, G. Graham, and R. K. Wallace. 1997. Development and implementation of fisheries bycatch monitoring programs in the Gulf of Mexico. Information Bulletin 324, Mississippi Agricultural and Forestry Experiment Station, Mississippi State University, MS, 103 p.

Coase, N. 1960. The problem of social cost. Journal of Law and Economics, 3:1-44.

Condrey, R. and J. de Silva. 1997. Bycatch in the U.S. Gulf of Mexico menhaden fishery. Results of onboard sampling conducted in the 1994 and 1995 fishing seasons. Executive Summary. MARFIN Project NA47FF0020, 9 p.

Divita, R., M. Creel and P. F. Sheridan. 1983. Foods of coastal fishes during brown shrimp, *Penaeus aztecus***, migration from Texas estuaries (June-July 1981). Fishery Bulletin 81: 396-404.**

Easley, J. C., Jr., W. N. Thurman, and H. J. Park. 1996. The South Atlantic snapper-grouper complex: demand estimation for individual species and the composite species complex. MARFIN Project NA47FF0009, 64 p.

Elsy, R. 1986. Marketing and development options for shrimp bycatch products in Bangladesh. FAO FI BGD/80/025, 623 p.

Gibson, M. R. 1994. Alternative estimates of weakfish bycatch in shrimp trawl fisheries in the South Atlantic using shrimp effort and relative weakfish abundance data. Report to ASMFC Weakfish Technical Committee, 18 p.

Goodyear, C. P. 1995. Red snappers in U.S. waters of the Gulf of Mexico. National Marine Fisheries Service, Southeast Fisheries Science Center, Miami Laboratory, Miami, FL. Laboratory Report, Contribution # MIA 95/96-05, 75 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.

Gordon, A. 1988. Discard of shrimp bycatch at-sea. How serious is this waste of resources? What can be done about it? Bay of Bengal News, Issue No. 32: 9-11.

Gordon, A. 1991. The bycatch from Indian shrimp trawlers in the Bay of Bengal: the potential for its improved utilization. Bay of Bengal Project, Natural Resources Institute, Overseas Development Administration, Madras, India. Techn. Rpt.# 244, 68 p.

Gordon, A. and B. Blake. 1991. Utilization of shrimp bycatch: report on a visit to India. Bay of Bengal Project, Natural Resources Institute, Overseas Development Administration, Madras, India. Techn. Rpt.# 73, 31 p.

Greene, G., C.B. Moss, and E.M. Thunberg. 1994. Estimation of recreational anglers' value of reef fish in the Gulf of Mexico. Final report prepared for the NMFS-SERO, St. Petersburg, FL, 84 p.

Gulland, J. A. and B. J. Rothschild (eds.). 1984. Penaeid Shrimps: Their Biology and Management. Fishing News Books, Ltd., Farnham, England, 308 p.

Hendrickson, H. M., and W. L. Griffin. 1993. An analysis of management policies for reducing shrimp bycatch in the Gulf of Mexico. North American Journal of Fisheries Management, 13:686-697.

Herzberg, A. and N. Shapira. 1978. Development prospects for less attractive species of fish: and ecological approach, pp. 488-491. In: Proceeding of the symposium on Fish Utilization Technology and Marketing in the IPFC Region, Manila, Philippines, March 8-11, 1978, 38 p.

Hoagland, P., D. Jin, P. Lee, C. Croft, L. Davidsion, and S. Wallis. 1996. Market-Based Incentives to Reduce Fisheries Bycatch. NOAA Contract No. 50-DGNF-5-00172, National Marine Fisheries Service, Silver Spring, MD, 120 pp.

Hoar, P., J. Hoey, J. Nance, and C. Nelson. 1992. A research plan addressing finfish bycatch in the Gulf of Mexico and South Atlantic shrimp fisheries. Gulf and South Atlantic Fisheries Development Foundation, Inc. Tampa, FL, 114 p.

Holiman, S. G. 1997. Summary Data for the Gulf of Mexico Reef Fish Fishery, 1982-1996. Prepared for the Gulf of Mexico Fishery Management Council Reef Fish Fishery Socioeconomic Panel Meeting on October 10, 1997, 185 pp.

Holiman, S. G., 1998. Impacts of alternative management scenarios on the Gulf of Mexico red snapper recreational fishery. SERO-ECON-98-12, 25 pp.

Keithly, W. R., K. J. Roberts, and J. M. Ward. 1993. Effects of Shrimp Aquaculture on the U.S. Market: An Econometric Analysis, 64-87 pp. In: U. Hatch and H. Kinnucan (eds.). Aquaculture, Models and Economics. Westview Press, Boulder, Colorado, 198 p.

Lemoine, M. 1982. French Guiana, pp. 128-129. In: Fish Bycatch; A Bonus From the Sea. Report of a Technical Consultation on Shrimp Bycatch Utilization held in Georgetown, Guyana, 27-30 October 1981. Jointly sponsored by: The Food and Agriculture Organization of the United Nations and International Development Research Centre, 163 p.

Luna, J. 1981. Advances in unconventional fish foods. ICLARM Newsletter 4 (1):85-86, 88.

Manooch, C. S., and M. Haimovici. 1983. Foods of greater amberjack, *Seriola dumerili***, and almaco jack,** *Seriola rivolana* **(Pisces:Carangidae), from the south Atlantic Bight. J. Elisha Mitchell Sci. Soc., 99: 1-9.**

Manooch, C. S., and W. T. Hogarth. 1983. Stomach contents and giant trematodes from wahoo, *Acanthocybium solanderi*, **collected along the south Atlantic and Gulf coasts of the United States. Bulletin of Marine Science 33: 227-238.**

Manooch, C. S., D. L. Mason, and R. S. Nelson. 1983. Food and gastrointestinal parasites of dolphin, *Coryphaena hippurus*, **collected along the southeastern and Gulf coasts of the United States. NOAA Technical Memorandum, NMFS-SEFC-124, 36 p.**

Mercer, L. P. 1985. Fishery Management Plan for Weakfish. ASMFC, Fish. Manage. Rep. 7, 129 p.

Minello, T. J., R. J. Zimmerman, and E. X. Martinez. 1989. Mortality of young brown shrimp *Penaeus aztecus* **in estuarine nurseries. Trans. Am. Fish. Soc. 118: 693-708.**

Mocking, G. and A. Machava. 1985. Storage life on ice of the bycatch from the shrimp fishery, pp. 74-80. In: Proceeding of Fish Processing in Africa, Expert Consultation on Fish Technology in Africa, Busaka, Zambia, January 21-25, 1985. UN/FAO, Rome, Italy. FIIU/R329, 126 p.

Morrissey, M. and A. Robles. 1992. Post-harvest fisheries losses in Mexico with a case study of shrimp bycatch, pp. 86-94. In: Proceedings of the World Fisheries Congress, May 3-8, 1992, Athens, Greece, 569 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.**

Muoneke, M. I., and W. M. Childress. 1994. Hooking mortality: A review for recreational fisheries. Reviews in Fisheries Science 2(2):123-156.

Murawski, S. A. 1994. Opportunities in bycatch mitigation, pp. 23-36. In: R. Stroud (ed.). Conserving U.S. Fisheries: A National Symposium on the Magnuson Act. National Coalition for Marine Conservation, Savannah, Georgia, 284 p.

Musuishi, I. 1982. Economic profiles for three (minced fish) products made from by catch (in Panama), pp. 118-119. In: Fish Bycatch; A Bonus From the Sea. Report of a Technical Consultation on Shrimp Bycatch Utilization held in Georgetown, Guyana, 27-30 October 1981. Jointly sponsored by: The Food and Agriculture Organization of the United Nations and International Development Research Centre, 163 p.

Nance, J. M., 1994. Estimation of effort for the Gulf of Mexico shrimp fishery. NOAA Technical Memorandum, NMFS-SEFC-300, 12 p.

Naughton, S. P., and C. H. Salomon. 1981. Stomach contents of juveniles of King mackerel (*Scomberomorus cavalla*) and Spanish mackerel (*S. maculatus*). NE Gulf Science 5: 71-74.

Nichols, S., A. Shah, G. J. Pellegrin, and K. Mullin. 1990. Updated estimates of shrimp fleet bycatch in the offshore waters of the US Gulf of Mexico. NMFS Mississippi Laboratory, Pascagoula, MS, 22 p.

NMFS. 1991. Shrimp trawl bycatch research requirements. National Marine Fisheries Service, Southeast Fisheries Science Center, Miami, FL and Southeast Regional Office, Miami, FL, 66 p.

NMFS. 1992a. Shrimp trawl bycatch characterization. Sampling protocol manual for data collection. NMFS Galveston Laboratory, Galveston TX, 62 p.

NMFS. 1992b. Evaluation of bycatch reduction devices. Sampling protocol manual for data collection. NMFS Galveston Laboratory, Galveston TX, 62 p.

Ordonez, J. 1985. A study of the trash fish caught by otter trawl in the Visayan Sea. Phil. J. Fish. 18:1-76.

Ostervold, O. K. 1998. Waste Not, Want Not. Seafood Leader, Jan/Feb 1998: 32-33.

Palafox, S. D. and E. D. Wolford. 1993. Non-fishing / human induced mortality of fisheries resources in Galveston Bay. The Galveston Bay National Estuary Program, Publication GBNEP-26, 305 p.

Pauly, D. and R. Neil. 1985. Shrimp vs. fish in Southeast Asian fisheries: the biological, technological and social problems, pp. 487-510. In: Yanez-Arancibia, A. (eds.). Recursos Pesqueros Potenciales de Mexico: La Pesca Acompanante del Camaron. Progr. Univ. de Alimentos, Inst. Cienc. Del Mar y Limnol., Inst. Nac. De Pesca, UNAM, Mexico, 793 p.

Peterson, T. E. 1982. The Guyana project: industrial us of (fish) bycatch, pp. 69-76. In: Fish Bycatch; A Bonus From the Sea. Report of a Technical Consultation on Shrimp Bycatch Utilization held in Georgetown, Guyana, 27-30 October 1981. Jointly sponsored by: The Food and Agriculture Organization of the United Nations and International Development Research Centre, 163 p.

Peuser, R. (ed.). 1996. Estimates of finfish bycatch in the south Atlantic shrimp fishery. Final Report From the Southeast Area Monitoring and Assessment Program (SEAMAP), SEAMAP-South Atlantic Committee, Shrimp Bycatch Work Group. Atlantic States Marine Fisheries Commission, 64p.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish population. Bull. Fish. Res. Bd. Can. 191, 328 p.

Rulifson, R. A., J. D. Murray, and J. J. Bahen. 1992. Finfish catch reduction in south Atlantic shrimp trawls using three designs of by-catch reduction devices. Fisheries 17: 9-20.

Saila, S. 1983. Importance and assessment of discards in commercial fisheries. UN/FAO, Rome, Italy. FAO Cir. 765, 62 p.

Salomon, C. H., and S. P. Naughton. 1983a. Food of King mackerel, *Scomberomorus cavalla*, **from the southeastern United States, including the Gulf of Mexico. NOAA Technical Memorandum, NMFS-SEFC-126, 25p.**

Salomon, C. H., and S. P. Naughton. 1983b. Food of Spanish mackerel, *Scomberomorus maculatus*, **from the Gulf of Mexico and southeastern seaboard of the United States. NOAA Technical Memorandum, NMFS-SEFC-128, 22 p.**

Seagraves, R. J. 1992. Weakfish Fishery Management Plan Amendment #1. ASMFC, Fish. Manage. Rep. 20, 68 p.

Sheridan, P. F., and D. L. Trimm. 1983. Summer foods of Texas coastal fishes relative to age and habitat. Fishery Bulletin 81: 643-647.

Sheridan P. F., J. A. Browder, and J. E. Powers, 1984a. Ecological interactions between penaeid shrimp and bottomfish assemblages, pp. 235-254. In: Gulland, J. A. and B. J. Rothschild (eds.), Penaeid Shrimps: Their Biology and Management. Fishing News Books, Ltd., Farnham, England, 308 p.

Sheridan, P. F., D. L. Trimm, and B. M. Baker, 1984b. Reproduction and food habits of seven species of northern Gulf of Mexico fishes. Contr. Mar. Sci. 27: 175-204.

Snell, P. 1978. The production of fish balls and fish cakes in Sabah and the possible use of trawler bycatch for such products, pp. 581-600. In: Proceedings of the Symposium on Fish Utilization Technology and Marketing in the IPFC Region, Manila, Philippines, 8-11 March, 1978. UN/FAO, Rome, Italy, 932 p.

SAFMC. 1996. Amendment 2 to the Fishery Management Plan for the Shrimp Fishery of the South Atlantic Region. South Atlantic Fishery Management Council, Charleston, SC, 101 p.

SAFMC. 1997. Bycatch reduction device testing protocol manual. South Atlantic Fishery Management Council, Charleston, SC, 34 p.

Suwanrangsi, S. 1986. Improved bycatch utilization in Thailand, pp. 467-469. In: Proceedings of the first Asian Fisheries Forum, 827 p.

Suwanrangsi, S. 1988. By-catch utilization in Thailand. INFOFISH Int. 5/88:40-42.

Thomas, J. S., G. D. Johnson, C. M. Formichella, and C. Riordan. 1993. Perceived social and economic effects of current management policies on red snapper fishermen operating in the Gulf of Mexico: a report to the Gulf of Mexico Fishery Management Council, 49 p.

Thomas, J. S., C. M. Formichella, G. D. Johnson, and C. Riordan. 1995. Shrimp fishermen on the eve of bycatch regulations: a report to the Gulf of Mexico Fishery Management Council, MARFIN Final Report Number NA37FF0049, 32 p.

Thornburg, G. N. 1992. Solutions from industry, pp. 202-204. In: R. W. Schoning, R. W. Jacobson, D. L. Alverson, T. G. Gentle, and Jan Auyong (eds.). Proceedings of the National Industry Bycatch Workshop, February 4-6, 1992, Newport, Oregon. Natural Resources Consultants, Inc., Seattle, Washington, 483 p.

Vaughan, D. S., R. J. Seagraves, and K. West. 1991. An assessment of the status of the Atlantic weakfish stock, 1982-1988. ASMFC, Spec. Rep. No. 21, 77 p.

Vaughan, D. S. and J. M. Nance. 1998. Estimates of bycatch of mackerel and cobia in U.S. south Atlantic shrimp trawls. NMFS Report to the Gulf of Mexico and South Atlantic Fishery Management Councils, 25 p.

Ward, J. M. 1994. The bioeconomic implications of a bycatch reduction device as a stock conservation management measure. Marine Resource Economics, 9(3):227-240.

Ward, J. M., and S. Macinko. 1996. Static and dynamic implications of a gear modification designed to reduce bycatch in a stylized fishery. The Southern Business and Economic Journal, 19(4):273-292.

Ward, J. M., and J. G. Sutinen. 1994. Vessel entry-exit behavior in the Gulf of Mexico shrimp fishery. American Journal of Agricultural Economics, 76(4):916-923.

Ward, J. M., T. Ozuna, and W. L. Griffin. 1995. Cost and revenues in the Gulf of Mexico shrimp fishery. NOAA Technical Memorandum NMFS-SEFSC-371, 76 p.

Waters, J. R. 1995. Economic assessment of the commercial reef fishery in the U.S. Gulf of Mexico. SERO/NMFS, 27 p.

Waters, J. R. 1996. An economic survey of commercial reef fish vessels in the U.S. Gulf of Mexico. SERO/NMFS, 73 p.

Waters, J. R. 1997. Economic assessment of the commercial reef fishery in the U.S. Gulf of Mexico. SERO/NMFS, 62 p.

Watson, J. W., A. Shah, and D. Foster. 1997a. Report on the status of bycatch reduction device (BRD) development. NMFS Mississippi Laboratory, Pascagoula, MS, 94 p.

Watson, J. W., A. Shah, S. Nichols, and D. Foster. 1997b. Bycatch reduction estimates for selected species in the Gulf of Mexico for bycatch reduction devices evaluated under the regional bycatch program. NMFS Mississippi Laboratory, Pascagoula, MS, 110 p.

Appendix I: List of Publications From Shrimp Fishery Bycatch Research

PUBLICATIONS

Adkins, G. 1993. A comprehensive assessment of bycatch in the Louisiana shrimp fishery. Tech. Bull. No. 42, Louisiana Dept. Wildlife and Fisheries, Marine Fisheries Div., Baton Rouge, LA 70343

Albert, O.T. and O.A. Bergstad. 1993. Temporal and spatial variation in the species composition of trawl samples. Journal of Fish Biology, 43: 209-222.

Alverson, D.L., M.H. Freeberg and S. Murawaski. 1994. A global assessment of fisheries bycatch and discards. FAO Fisheries Technical Paper No. 339. 233 p.

Anonymous. 1995. Twenty percent of the world fisheries catch is discarded. NAGA, The ICLARM Quarterly 1995: 23-24.

Bahen, J.J., J.D. Murray, and R.A. Rulifson. 1993. Development and evaluation of finfish separator device and TED combination to reduce bycatch in the shrimp fishery. Final Report (Award NA17FD0101). University of North Carolina, Sea Grant Program, Box 8605, North Carolina State University, Raleigh, NC 27695.

Baltz, D.M. 1993. Patterns in the distribution and abundance of fishes and macroinvertebrates in a Louisiana marsh: shrimp bycatch in the inshore, fishery-independent trawl samples. MARFIN Final Report (Award NA17FF0263-01). Louisiana State University, Coastal Fisheries Institute, Baton Rouge, LA 70803.

Baltz, D.M. and E.J. Chesney. 1996. Spatial and temporal patterns in the distribution and abundance of fishes and macroinvertebrates in coastal Louisiana: Shrimp bycatch species in fishery-independent trawl samples. Louisiana State University, Coastal Fisheries Institute, Baton Rouge, LA 70803.

Berry, R.J. and J.B. Harvey. 1964. Mesh Selectivity Studies. U.S. Department of Interior, U.S. Fish & Wildlife Service, Bureau of Commercial Fisheries Biological Laboratory, Galveston.

Boehlert, G.W. 1996. Biodiversity and the sustainability of marine fisheries. Oceanography, 9: 28-35.

Boylan, J.M., R.P. Webster, H.R. Beatty, and E.L. Wenner. 1990. Results of trawling efforts in the coastal habitat of the South Atlantic Bight. SEAMAP-SA Final Report, FY-1990. Marine Resources Research Division, South Carolina Wildlife and Marine Resources Dept., P.O. Box 12559, Charleston, SC 29412.

Browder, J.A. 1992. An application of the ecosystem approach to fishery management research in the Gulf of Mexico. In, Proceedings of the shrimp trawl bycatch workshop, November 22-23, 1991, St. Petersburg, FL. Center for Marine Conservation, Washington, DC. pp. 8-20.

Browder, J.A. 1983. A simulation model of a near-shore marine ecosystem of the north-central Gulf of Mexico. In: Turgeon, K. W. (ed.), Marine Ecosystem Modeling - Proceedings from a workshop held April 6-8, 1982, Frederick, MD. NOAA, Washington, DC. pp. 179-222.

Bryan, C.E., T. Cody and G.C. Matlock. 1982. Organisms captured by the commercial shrimp fleet. Texas Parks & Wildlife Department.

Burgess, G.H., and D.B. Snyder. 1993. Fish bycatch from inshore shrimp fisheries in Florida. In, Proceedings of the International Conference on Shrimp Bycatch, May 24-27, 1992, Lake Buena Vista, Florida. Southeastern Fisheries Association, Tallahassee, FL. pp. 83-84.

Cabot, C. 1996. Shrimp and sea turtles in the Gulf of Mexico: an economic analysis of the effects of turtle excluder devices on the shrimp fishery and the benefits of protecting sea turtles. Northwestern University. Undergraduate Thesis.

Caillouet, C. and J. Nance. 1994. Relationship between sea turtle strandings and shrimp fishing effort in the Northwestern Gulf of Mexico: 1986-1989 versus 1990-1993. Unpublished report (manuscript draft): 40 p.

Carter, N. and B. Colura. 1996. Comparison of survival of bycatch associated with bait shrimping in three Texas estuarine areas. Texas Parks & Wildlife Department.

Casteel, P. 1991. Bycatch - a matter of opinion. Texas Shores, 23(3): 33 pp. Texas A&M Sea Grant, Texas A&M University, College Station, TX 77843.

Castro, K., T Corey, J. DeAlteris and C. Gagnon (eds.). 1996. Proceedings of the East Coast Bycatch Conference, April 7-8, 1995, Newport, RI. Rhode Island Sea Grant, University of Rhode Island Bay Campus, Narragansett, RI. December 1996.

Chittenden, M.E., Jr., and J.D. McEachran. 1976. Composition, ecology and dynamics of demersal fish communities on the northwestern Gulf of Mexico continental shelf, with a similar synopsis for the entire Gulf. Final Report to Texas Sea Grant (TAMU-SG-76-208). Texas A&M University, College Station, TX 77843.

Chopin, F.S. and T. Arimoto. 1995. The condition of fish escaping from fishing gears - a review. Fisheries Research, 21: 315-327.

Christian, P.A. and D.L. Harrington. 1987. Loggerhead turtle, finfish, and shrimp retention studies on four turtle excluder devices (TEDs). In: Proceedings of the nongame and endangered wildlife symposium. September 8-10, Georgia Dept. of Natural Resources, Social Circle, GA. pp. 114-127.

Christian, P.A., D.L. Harrington, D.R. Amos, R.G. Overman, L.G. Parker, and J.B. Rivers. 1993. The reduction of finfish capture in South Atlantic shrimp trawls. Final report, Saltonstall-Kennedy Grant Program (Award NA27FD0070).

Clark, J., W. Griffin, J. Clark, and J. Richardson. 1991. Simulated Economic Impact of TED Regulations on Selected Vessels in the Texas Shrimp Fishery. Marine Fisheries Review, 53(2): 1-8.

Coale, J.S. 1992. Changes in bycatch using skimmer trawl in the North Carolina shrimp fishery. M.S. Thesis, East Carolina University, Dept. of Biology, Greeneville, NC 27858.

Coale, J.S., R.A. Rulifson, J.D. Murray, and R. Hines. 1994. Comparisons of shrimp catch and bycatch between a skimmer trawl and an otter trawl in the North Carolina inshore shrimp fishery. North American Journal of Fisheries Management, 14: 751-768.

Coleman, E. 1995. Shrimpers in crisis. Coast & Sea, 4: 4-6. Louisiana Sea Grant.

Coleman, E. 1995. Commercial shrimpers - living with change. Coast & Sea, 4: 7-9. Louisiana Sea Grant.

Coleman, E. 1996. A stitch in time...reducing bycatch now. Coast & Sea : 4-8. Louisiana Sea Grant.

Coleman, F.C., C.C. Koenig and W.F. Herrnkind. 1992. Survey of Florida inshore trawling by-catch and preliminary tests of by-catch reduction devices. Florida State University, Department of Biological Sciences.

Colura, R.L. and B.W. Bumguardner. 1996. The Texas shrimp industry salt-box catch separation procedure effect on bycatch survival. Texas Parks & Wildlife Dept., Perry R. Bass Marine Fisheries Research Station, Palacios, TX 77465.

Cook, D. 1993. A South Atlantic shrimp captain's perspective. In, Proceedings of the International Conference on Shrimp Bycatch, May 24-27, 1992, Lake Buena Vista, Florida. Southeastern Fisheries Association, Tallahassee, FL. pp. 57-60.

Croft, C. 1996. Approaches to reduce bycatch in the shrimp fishery. Environmental Solutions International.

Cushing, D.H. 1984. Do discards affect production of shrimps in the Gulf of Mexico? In: ulland, J.A. and B.J. Rothschild (eds.), Penaeid shrimps - their biology and management. Selected papers presented at the workshop on the scientific basis for the management of penaeid shrimp held at Key West, Florida, USA, November 1981. Fishing News Books, Ltd., Farnham, Surrey, UK. p. 254-258.

Dawson, C.E. 1957. Preliminary report on the effects of closing Calibogue Sound, South Carolina, to shrimp trawling. South Carolina Wildlife Resources Commission.

Ditton, R.B. 1992. A social perspective on the finfish bycatch issue. In, Proceedings of the shrimp trawl bycatch workshop, November 22-23, 1991, St. Petersburg, FL. Center for Marine Conservation, Washington, DC. pp. 64-67.

Durrenberger, E.P. 1990. Policy, power and science: The implementation of turtle excluder device regulations in the U.S. Gulf of Mexico shrimp fishery. Marit. Anthropol. Stud., 3: 69-86.

Ehrhardt, N. 1996. Impacts of TED and BRD designs on overall finfish bycatch reduction and their relative effects on management strategies adopted in directed finfish fisheries. University of Miami - RSMAS.

Fertl, D. 1994. Occurrence, movements, and behavior of bottlenose dolphins (*Tursiops truncatus*) in association with the shrimp fishery in Galveston Bay, Texas. Texas A&M University. M.S. Thesis.

Fowle, S. and R. Bierce (eds.). 1991. Proceedings of the shrimp trawl bycatch workshop, November 22-23, 1991. St. Petersburg, FL. Center for Marine Conservation. Washington, DC. 183 p.

Fowle, S. 1993. A national organizations perspective of the shrimp byactch issue. In, Proceedings of the International Conference on Shrimp Bycatch, May 24-27, 1992, Lake Buena Vista, Florida. Southeastern Fisheries Association, Tallahassee, FL. pp. 153-162.

Fuls, B. 1995. Assessment of composition and magnitude of bycatch associated with the commercial shrimp trawling industry in central lower Texas coastal bays during the spring and Fall Texas commercial bay-shrimp open seasons. Texas Parks & Wildlife Department.

Garcia, S.M. and C. Newton. 1995. Status of the world's capture fisheries. NAGA, The ICLARM Quarterly : 22-24.

Gulf of Mexico Fishery Management Council. 1995. Amendment number 9 to the fishery management plan for the shrimp fishery of the Gulf of Mexico, United States waters, with supplemental environmental impact statement, regulatory impact review, and initial regulatory flexibility analysis. Gulf of Mexico Fishery Management Council.

Goodyear, C.P. 1991. Sensitivity of shrimp-bycatch mortality estimates to natural mortality for red snapper. National Marine Fisheries Service, Southeast Fisheries Science Center, Miami Laboratory, 75 Virginia Beach Drive, Miami, FL 33149.

Goodyear, C.P. 1992. Red snappers in U.S. waters of the Gulf of Mexico. Contribution MIA91/92-70. National Marine Fisheries Service, Southeast Fisheries Science Center, Miami Laboratory, 75 Virginia Beach Drive, Miami, FL 33149.

Goodyear, C.P. 1994. Red snappers in U.S. waters of the Gulf of Mexico. Contribution MIA93/94-63. National Marine Fisheries Service, Southeast Fisheries Science Center, Miami Laboratory, 75 Virginia Beach Drive, Miami, FL 33149.

Goodyear, C.P. 1995. Red snappers in U.S. waters of the Gulf of Mexico. Contribution MIA95/96-05. National Marine Fisheries Service, Southeast Fisheries Science Center, Miami Laboratory, 75 Virginia Beach Drive, Miami, FL 33149.

Gramlind, B. 1996. Fisheries bycatch reduction and management alternatives in the Gulf of Mexico. University of Southwestern Louisiana.

Greenberg, E.V.C. 1993. A legal overview on bycatch issues. In, Proceedings of the International Conference on Shrimp Bycatch, May 24-27, 1992, Lake Buena Vista, Florida. Southeastern Fisheries Association, Tallahassee, FL. pp. 91-94.

Gregory, D.R., Jr. (1988). An annotated bibliography of literature pertaining to reef fish bycatch in shrimp trawls. Gulf of Mexico Fishery Management Council. (Draft).

Griffin, W.L., and A.K. Shah. 1995. Estimation of standardized effort in the heterogenous Gulf of Mexico shrimp fleet. MARFIN Final Report (Award NA37FF0053).

Griffin, W.L. 1994. An analysis of management policies for reducing shrimp by-catch in the Gulf of Mexico. Proceedings on the 7th IIFET Conference on International Cooperation for Fisheries and Aquaculture Development, July 18-21, 1994, Taipei, Taiwan, R.O.C.

Griffin, W.L., D.A. Tolman, and C. Oliver. 1993. Economic impacts of TEDs on the shrimp production sector. Society and Natural Resources, 6: 291-308.

Griffin, W., H. Hendrickson, C. Oliver, G. Matlock. C.E. Bryan, R. Riechers, and J. Clark. 1992. An economic analysis of Texas shrimp season closures. Marine Fisheries Review, 54(3): 21-28.

Gulf and South Atlantic Fisheries Development Foundation. 1994. Organization and management of a Gulf of Mexico and South Atlantic Ocean fishery bycatch management program (Year II). Saltonstall-Kennedy Grant Program, Final Report (Award NA37FD0032). Suite 997, 5401 W. Kennedy, Tampa, FL 33609.

Gulf and South Atlantic Fisheries Development Foundation. 1995a. Continued implementation of high priority objectives outlined in a Gulf of Mexico and South Atlantic fishery bycatch research program. Final Report, (MARFIN Award NA47FF0007). Gulf and South Atlantic Fisheries Development Foundation, Suite 997, 5401 W. Kennedy, Tampa, FL 33609.

Gulf and South Atlantic Fisheries Development Foundation. 1995b. Continued observer coverage of the Gulf of Mexico and South Atlantic shrimp fisheries to characterize the catch and evaluate the efficiency of bycatch reduction devices.. Final Report (Award NA47FM0131). Gulf and South Atlantic Fisheries Development Foundation, Suite 997, 5401 W. Kennedy, Tampa, FL 33609.

Gulf of Mexico Fishery Management Council. 1990. Report of the workshop to evaluate potential management alternatives for reducing directed effort and shrimp trawl bycatch of red snapper. Gulf of Mexico Fishery Management Council.

Gulland, J.A., and B.J. Rothschild. 1984. Penaeid shrimps - their biology and management. Selected papers presented at the workshop on the scientific basis for the management of penaeid shrimp held at Key West, Florida, USA, November 1981. Fishing News Books, Ltd., Farnham, Surrey, UK, 309 pp.

Gutherz, E.J., and G.J. Pellegrin. 1986. Report on snapper-grouper mortality by shrimp trawlers in the U.S. Gulf of Mexico. Report to the Gulf of Mexico Fishery Management Council.

Gutherz, E.J., and G.J. Pellegrin. 1988. Estimate of the catch of red snapper, *Lutjanus campechanus*, by shrimp trawlers in the U.S. Gulf of Mexico. Fisheries, 50(1): 17-25.

Hall, M. 1994. On bycatches. Inter-American Tropical Tuna Commission, 8604 La Jolla Shores Dr., La Jolla, CA 92037.

Harrington, D. 1993. A Sea Grant perspective on reducing bycatch. In, Proceedings of the International Conference on Shrimp Bycatch, May 24-27, 1992, Lake Buena Vista, Florida. Southeastern Fisheries Association, Tallahassee, FL. pp. 65-82.

Harrington, D.L. 1996. Finfish excluder devices in the South Atlantic shrimp fishery. In, Castro, K., T Corey, J. DeAlteris and C. Gagnon (eds.), Proceedings of the East Coast Bycatch Conference, April 7-8, 1995, Newport, RI. Rhode Island Sea Grant, University of Rhode Island Bay Campus, Narragansett, RI. December 1996. pp.91-94.

Hendrickson, H.M., and W.L. Griffin. 1993. An analysis of management policies for reducing shrimp by-catch in the Gulf of Mexico. North American Journal of Fisheries Management, 13: 686-697.

Hines, B., S. Coale, R. Rulifson, and J. Murray. 1993. The skimmer trawl in North Carolina estuaries. Publication UNC-SG-93-01. University of North Carolina, Sea Grant College Program. Final Report, Saltonstall-Kennedy Award NA90AADSG062.

Hoar, P., J. Hoey, J. Nance and C. Nelson. 1992. A research plan addressing finfish bycatch in the Gulf of Mexico and South Atlantic shrimp fisheries. Gulf & South Atlantic Fisheries Development Foundation.

Holland, B.F., Jr. 1989. Evaluation of certified trawl efficiency devices (TEDs) in North Carolina's nearshore ocean. Final Report, Project 2-439-R (NOAA award NA87WCD06100). North Carolina Division of Marine Fisheries, P.O. Box 769, Morehead City, NC 28557. 38 p.

Hubley, R.C. 1993. By-catch reduction = True conservation. Fisheries, 18: 42.

Jones, R.P. 1993. Proceedings of the International Conference on Shrimp Bycatch. May 24-27, 1992. Lake Buena Vista, Florida. Southeastern Fisheries Association, Tallahassee, FL.

Kaiser, M.J., and B.E. Spencer. 1994. Fish scavenging behavior in recently trawled areas. Marine Ecology Progress Series, 112: 41-49.

Keiser, R.K., Jr. 1976. Species composition, magnitude and utilization of the incidental catch of the South Carolina shrimp fishery. Technical Report No. 16, South Carolina Marine Resources Center, Charleston, SC 29412.

Keiser, R K., Jr. 1977. The incidental catch from commercial shrimp trawlers of the South Atlantic states. Technical Report No. 26, South Carolina Wildlife & Marine Resources Dept., Charleston, SC 29412.

Kendall, D. 1990. Shrimp retention characteristics of the Morrison soft TED: a selective webbing exclusion panel inserted in a shrimp trawl net. Fisheries Research, 9: 13-21.

Klima, E.F. 1993. Shrimp bycatch -- hopes and fears. In, Proceedings of the International Conference on Shrimp Bycatch, May 24-27, 1992, Lake Buena Vista, Florida. Southeastern Fisheries Association, Tallahassee, FL. pp. 5-12.

Ludemann, K. 1993. Fishery-induced skin injuries in flatfish from the by-catch of shrimpers. Diseases of Aquatic Organisms, 16: 127-132.

Martinez, E.X., J.M. Nance, Z.P. Zein-Eldin, J. Davis, L. Rathmell and D.A. Emiliani. 1993. Trawling bycatch in the Galveston Bay system. Abstract. In: Jensen, R.W., R.W. Kiesling and F.S. Shipley. Proceedings: The Second State of the Bay Symposium, February 4-6, 1993. Galveston Bay National Estuary Program, Webster, TX. GBNEP-23**:** 249-253.

Martinez, E.X., J. M. Nance, Z.P. Zein-Eldin, J. Davis, L. Rathmell and D.A. Emiliani. 1993. Trawling bycatch in the Galveston Bay system. Galveston Bay National Estuary Program, Webster, TX. GBNEP-34**:** 185 pp.

Martinez, E.X., J.M. Nance, and R.J. Zimmerman. 1996. A model for assessment of ecological interactions among living marine resources in the Gulf of Mexico: Implications for bycatch management and shrimp production. Report to the Gulf of Mexico Fishery Management Council.

McKenna, S.A., and J.P. Monoghan, Jr. 1991. Gear development to improve management of commercial fisheries in North Carolina. Saltonstall-Kennedy Award NA90AAHSK052; annual contract report to the Gulf and South Atlantic Fisheries Development Foundation (contract 43-01), Suite 997, 5401 W. Kennedy, Tampa, FL 33609.

McKenna, S.A., and J.P. Monaghan Jr. 1993. Gear development to reduce bycatch in the North Carolina trawl fisheries. North Carolina Department of Environmental Health and Natural Resources, division of Marine Fisheries, Com. Rep., Project NA90AA-H-SK052. 75 p.

McKenna, S. 1996. Effectiveness of excluder devices on bycatch reduction and shrimp retention. In, Castro, K., T Corey, J. DeAlteris and C. Gagnon (eds.), Proceedings of the East Coast Bycatch Conference, April 7-8, 1995, Newport, RI. Rhode Island Sea Grant, University of Rhode Island Bay Campus, Narragansett, RI. December 1996. pp. 106-112.

Millar, R.B. 1993. Analysis of trawl selectivity studies (addendum): implementation in SAS. Fisheries Research, 17: 373-377.

Muller, R.G. 1992. Shrimp bycatch from the state of Florida perspective. In, Proceedings of the shrimp trawl bycatch workshop, November 22-23, 1991, St. Petersburg, FL. Center for Marine Conservation, Washington, DC. pp. 21-28.

Murray, J.D., J.J. Bahen, and R.A. Rulifson. 1992. Management considerations for by-catch in the North Carolina and southeast shrimp fishery. Fisheries, 17(1): 21-26.

Murray, J.D., S.L. Diamond, and J.J. Bahen. 1994. A program to distribute and evaluate bycatch reduction devices in inshore waters of North Carolina. Final Report (MARFIN Award NA37FF038). University of North Carolina Sea Grant Program, Box 8605, North Carolina State University, Raleigh, NC 27695.

Murray, J.D., J.L. Gearhardt, R.A. Rulifson, and C.W. Wescott. 1995. Introduction of larger mesh webbing in the belly and wings of traditional shrimp trawls to reduce bycatch in inshore waters. Final Report, Saltonstall-Kennedy Award NA37FD0088. University of North Carolina Sea Grant Program, Box 8605, North Carolina State University, Raleigh, NC 27695

Nance, J. 1995. Shrimp CPUE comparison - bycatch and commercial data. National Marine Fisheries Service, Southeast Fisheries Science Center, Galveston Laboratory, 4700 Ave. U, Galveston, TX 77551.

Nance, J.M., and E. Scott-Denton. 1996. Bycatch in the Gulf of Mexico shrimp fishery. Proceedings of the 2nd World Fisheries Congress, in press.

Nance, J.M. 1992. Estimation of effort in the Gulf of Mexico shrimp fishery. NOAA Tech. Memo. NMFS-SEFSC-300. National Marine Fisheries Service, Southeast Fisheries Science Center, 4700 Ave. U., Galveston, TX 77551. 12 pp.

Nance, J.M. 1993. Effort trends for the Gulf of Mexico shrimp fishery. NOAA Tech. Memo. NMFS-SEFSC-337. National Marine Fisheries Service, Southeast Fisheries Science Center, 4700 Ave. U., Galveston, TX 77551. 37 pp.

National Marine Fisheries Service. 1991. Shrimp trawl bycatch research requirements. National Marine Fisheries Service, Southeast Fisheries Center, Southeast Regional Office.

National Marine Fisheries Service. 1993. Cruise results: Shrimp trawl bycatch reduction, NOAA ship Oregon II cruise 92-05 (201), 9/4-29/92. National Marine Fisheries Service, Southeast Fisheries Science Center, Pascagoula Laboratory, P.O. Drawer 1207, Pascagoula, MS 39568.

National Marine Fisheries Service. 1994. Mass mortalities of marine mammals in Texas during the spring of 1994. National Marine Fisheries Service, Southeast Fisheries Science Center.

National Marine Fisheries Service. 1995. Cooperative research program addressing finfish bycatch in the Gulf of Mexico and South Atlantic shrimp fisheries: A report to Congress. National Marine Fisheries Service, Southeast Fisheries Center, Southeast Regional Office.

National Marine Fisheries Service. 1995. Cooperative research program addressing finfish bycatch in the Gulf of Mexico and South Atlantic shrimp fisheries: a report to Congress, April 1995. U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, 9721 Executive Center Drive, St. Petersburg, FL 33702.

Nelson, C. 1993. A shrimp packer's perspective on the shrimp trawl bycatch issue. In, Proceedings of the International Conference on Shrimp Bycatch, May 24-27, 1992, Lake Buena Vista, Florida. Southeastern Fisheries Association, Tallahassee, FL. pp. 47-52.

Nelson, R. 1993. State agency perspective on shrimp trawl related bycatch. In, Proceedings of the International Conference on Shrimp Bycatch, May 24-27, 1992, Lake Buena Vista, Florida. Southeastern Fisheries Association, Tallahassee, FL. pp. 29-32.

Nichols, S., A. Shah, G. Pellegrin Jr., and K. Mullin. 1987. Estimates of annual shrimp fleet bycatch for thirteen finfish species in the offshore waters of the Gulf of Mexico. Report to the Gulf of Mexico Fishery Management Council. National Marine Fisheries Service, Southeast Fisheries Science Center, Pascagoula Laboratory, P.O. Drawer 1207, Pascagoula, MS 39568.

Nichols, S. (ed). 1990. Report of the workshop to evaluate potential management alternatives for reducing directed effort and shrimp trawl bycatch of red snapper. Report to the Gulf of Mexico Fishery Management Council. National Marine Fisheries Service, Southeast Fisheries Science Center, Pascagoula Laboratory, P.O. Drawer 1207, Pascagoula, MS 39568.

Nichols, S., A. Shah, G.J. Pellegrin Jr., and K. Mullin. 1990. Updated estimates of shrimp fleet bycatch in the offshore waters of the U.S. 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.

Nichols, S. 1990. The spatial and temporal distribution of the bycatch of red snapper by the shrimp fishery in the offshore waters of the U.S. Gulf of Mexico. Report to the Gulf of Mexico Fishery Management Council. National Marine Fisheries Service, Southeast Fisheries Science Center, Pascagoula Laboratory, P.O. Drawer 1207, Pascagoula, MS 39568.

Nichols, S. 1992. Effect of shrimp trawl bycatch on finfish populations and ecosystems. In, Proceedings of the shrimp trawl bycatch workshop, November 22-23, 1991, St. Petersburg, FL. Center for Marine Conservation, Washington, DC. pp. 5-7.

Nichols, S. and G.J. Pellegrin, Jr. 1992. Revision and update of estimates of shrimp fleet bycatch 1972-1991. Report to the Gulf of Mexico Fishery Management Council. National Marine Fisheries Service, Southeast Fisheries Science Center, Pascagoula Laboratory, P.O. Drawer 1207, Pascagoula, MS 39568.

Nichols, S. 1994. Update and Revision of Bycatch Estimate for King and Spanish Mackerel 1972-1993. Report to the Gulf of Mexico Fishery Management Council. National Marine Fisheries Service, Southeast Fisheries Science Center, Pascagoula Laboratory, P.O. Drawer 1207, Pascagoula, MS 39568.

Nichols, S., J. Nance, C.P. Goodyear, A. Shah, and J. Watson, 1995. Some considerations in determining bycatch reduction requirements. Report to the Gulf of Mexico Fishery Management Council. NMFS Mississippi Laboratories. P.O. Drawer 1207, Pascagoula, MS 39568-1207.

Nichols, S. 1996. An Update on some issues relating to the distribution of red snapper bycatch. Report to the Gulf of Mexico Fishery Management Council. National Marine Fisheries Service, Southeast Fisheries Science Center, Pascagoula Laboratory, P.O. Drawer 1207, Pascagoula, MS 39568.

Nichols, S. 1996. An Update of Bycatch Findings for Mackerels and Cobia in the Gulf of Mexico Shrimp Fishery. Unpublished report. National Marine Fisheries Service, Southeast Fisheries Science Center, Pascagoula Laboratory, P.O. Drawer 1207, Pascagoula, MS 39568.

Pearce, K.B., D.W. Moye, and S.K. Strasser. 1989. Evaluation of trawl excluder devices in the Pamlico Sound shrimp fishery. Albermarle-Pamlico Estuarine Study, Report 88-07, North Carolina Dept. of Natural Resources and Commercial Development, Division of Marine Fisheries, Morehead City, NC 28557.

Pellegrin, G. Jr. 1982. Fish discards from the southeastern United States shrimp fishery. In: Fish Bycatch...Bonus From the Sea: A report of a technical consultation on shrimp by-catch utilization held in George, Guyana, 27-30 October 1981. pp. 51-54. FAO and International Development Research Centre, Ottawa (IDRC 198-e).

Pellegrin, G.J. Jr., S.B. Drummond, and R.S. Ford, Jr. (no date). The incidental catch of fish by the northern Gulf of Mexico shrimp fleet. Draft manuscript by the National Marine Fisheries Service, P.O. Drawer 1207, Pascagoula, MS 39568.

Perkins, P.C. and E.F. Edwards. 1996. A mixture model for estimating discarded bycatch from data with many zero observations: tuna discards in the eastern tropical Pacific Ocean. Fishery Bulletin, U.S., 94: 330-340.

Perret, W.S., and P.E. Bowman. 1993. Butterfly and skimmer nets in the Gulf of Mexico and their potential use elsewhere. In, Proceedings of the International Conference on Shrimp Bycatch, May 24-27, 1992, Lake Buena Vista, Florida. Southeastern Fisheries Association, Tallahassee, FL. pp. 325-340.

Perrett, W.S., P.E. Bowman, and L.B. Savoie. 1995. Bycatch in the shrimp fishery of Louisiana. Manuscript for the Proceedings of the industry-sponsored international workshop - Solving Bycatch Workshop - held in Seattle, WA, Sept. 1995.

Peterkin, F.A. 1982. Developing a shrimp bycatch utilization program. Proceedings of the Gulf and Caribean Fisheries Institute, 34: 112-119.

Peuser, R. (ed.) 1996. Estimates of finfish bycatch in the south Atlantic shrimp fishery. Prepared by the SEAMAP South Atlantic Committee, Shrimp Bycatch Work Group, Final Report. Atlantic States Marine Fisheries Commission, April 1996, 64 pp.

Powers, J.E., C.P. Goodyear, and G.P. Scott. 1987. The potential effect of shrimp fleet bycatch on fisheries production of selected fish stocks in the Gulf of Mexico. Contribution No. CRD-87/88-06. National Marine Fisheries Service, Southeast Fisheries Science Center, Miami Laboratory, Coastal Resources Division. 75 Virginia Beach Drive, Miami, FL 33149.

Pritchard, D.L., E.F. Roche and F.C. Sutter. 1995. Marine Fisheries Initiative Program (MARFIN) 1994 annual report. National Marine Fisheries Service, SERO, Coop. Programs Division, 9721 Executive Center Drive North, St. Petersburg, FL 33702.

Rayburn, R. 1993. Shrimp bycatch from the perspective of the State's role as fishery trustee. In, Proceedings of the International Conference on Shrimp Bycatch, May 24-27, 1992, Lake Buena Vista, Florida. Southeastern Fisheries Association, Tallahassee, FL. pp. 33-46.

Renaud, M., G. Gitschlag, E. Klima, A. Shah, J. Nance, C. Caillouet, Z. Zein-Eldin and D. Koi. 1990. Evaluation of the impacts of turtle excluder devices (TEDs) on shrimp catch rates in the Gulf of Mexico and South Atlantic, March 1988 through July 1989. NOAA Tech, Memo., NMFS-SEFC-254: 165 p.

Renaud, M., G. Gitschlag, E. Klima, A Shah, D. Koi, J. Nance. 1991. Evaluation of the impacts of turtle excluder devices (TEDs) on shrimp catch rates in the Gulf of Mexico and South Atlantic, September 1989 through August 1990. NOAA Tech. Memo. NMFS-SEFC-288. 80 p.

Renaud, M., G. Gitschlag, E. Klima, A Shah, D. Koi, J. Nance. 1992. Loss of shrimp by turtle excluder devices (TEDs) in coastal waters of the United States, North Carolina to Texas: March 1988 - August 1990. Fishery Bulletin, U.S., 91: 129-137.

Renaud, M.L., J.M. Nance, E. Scott-Denton and G.R. Gitschlag. 1996. Incidental capture of sea turtles in shrimp trawls. Chelonian Conservation and Biology: in press.

Rogers, D., B.D. Rogers, J.A. de Silva, and V.L. Wright. 1993. Evaluation of shrimp trawls designed to reduce bycatch in inshore waters of Louisiana. Year 1 Report (MARFIN Award NA17FF0375). Louisiana, State University, School of Forestry, Dept. of Wildlife and Fisheries, Baton Rouge, LA 70803.

Rogers, D., B.D. Rogers, J.A. de Silva, and V.L. Wright. 1994. Evaluation of shrimp trawls designed to reduce bycatch in inshore waters of Louisiana. Final Report (MARFIN Award NA17FF0375). Louisiana, State University, School of Forestry, Dept. of Wildlife and Fisheries, Baton Rouge, LA 70803.

Rowe, R. 1993. A Gulf of Mexico shrimp captain's perspective. In, Proceedings of the International Conference on Shrimp Bycatch, May 24-27, 1992, Lake Buena Vista, Florida. Southeastern Fisheries Association, Tallahassee, FL. pp. 61-64.

Rulifson, R.A., J.D. Murray, and J.J. Bahen. 1992. Finfish catch reduction in South Atlantic shrimp trawls using three designs of by-catch reduction devices. Fisheries, 17(1): 9-19.

Saul, G.E. 1992. Recreational fishery bycatch in the Galveston Bay system. Galveston Bay National Estuary Program, Webster, TX. GBNEP-25.

Schoning, R.W., R.W. Jacobson, D.L. Alverson, T.H. Gentle and J. Auyong. 1992. Proceedings of the National Industry Bycatch Workshop, February 4-6, 1992, Newport, OR. Natural Resource Consultants, Seattle, WA. 222 p.

Scott-Denton, E. and J.M. Nance. 1996. Shrimp trawl bycatch research in the U.S. Gulf of Mexico and southeastern Atlantic. In: F. Arregu’n-Sanchez, J.L. Munro, M.C. Balgos, and D. Pauly (eds.), Biology, fisheries and culture of tropical groupers and snappers. ICLARM Conference Proceedings, p. 369-371. in press.

Seidel, W.R. 1993. Federal perspective of bycatch in the United States. In, Proceedings of the International Conference on Shrimp Bycatch, May 24-27, 1992, Lake Buena Vista, Florida. Southeastern Fisheries Association, Tallahassee, FL. pp. 21-28.

Shaffer, W.L. Jr. 1993. A cooperative research plan to address finfish bycatch in the Gulf of Mexico and South Atlantic shrimp fisheries. In, Proceedings of the International Conference on Shrimp Bycatch, May 24-27, 1992, Lake Buena Vista, Florida. Southeastern Fisheries Association, Tallahassee, FL. pp. 85-90.

Shaffer, W. 1996. Cooperative shrimp trawl bycatch research in the Southeast. In, Castro, K., T Corey, J. DeAlteris and C. Gagnon (eds.), Proceedings of the East Coast Bycatch Conference, April 7-8, 1995, Newport, RI. Rhode Island Sea Grant, University of Rhode Island Bay Campus, Narragansett, RI. December 1996. p. 95.

Sheridan, P.F., J.A. Browder and J.E. Powers. 1984. Ecological interactions between penaeid shrimp and bottomfish assemblages. In: Gulland, J.A. and B.J. Rothschild (ed.). Penaeid shrimps - their biology and management. Selected papers presented at the workshop on the scientific basis for the management of penaeid shrimp held at Key West, Florida, USA, November 1981. Fishing News Books, Ltd., Farnham, Surrey, UK, p. 235-254.

South Atlantic Fishery Management Council. 1996. Bycatch reduction device testing protocol manual. South Atlantic Fishery Management Council, 1 Southpark Circle. Suite 306, Charleston, SC 29407-4699.

South Carolina Department of Natural Resources. 1996. Results of trawling efforts in the coastal habitat of the South Atlantic Bight, FY-1995. SEAMAP-South Atlantic Annual Report. South Carolina Dept. of Natural Resources, P.O. Box 12559, Charleston, SC, 29422.

Stender, B.W., and C.A Barans. 1991. A comparison of the catch from two types of shrimp nets off South Carolina, USA. Saltonstall-Kennedy program, Final Report, (GASAFDI #40-44769/22494; Award NA90AA-H-SK006). South Carolina Wildlife and Marine Resources Department, P.O. Box 12559, Charleston, SC, 29422.

Taylor W., J. Watson, and D. Foster. 1996. Instructions for fisheye BRD. National Marine Fisheries Service, Southeast Fisheries Science Center, Pascagoula Laboratory, P.O. Drawer 1207, Pascagoula, MS 39568.

Taylor, W., J. Watson, and D. Foster. 1996. Instructions for large mesh funnel & extended funnel BRD. National Marine Fisheries Service, Southeast Fisheries Science Center, Pascagoula Laboratory, P.O. Drawer 1207, Pascagoula, MS 39568.

Thomas, J.S., G.D. Johnson, and C. Formichella. 1995. Bycatch: The social dimensions. Report to the Gulf of Mexico Fishery Management Council. University of South Alabama, Alabama.

Thompson, N. B. 1993. Assessment of the status of Cobia in the Gulf and Atlantic - A working paper presented to the Mackerel stock assessment panel. NOAA/NMFS/Southeast Fisheries Science Center, Miami Laboratory, Miami, FL.

Tillman, M.F. 1993. Bycatch -- the issue of the 90s. In, Proceedings of the International Conference on Shrimp Bycatch, May 24-27, 1992, Lake Buena Vista, Florida. Southeastern Fisheries Association, Tallahassee, FL. pp. 13-18.

Vendetti, R. 1996. Reducing the inadvertent capture of non-targeted species and eliminating shrimp loss through the refinement, demonstration, and evaluations of BRDs and harvesting methods. University of Georgia.

Vendetti, R. 1996. Reducing the incidental impact of shrimp trawls on protected and nontargeted species by technical demonstration and evaluation of TED modifications. University of Georgia.

Vendetti, R.A., R.G. Overman, L.G. Parker, and D.L. Harrington. 1996. Improved methods and procedures for the transfer of technology and the education of constituency groups for devices that will reduce the bycatch in shrimp trawls. MARFIN final report (Award NA57FF0051). University of Georgia Marine Extension Service, 715 Bay St., Brunswick, GA 31523.

Wallace, R.K. and C.L. Robinson. 1994. Bycatch and bycatch reduction in recreational shrimping. Northeast Gulf Science, 13: 139-144.

Ward, J.M. 1992. Socioeconomic effects of shrimp trawl bycatch. In, Proceedings of the shrimp trawl bycatch workshop, November 22-23, 1991, St. Petersburg, FL. Center for Marine Conservation, Washington, DC. pp. 51-63.

Ward, J.M. 1994. The bioeconomic implications of a bycatch reduction device as a stock conservation management measure. Marine Resources Economics, 9: 227-240.

Ward, J. 1995. Marine resource economics annotated bibliography of economic and biological research related to the fishery resources of the United States. National Marine Fisheries Service, Southeast Regional Office, 9721 Executive Center Drive, St. Petersburg, FL.

Ward, J. M., W. Griffin and J. Nance. 1995. A bioecomomic analysis of existing and proposed fishery management alternatives to control sea turtle mortality in the Gulf of Mexico shrimp fishery. NMFS Report to Congress.

Ward, J. and S. Macenko. 1996. Bioeconomic implications of bycatch reduction regulations. National Marine Fisheries Service, Southeast Regional Office, 9721 Executive Center Drive, St. Petersburg, FL.

Ward, J., W. Griffin, and J. Nance. 1996. A Bioeconomic analysis of existing and proposed fishery management alternatives to control sea turtle mortality in the Gulf of Mexico shrimp fishery. Report to Congress, July 1996.

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

Watson, J., D. Foster, and A. Shah. 1997. Report on the results of evaluations of the Jones/Davis BRD. National Marine Fisheries Service, Southeast Fisheries Science Center, Pascagoula Laboratory, P.O. Drawer 1207, Pascagoula, MS 39568.

Watson, J. and A. Shah. 1997. Results of BRD and proxy analyses. National Marine Fisheries Service, Southeast Fisheries Science Center, Pascagoula Laboratory, P.O. Drawer 1207, Pascagoula, MS 39568.

Watson, J.W., Jr., and C.W. Taylor. 1990. Research on selective shrimp trawl design for penaeid shrimp in the United States: a review of selective shrimp trawl research in the United States since 1973. Proceedings of Fisheries Conservation Engineering Workshop, April 4-5, 1990, Narranganasett, RI.

Watson, J.W. Jr. 1980. Sea turtle excluder project: milestone report. National Marine Fisheries Service, Southeast Fisheries Science Center, Pascagoula Laboratory. P.O. Drawer 1207, Pascagoula, MS 39568.

Watson, J.W. Jr. 1981. Sea turtle excluder project: milestone report. National Marine Fisheries Service, Southeast Fisheries Science Center, Pascagoula Laboratory. P.O. Drawer 1207, Pascagoula, MS 39568.

Watson, J.W. Jr. 1981. Sea turtle excluder trawl development - annual report, FY81. National Marine Fisheries Service, Southeast Fisheries Science Center, Pascagoula Laboratory. P.O. Drawer 1207, Pascagoula, MS 39568.

Watson, J.W. Jr. 1983. Sea turtle excluder trawl development - annual report, FY82. National Marine Fisheries Service, Southeast Fisheries Science Center, Pascagoula Laboratory. P.O. Drawer 1207, Pascagoula, MS 39568.

Watson, J.W. Jr. 1983. Sea turtle excluder trawl development - annual report, FY83. National Marine Fisheries Service, Southeast Fisheries Science Center, Pascagoula Laboratory. P.O. Drawer 1207, Pascagoula, MS 39568.

Watson, J.W. Jr. 1984. Sea turtle excluder trawl development - annual report, FY84. National Marine Fisheries Service, Southeast Fisheries Science Center, Pascagoula Laboratory. P.O. Drawer 1207, Pascagoula, MS 39568.

Watson, J.W., J.F. Mitchell, and A.K. Shah. 1986. Trawling efficiency device: a new concept for selective shrimp trawling gear. Fisheries, 48(1): 1-9.

Watson, J.W. 1989. Fish behavior and trawl design: potential for selective trawl development. In: C.M. Campbell (ed.), Proceedings of the World Symposium on Fishing Gear and Fishing Vessels. Marine Institute, St. Johns, Newfoundland, Canada. p. 25-29.

Watson, J.W. 1993. Status of knowledge in the United States relating fish behavior to the reduction of bycatch. In, Proceedings of the International Conference on Shrimp Bycatch, May 24-27, 1992, Lake Buena Vista, Florida. Southeastern Fisheries Association, Tallahassee, FL. pp. 185-195.

Watson, J., I. Workman, D. Foster, C. Taylor, A. Shah, J. Barbour and D. Hataway. 1993. Status report on the potential of gear modifications to reduce finfish bycatch in shrimp trawls in the southeastern United States, 1990-1992. National Marine Fisheries Service, Southeast Fisheries Science Center, Pascagoula Laboratory. P.O. Drawer 1207, Pascagoula, MS 39568.

Watson, J. 1995. Summary report on the status of bycatch reduction device development. Presentation to the South Atlantic Fishery Management Council. National Marine Fisheries Service, Southeast Fisheries Science Center, Pascagoula Laboratory. P.O. Drawer 1207, Pascagoula, MS 39568.

Watson, J. 1996. Summary report on the status of bycatch reduction device development. National Marine Fisheries Service, Southeast Fisheries Science Center, Pascagoula Laboratory. P.O. Drawer 1207, Pascagoula, MS 39568.

Watson, J. 1996. Report on the status of bycatch reduction device (BRD) development. January 1996 report. National Marine Fisheries Service, Southeast Fisheries Science Center, Pascagoula Laboratory. P.O. Drawer 1207, Pascagoula, MS 39568.

Watson, J., 1996. Summary report on the status of bycatch reduction device development. November 1996 report. National Marine Fisheries Service, Southeast Fisheries Science Center, Pascagoula Laboratory. P.O. Drawer 1207, Pascagoula, MS 39568.

Watson, J.W. 1996. A cooperative research program addressing finfish bycatch in the Gulf of Mexico and South Atlantic shrimp fishery. In, Castro, K., T Corey, J. DeAlteris and C. Gagnon (eds.), Proceedings of the East Coast Bycatch Conference, April 7-8, 1995, Newport, RI. Rhode Island Sea Grant, University of Rhode Island Bay Campus, Narragansett, RI. December 1996. pp.97-105.

Wenner, C.A. 1987. Results of tests on two different trawl efficiency devices (TED) in South Carolina coastal waters - final report. Marine Research Institute, South Carolina Wildlife and Marine Resources Dept., P.O. Box 12559, Charleston, SC, 29412.

Whitaker, J.D., L.B. DeLancey, and J.E. Jenkins. 1989. A study of the experimental closure of South Carolina's sounds and bays to commercial fishing. South Carolina Wildlife and Marine Resources Dept., Division of Marine Resources, Commercial Crustacean Management Section, Tech. Rep. No. 72, 54 p.

Whitaker, J.D. 1993. Shrimp bait fishing in South Carolina and preliminary notes on bycatch. In, Proceedings of the International Conference on Shrimp Bycatch, May 24-27, 1992, Lake Buena Vista, Florida. Southeastern Fisheries Association, Tallahassee, FL. pp. 215-228.

Workman, I.K., J.W. Watson, Jr., and C.W. Taylor. 1992. Trawl gear modifications to reduce bycatch in the southeastern United States shrimp fishery. Draft manuscript. National Marine Fisheries Service, Southeast Fisheries Science Center, Pascagoula Laboratory. P.O. Drawer 1207, Pascagoula, MS 39568.

Workman, I., J. Watson, D. Foster, C. Taylor, A. Shah and J. Barbour. 1994. Status report on the potential of gear modifications to reduce finfish bycatch in shrimp trawls in the southeastern United States. 1993 Annual report. National Marine Fisheries Service, Southeast Fisheries Science Center, Pascagoula Laboratory. P.O. Drawer 1207, Pascagoula, MS 39568.

PROJECTS

MARFIN and S-K (Saltonstall-Kennedy) funding for bycatch research projects, 1992-1997. Redundant titles indicate continuing or second-year projects. Principal investigator and institutional affiliation only. Names of secondary or other investigators omitted.

Anderson, W. 1992. Feasibility study of finfish excluding gear in shrimp trawls in the western Gulf of Mexico bycatch. Grant NA17FF0374-01. Gulf Shrimp Research and Development Foundation.

Anderson, W. 1993. Feasibility study finfish excluding gear in shrimp trawls in the western Gulf of Mexico bycatch. Grant NA90AAHMF44. Gulf Shrimp Research and Development Foundation.

Baltz, D. 1992. Patterns in the distribution and abundance of fishes and macroinvertebrates in a Louisiana marsh: shrimp bycatch in inshore, fishery-independent trawl samples. Grant NA17FF0263-01. Louisiana State University.

Baltz, D. 1994. Spatial and temporal patterns in the distribution and abundance of fishes and macroinvertebrates in coastal Louisiana: shrimp bycatch species in fishery-independent trawl samples. Grant NA37FF0044-01. Louisiana State University.

Baltz, D. 1995. Spatial and temporal patterns in the distribution and abundance of fishes and macroinvertebrates in coastal Louisiana: shrimp bycatch species in fishery-independent trawl samples. Grant NA37FF0044-02. Louisiana State University.

Branstetter, S. 1994. Continued implementation of high priority objectives outlined in a Gulf of Mexico and South Atlantic shrimp fishery bycatch research program. Grant NA47FF0007-01. Gulf and South Atlantic Fisheries Development Foundation.

Branstetter, S. 1997. Final implementation of high-priority objectives of a bycatch reduction research program for the Gulf of Mexico and south Atlantic shrimp fishery. Grant NA57FD0261. Gulf and South Atlantic Fisheries Development Foundation.

Branstetter, S. 1997. Summation of a multi-year program to address bycatch reduction in the Gulf of Mexico and South Atlantic shrimp fisheries. Grant NA57FF0285-01. Gulf and South Atlantic Fisheries Development Foundation Inc.

Branstetter, S. 1998. Continued efforts to reduce bycatch in the Gulf of Mexico and South Atlantic shrimp fisheries and disseminate such information to the fishing industry. Grant NA77FD0067. Gulf and South Atlantic Fisheries Development Foundation Inc.

Brown, B. 1992. Bycatch allocation. Grant 92NMFS. Southeast Fisheries Center.

Collins, M.R. 1994, Bycatch of Atlantic and shortnose sturgeons in the South Carolina shad fishery. Grant NA37FD0080-01. South Carolina Department of Natural Resources.

Coleman, F. 1994. Florida inshore shrimping: experimental analysis of bycatch reduction and a state-wide bycatch survey. Grant NA37FF0051-01. Florida State University.

Coleman, F. 1995. Florida inshore bait shrimping; experimental analysis of bycatch exclusion and capture-related mortality of selected seagrass-associated finfish species. Grant NA57FF0048-01. Florida State University.

Coleman, F. 1997. Florida inshore bait shrimping: experimental analysis of bycatch exclusion and capture-related mortality of selected seagrass-associated finfish species. Grant NA57FF0048-02. Florida State University.

Collins, M. 1995. Bycatch of Atlantic and shortnose sturgeons in the South Carolina shad fishery. Grant NA47FD0293. South Carolina Department of Natural Resources.

Collins, M. 1996. Bycatch of Atlantic and shortnose sturgeons in the South Carolina shad fishery. Grant NA67FD0032. South Carolina Department of Natural Resources.

Colura, R. 1995. The Texas shrimp industry salt-box catch separation procedure effect on bycatch survival. Grant NA57FF0047-01. Texas Parks & Wildlife Department.

Condrey, R. 1995. Bycatch in the U.S. Gulf of Mexico menhaden fishery. Grant NA47FF0020-02. Louisiana State University.

Condrey, R. 1994. Bycatch in the U.S. Gulf of Mexico menhaden fishery. Grant NA47FF0020-01. Louisiana State University.

Dameier, J. 1989. Comprehensive assessment of bycatch in Louisiana shrimp fishery. Grant NA89WCHMF006. Louisiana Department of Wildlife and Fisheries.

Dean, J. 1993. Biosocioeconomic characterization of the commercial shrimp trawler bycatch landed in South Carolina and the effect of juvenile mackerel mortality caused by the trawls on the stock of adult mackerel. Grant NA27FD0067-01. University of South Carolina.

Edwards, R.E. 1995. Reduction of billfish bycatch in longline fisheries: feasibility of gear modifications based on differences in feeding patterns. Grant NA47FF0019-01. Mote Marine Laboratory.

Edwards, R.E. 1996. Reduction of billfish bycatch in longline fisheries: feasibility of gear modifications based on differences in feeding patterns. Grant NA47FF0019-02. Mote Marine Laboratory.

Edwards, R.E. 1997. Reduction of bluefin tuna and undersize swordfish bycatch in Atlantic longline fisheries. Grant NA57FD0031. Mote Marine Laboratory.

Ehrhardt, N. 1996. Assessment and management models for coastal pelagic resources (Spanish mackerel) significantly impacted by shrimp trawler bycatch. Grant NA57FF0283-01. University of Miami

Fuls, B. 1994. Assessment of composition and magnitude of bycatch associated with the commercial shrimp trawling industry in central and lower Texas coastal bays during the spring and fall Texas commercial bay-shrimp open seasons. Grant NA37FD0083-01. Texas Parks and Wildlife Department.

Fuls, B. 1996. Assessment of composition and magnitude of bycatch associated with the commercial shrimp trawling industry on the northern and mid-Texas coast during spring and fall Texas commercial bay-shrimp open seasons. Grant NA57FD0131. Texas Parks and Wildlife Department.

Gibbs, L.L. 1990. Evaluating trawl bycatch impact on high level carnivores in pelagic environments of the western Gulf of Mexico. Grant 8X1NA89WCHSK033. Gulf Shrimp Research and Development Foundation.

Graham, G. 1996. Enhancement of shrimp retention and finfish reduction of selected bycatch reduction devices employed in the Gulf Shrimp Fishery. Grant NA57FF0281-01. Texas A&M University.

Griffin, W.L. 1992. Potential for reduction of shrimp trawl bycatch of selected finfish species in the Gulf of Mexico. Grant NA17FL0099-01. Texas A&M Research Foundation.

Griffin, W.L. 1994. Estimation of real effort in the heterogeneous Gulf of Mexico shrimp fleet (bycatch). Grant NA37FF0053-01. Texas A&M Research Foundation.

Griffin, W. 1996. Shrimp bycatch reduction impacts on the harvesting, processing, and community sectors in the Gulf of Mexico. Grant NA57FF0050-01. Texas A&M Research Foundation.

Griffin, W.L. 1997. Shrimp bycatch reduction impacts on the harvesting, processing, and community sectors in the Gulf of Mexico. Grant NA57FF0050-02. Texas A&M Research Foundation.

Griffin, W.L. 1997. Shrimp bycatch reduction impacts on the shrimp and red snapper harvesting sectors in the Gulf of Mexico. Grant NA57FF0284-02. Texas A&M Research Foundation.

Harrington, D.L. 1993. Reduction of finfish capture in South Atlantic shrimp trawls - bycatch. Grant NA27FD0070-01. University of Georgia.

Harrington, D.L. 1995. Development and classification of devices for use in South Atlantic shrimp trawls and to classify them by size; to enhance BRD technology transfer within the commercial fisheries of the region (bycatch). Grant NA47FF0010-01. University of Georgia.

Harrington, D. 1995. Improved methods and procedures for the transfer of technology and the education of constituency groups for devices that will reduce the fish bycatch in shrimp trawls. Grant NA57FF0051-01. University of Georgia.

Harrington, D. 1996. Assessing shrimp retention and bycatch exclusion rates of new TED designs, compared to conventional TEDs, to address the capture of leatherback turtles in shrimp fisheries. Grant NA57FD0033. University of Georgia.

Hueter, R. 1996. Early life history and relative abundance of Blacktip and other coastal sharks in eastern Gulf of Mexico nursery area, including bycatch mortality of sharks and associated fishes. Grant NA57FF0034-02. Mote Marine Laboratory.

Hueter, R.E. 1997. Early life history and relative abundance of blacktip and other coastal sharks in eastern Gulf of Mexico nursery area, including bycatch mortality of sharks and associated fishes. Grant NA57FF0034-03. Mote Marine Laboratory.

Jamison, J. 1991. Evaluation of incidental finfish catch by two types of shrimp nets - bycatch. Grant NA90AAHSK006. Gulf and South Atlantic Fisheries Development Foundation.

Jamison, J. 1991. Gear development to improve management of commercial fisheries in North Carolina bycatch. Grant 9X1NA90AAHSK052. Gulf and South Atlantic Fisheries Development Foundation.

Jamison, J. 1992. Gear development to reduce bycatch in the North Carolina trawl fisheries. Grant 9X2NA90AAHSK052. Gulf and South Atlantic Fisheries Development Foundation.

Jamison, J. 1993. Strategic planning, data collection, and gear evaluation for the management of bycatch in the directed commercial fisheries of the Gulf of Mexico. Grant NA17FF0233-01. Gulf and South Atlantic Fisheries Development Foundation.

Jamison, J. 1993. Organization and management of a Gulf of Mexico and South Atlantic ocean fishery bycatch management program. Grant NA17FD0103-01. Gulf and South Atlantic Fisheries Development Foundation.

Jamison, J. 1993. Development of statistical methods to incorporate uncertainty of bycatch in stock assessment methods of directed finfish fisheries. Grant NA27FD0072-01. Gulf and South Atlantic Fisheries Development Foundation.

Jamison, J. 1994. Organization and management of Gulf of Mexico and South Atlantic ocean fishery bycatch management program (Year 2). Grant NA37FD0032-01. Gulf and South Atlantic Fisheries Development Foundation.

Jones, R.P. 1991. An international conference on the reduction of bycatch in shrimp trawling operations and alternative harvesting methods for the shrimp fishery. Grant 0X1NA90AAHMF745. Southeast Fisheries Association Inc.

Jones, R.P. 1993. An international conference on the reduction of bycatch in shrimp trawling operations and alternative harvesting methods for the shrimp fishery. Grant 0X2NA90AAHMF745. Southeast Fisheries Association Inc.

Klima, E. 1989. Evaluation of the impacts of TEDs on shrimp, catch rates, and bycatch in Gulf of Mexico. Grant 89NMFS05. NMFS Galveston Laboratory.

Klima, E. 1991. Evaluation of the impacts of bycatch excluder devices (BEDs) on finfish and shrimp catch rates in the Gulf of Mexico. Grant 91NMFS05. NMFS Galveston Laboratory.

Macinko, S. 1993. Investigation of the basic bioeconomic dynamics of bycatch problems in Gulf of Mexico fishery management. Grant NA27FD0068-01. Seth S. Macinko.

Matthews, T. 1996. Trap induced mortality and incidental bycatch of reef fish in wood and wire spiny lobster traps in South Florida. Grant NA57FF0292-01. Florida Department of Environmental Protection.

McKenna, S. 1995. Evaluation of trawl efficiency devices/bycatch reduction devices in estuarine and nearshore waters of North Carolina. Grant NA47FF0016-01. North Carolina Department of Environment, Health & Natural Resources.

Monaghan, J. 1996. Reduction of bycatch in North Carolina otter trawl fisheries. Grant NA47FD0298. North Carolina Department of Environment, Health & Natural Resources.

Murray, J.D. 1990. Lab and field experiments of three finfish separator devices to reduce bycatch in the shrimp fishery. Grant NA90AAHSK048. North Carolina State University.

Murray, J.D. 1992. Development and evaluation of finfish separator device and TED combinations to reduce bycatch in the shrimp fishery. Grant NA17FD0101-01. North Carolina State University.

Murray, J.D. 1992. Introduction of the skimmer trawl to reduce bycatch and incidental capture of sea turtles in inshore waters. Grant NA17FD0104-01. North Carolina State University.

Murray, J.D. 1994. A program to distribute and evaluate bycatch reduction devices in inshore waters of North Carolina. Grant NA37FF0038-01. North Carolina State University.

Murray, J.D. 1994. Introduction of larger mesh webbing in the belly and wings of traditional shrimp trawls to reduce bycatch in inshore waters. Grant NA37FD0088-01. North Carolina State University.

Murray, J. 1996. Skimmer trawl modifications to reduce bycatch in the inshore brown and pink shrimp fishery in North Carolina. Grant NA57FD0130. North Carolina State University.

Nance, J.M. 1993. Shrimp trawl fishery bycatch characterization study. Grant 93NMFS20. NMFS Galveston Laboratory.

Nance, J.M. 1994. Shrimp bycatch characterization research. Grant 94MF1H08. NMFS Galveston Laboratory.

Nance, J. 1995. Shrimp bycatch reduction device evaluation research. Grant 95MFIH19. NMFS Galveston Laboratory.

Nance, J.M. 1996. Shrimp bycatch research in the southeastern shrimp fishery. Grant 96MF1H02. NMFS Galveston Laboratory.

Nichols, S. 1991. Gear development for bycatch reduction. Grant 01NMFS09. NMFS Mississippi Laboratory.

Powers, J. 1994. Analysis of the longline fishery effort, catch and bycatch in the southwestern Atlantic and Gulf of Mexico. Grant NA37FF0040-01. Louisiana State University.

Rice, J. 1996. Population level impacts of shrimp trawl bycatch on Atlantic croaker in the South Atlantic: estimating growth and mortality of late juveniles. Grant NA57FF0299-01. North Carolina State University.

Rice, J.A. 1997. Population level impacts of shrimp trawl bycatch on Atlantic croaker in the South Atlantic: Estimating growth and mortality of late juveniles. Grant NA57FF0299-02. North Carolina State University.

Rogers, B. 1992. Evaluation of shrimp trawls designed to reduce bycatch in inshore waters of Louisiana. Grant NA17FF0375-01. Louisiana State University.

Rogers, B. 1993. Evaluation of shrimp trawls designed to reduce bycatch in inshore waters of Louisiana. Grant NA17FF0375-02. Louisiana State University.

Rogers, D. 1995. The behavior of fish and shrimp in relation to trawl modifications to reduce shrimp trawler bycatch. Grant NA57FF0049-01. Louisiana State University.

Rogers, D. 1997. The behavior of fish and shrimp in relation to trawl modifications to reduce shrimp trawler bycatch. Grant NA57FF0049-02. Louisiana State University.

Scholz, P.M. 1992. Bioeconomic characterization of the commercial shrimp trawler bycatch landed in McClellanville, South Carolina and socioeconomic description of local bycatch consumers. Grant NA17FD0109-01. University of South Carolina.

Seidel, W. 1990. Shrimp trawl bycatch reduction. Grant 90NMFS07. NMFS Mississippi Laboratory.

Seidel. W. and J.M. Nance. 1993. Shrimp trawl bycatch reduction. Grant 93NMFS18. NMFS Mississippi Laboratory.

Seidel, W., J. Watson and J. Nance. 1994. Shrimp trawl bycatch reduction. Grant 94MF1H10. NMFS Mississippi Laboratory.

Seidel, W. and J. Watson. 1995. Shrimp trawl bycatch reduction.   Grant 95MFIH13. NMFS Mississippi Laboratory.

Seidel, W. and J. Watson. 1996. Shrimp trawl bycatch reduction. Grant 96MF1H01. NMFS Mississippi Laboratory.

Storck, T. 1994. Characterization of finfish bycatch of private boat recreational anglers in Texas marine waters. Grant NA37FD0084-01. Texas Parks and Wildlife Department.

Thomas, S. 1994. Decision-making by shrimp fishermen as reasoned action: behavioral determinants of bycatch characteristics and projected effects of bycatch regulations on labor decisions. Grant NA37FF0049-01. University of South Alabama.

Thomas, S. 1995. Decision-making by shrimp fishermen as reasoned action: behavioral determinants of bycatch characteristics and projected effects of bycatch regulations on labor decisions. Grant NA37FF0049-02. University of South Alabama.

Wallace, R.K. 1991. Documentation of bycatch from small inshore shrives and evaluation of bycatch reduction devices. Grant NA90AAHSK120. Auburn University.

Ward, J. 1991. Economic analysis of finfish bycatch in the Gulf of Mexico shrimp fishery. Grant 91NMFS04. Southeast Regional Office.

Ward, J. 1992. Economic analysis of finfish bycatch in the Gulf of Mexico shrimp fishery. Grant 92NMFS11. NMFS, Southeast Regional Office, St. Petersburg, FL.

Wilson, C. 1990. Application of pelagic longline data in reducing billfish bycatch and resource monitoring. Grant NA89WCHMF013. Louisiana State University.

Appendix II: Report Tables

Table 1. Annual bycatch levels for selected species in the Gulf of Mexico.

BYCATCH ESTIMATES (MILLIONS) FOR 1972-1997
DATA INCLUDED: ALL OBSERVER DATA

YEAR	FINFISH (POUNDS)	ATLANTIC CROAKER	LONGSPINE PORGY	COBIA	RED SNAPPER	KING MACKEREL	SPANISH MACKEREL	RED DRUM
1972	1474	17277	4296	0.082	64.6	0.816	2.45	0.075
1973	1189	28679	1123	0.022	23.1	0.309	2.07	0.079
1974	930	20003	906	0.148	17.2	0.374	1.63	0.091
1975	1193	44834	1042	0.093	15.3	0.288	1.53	0.100
1976	1325	31484	1740	0.093	23.4	0.325	2.31	0.196
1977	828	12285	3822	0.057	24.5	0.303	2.77	0.147
1978	1222	19609	3955	0.092	22.2	0.552	3.40	0.086
1979	1024	18426	2839	0.191	22.4	0.631	3.44	0.251
1980	1027	23978	960	0.138	34.2	0.378	4.22	0.106
1981	904	10153	2985	0.070	34.3	0.372	2.55	0.095
1982	1008	11703	3161	0.113	33.9	0.369	2.84	0.120
1983	774	15488	2518	0.214	21.3	0.342	2.57	0.316
1984	1192	21911	3269	0.116	16.5	0.521	2.78	0.104
1985	958	24349	2492	0.231	20.3	0.443	2.78	0.061
1986	595	7099	5869	0.064	19.1	0.375	2.89	0.142
1987	647	7409	4670	0.128	24.2	0.858	3.37	0.200
1988	573	8121	4168	0.055	23.0	0.648	3.87	0.218
1989	583	9702	2355	0.116	27.8	1.314	4.13	0.198
1990	737	9875	1936	0.129	53.8	0.879	3.72	0.146
1991	745	19381	2137	0.202	47.5	1.102	4.13	0.125
1992	711	24981	7722	0.226	30.7	0.586	5.07	0.221
1993	582	10795	3559	0.292	34.9	1.055	4.75	0.171
1994	657	10512	4923	0.287	43.1	0.989	3.03	0.193
1995	670	8244	4350	0.207	45.2	1.105	2.73	0.233
1996	626	6747	7738	0.310	36.8	0.617	2.76	0.184
1997	766	8200	7196	0.374	41.7	0.742	2.59	0.320

Table 2. Bycatch reduction devices (BRDs) tested under the regional bycatch program.

BRD and TED Type	Area	Number of Tows
12x5 Fisheye (30 mesh), Supershooter	Gulf of Mexico	105
12x5 Fisheye (5 mesh), Supershooter	Gulf of Mexico	35
12x5 Fisheye (offset), Supershooter	Gulf of Mexico	45
4x7 Fisheye (30 mesh), Anthony Weedless	Gulf of Mexico	44
Extended funnel, Supershooter	Gulf of Mexico	88
3/5 Extended Funnel, Busken	Gulf of Mexico	47
Jones/Davis, Supershooter	Gulf of Mexico	33
Side opening Supershooter	Gulf of Mexico	34
12x5 Fisheye (30 mesh), Burbank	South Atlantic	34
12x5 Fisheye (offset), Burbank	South Atlantic	55
4x7 Fisheye (30 mesh), none	South Atlantic	60
6x6 Fisheye (middle), none	South Atlantic	30
Extended Funnel, Georgia	South Atlantic	39
Extended Funnel, Burbank	South Atlantic	167
Extended Funnel, Supershooter	South Atlantic	32
Snake eyes, Parrish	South Atlantic	31

Table 3. Estimates of reduction in fishing mortality (F) for red snapper based on BRD reduction estimates by size class.

BRD TYPE	Estimate based on smoothed curve	Estimate based on raw interval	Range
Jones/Davis	52%	65% - 67%	52% - 67%
Fisheye (30 mesh)	59% - 60%	60%	59% - 60%
Fisheye (5 mesh)	66% - 68%	67% - 70%	66% - 70%
Fisheye (offset)	66% - 71%	73% - 77%	66% - 77%

Table 4. Fish predators of penaeid shrimp in the Gulf of Mexico, ranked in order of importance (based on predation rates and magnitude of predator stock). The table provides information on percent frequency of occurrence of shrimp in stomachs examined and abundance of fish captured in trawls during NMFS bycatch characterization surveys on commercial vessels during 1992-1994 (offshore only).

	Scientific Name	Common Name	% Frequency of Penaeus in Stomachs	Mean # Fish/Hr. in Trawls
1	*Cynoscion arenarius*	Sand Seatrout	0.55	16
2	*Cynoscion nebulosus*	Spotted Seatrout	4.76	< 1
3	*Micropogon undulatus*	Atlantic Croaker	0.02	177
4	*Synodus foetens*	Inshore Lizardfish	0.19	18
5	*Centropristis philadelphica*	Rock Sea Bass	0.12	18
6	*Ancylopsetta quadrocellata*	Ocellated Flounder	1.14	< 1
7	*Diplectrum bivittatum*	Dwarf Sand Perch	0.08	12
8	*Lutjanus synagris*	Lane Snapper	0.42	< 1
9	*Lagocephalus laevigatus*	Smooth Puffer	0.38	< 1
10	*Prionotus tribulus*	Bighead Searobin	0.32	1
11	*Rhizoprionodon terraenovae*	Atlantic Sharpnose Shark	2.17	2
12	*Scombermorus maculatus*	Spanish Mackerel	0.19	< 1
13	*Lutjanus campechanus*	Red Snapper	0.09	2
14	*Cynoscion nothus*	Silver Seatrout	0.06	2

Table 5. Nitrogen Inputs for individual components in the ecosystem model. Despite their inclusion as a functional relationship in the model, some of the specific parameters may be set to zero due to lack of quantitative data.

Model Component / Stock	Sources of Nitrogen Input
Organic Animal Nitrogen	Riverine input, zooplankton fecal pellets, discarded bycatch (dead, natural
	mortality of benthos, shrimp, other curstaceans, fish, sharks, dolphins
Organic Plant Nitrogen	Phytoplankton mortality and unassimilated phytoplankton
Dissolved Inorganic Nitrogen	Riverine input, degradation of organic nitrogen (plant and animal),
	excretion from zooplankton, shrimp, crustaceans, fish, sharks, and dolphins
Phytoplankton	Riverine input, inorganic and organic nitrogen pools
Zooplankton	Phytoplankton, organic nitrogen pools (plant and animal)
Benthos	Organic nitrogen pools (plant and animal)
Shrimp	Organic nitrogen (plant and animal), benthos
Other Crustaceans	Organic animal nitrogen, benthos
Pelagic Fish (Menhaden)	Phytoplankton, zooplankton
Bottomfish and Reefish	Organic nitrogen (plant and animal), benthos, shrimp, crustaceans, discards
Migratory Fish	Shrimp, crustaceans, pelagics, bottomfish
Dolphins	Shrimp, crustaceans, pelagics, bottomfish, migratory fish, discards
Sharks	Shrimp, crustaceans, pelagics, bottomfish, migratory fish, discards, dolphins
Birds	Discards

Appendix III: Report Figures

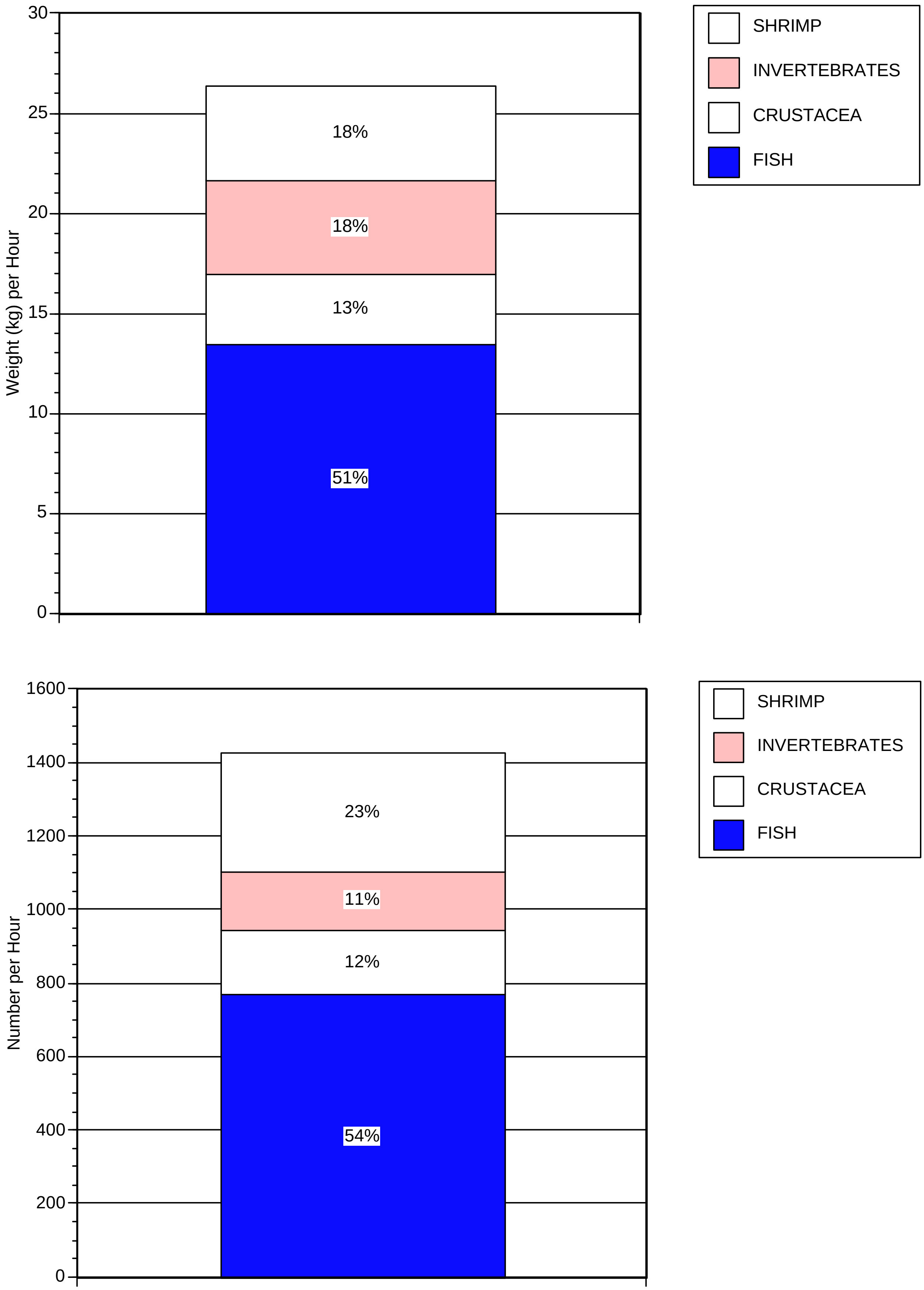
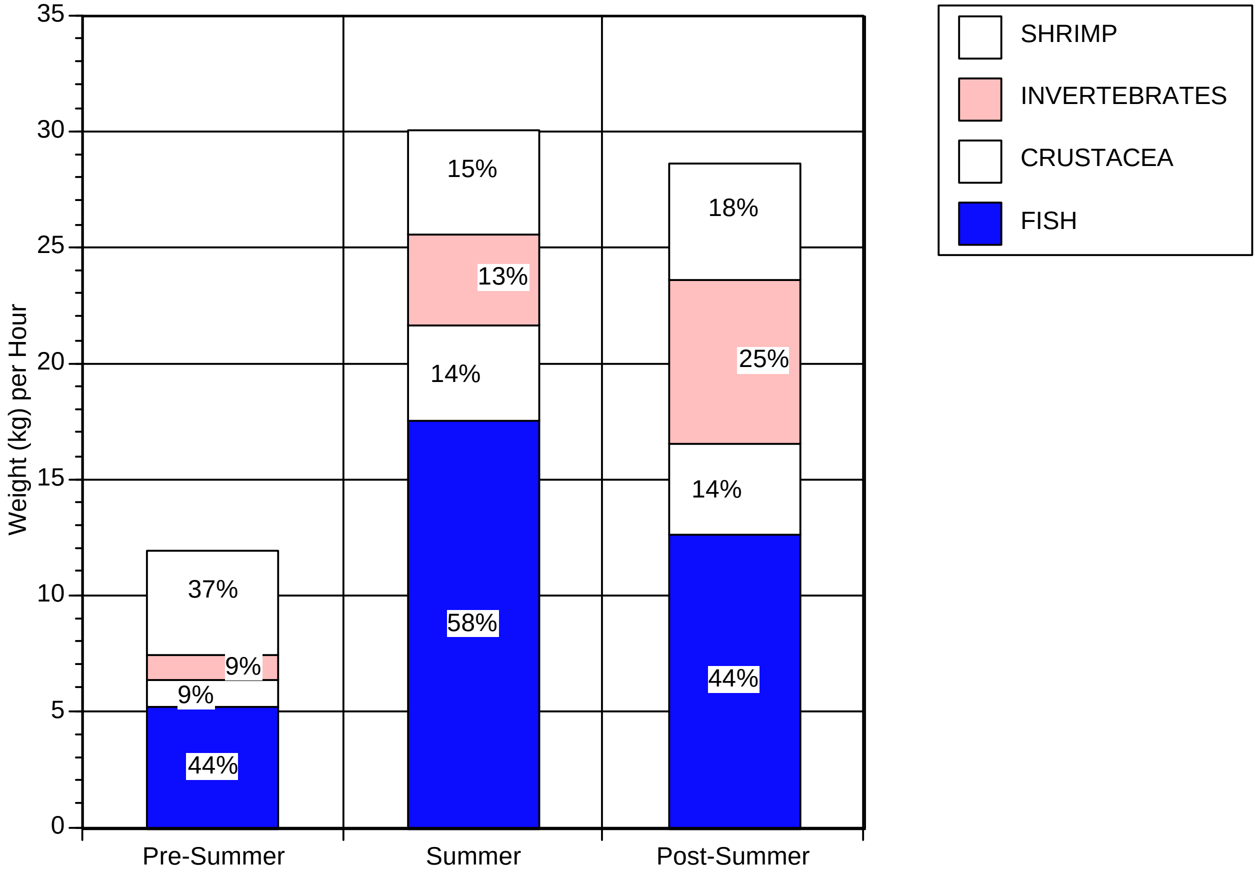


Figure 1. Overall catch composition in the south Atlantic.



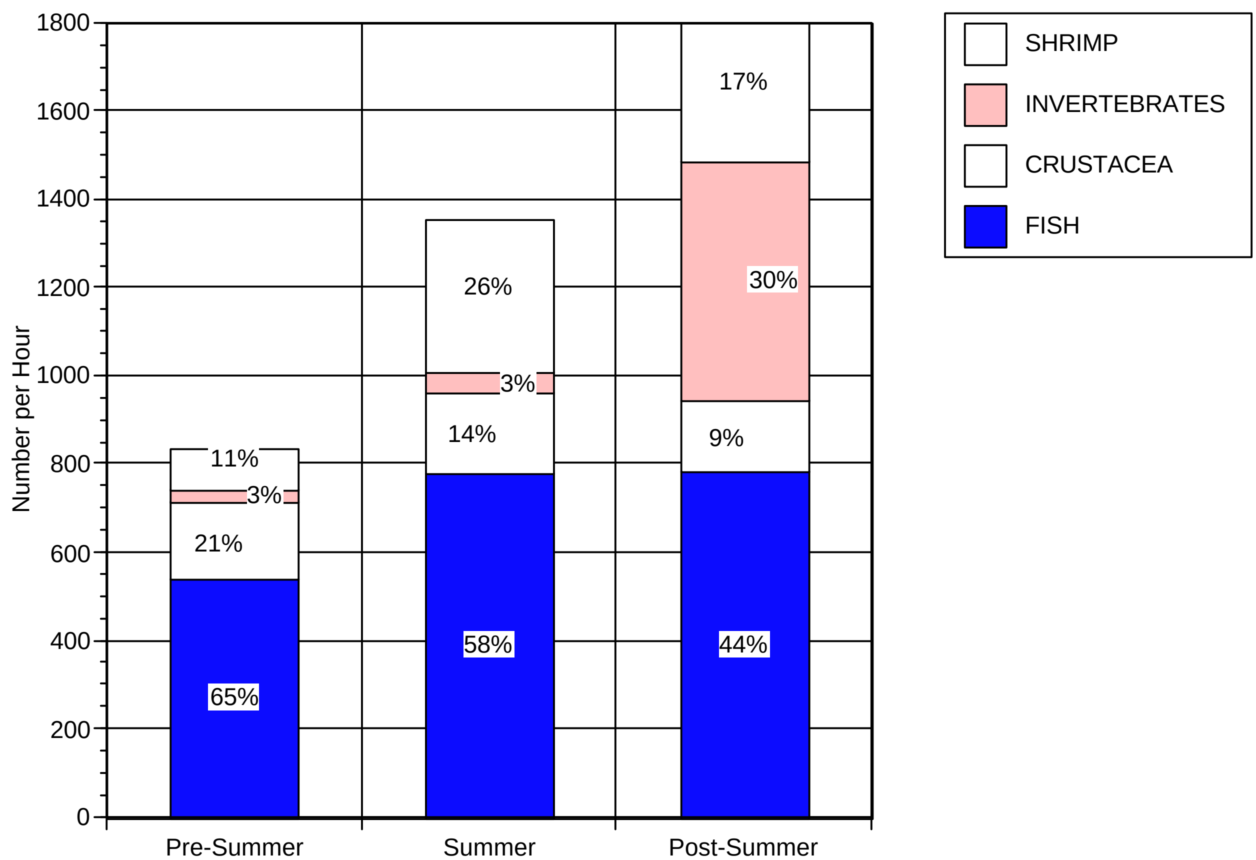


Figure 2. Seasonal catch composition in the south Atlantic.

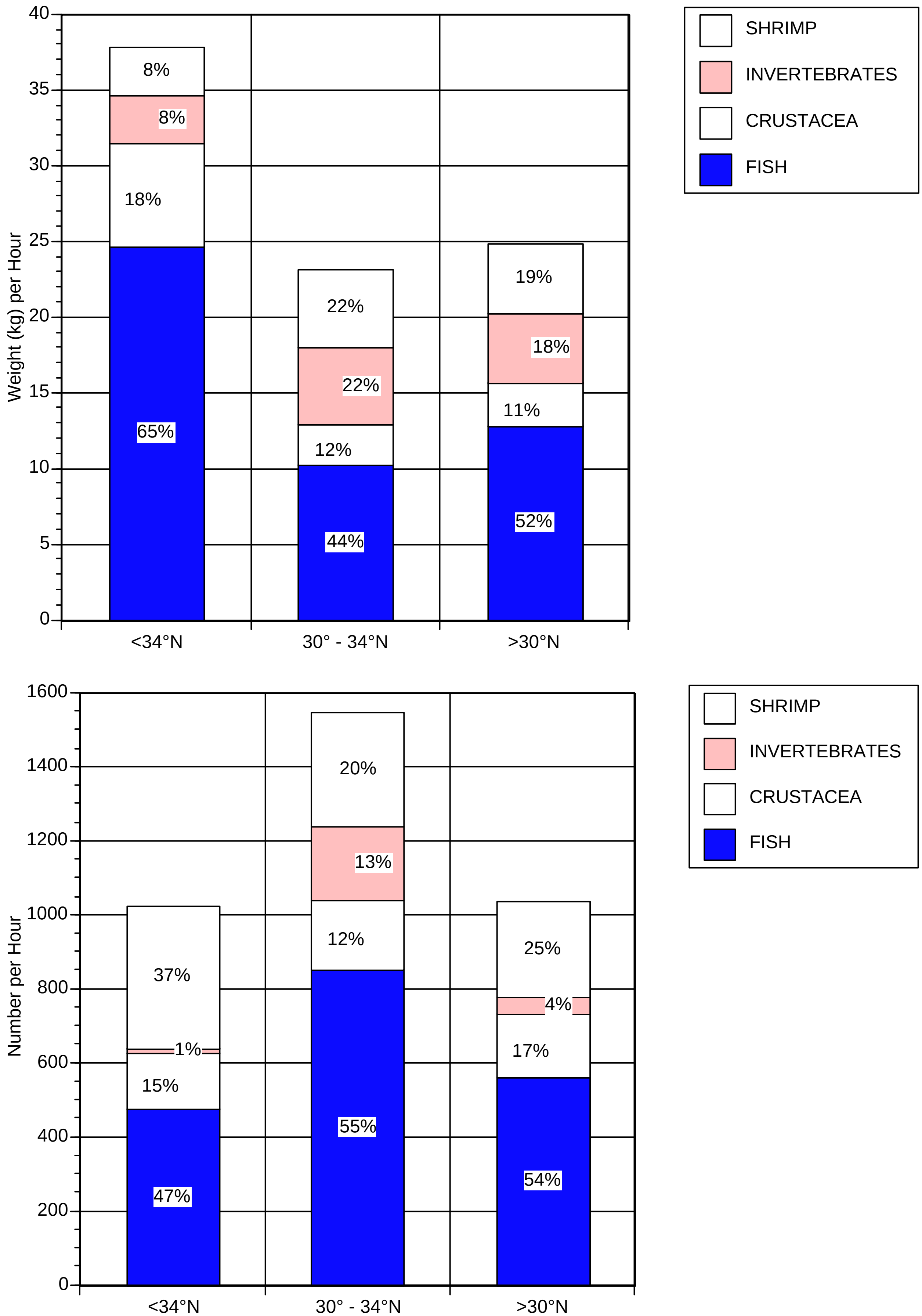
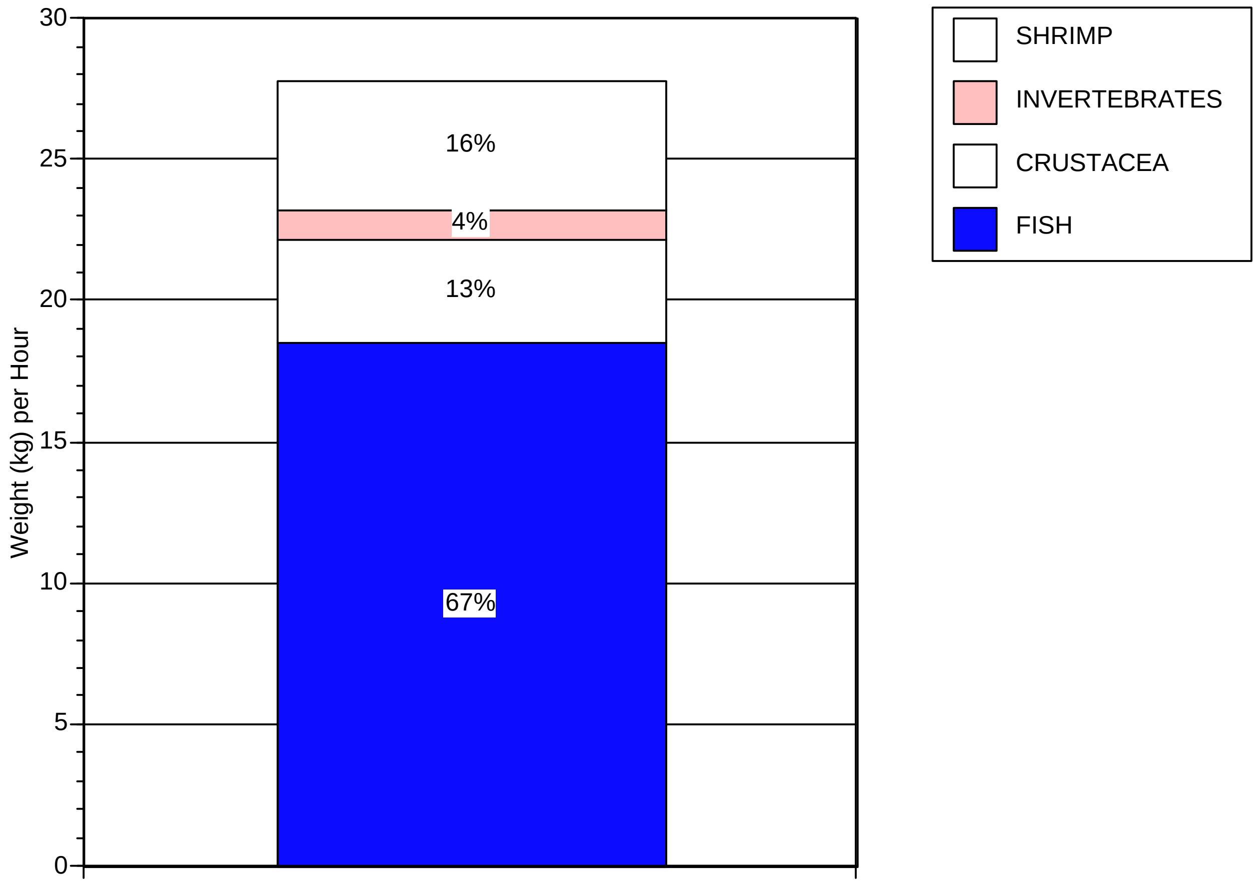


Figure 3. Area catch composition in the south Atlantic.



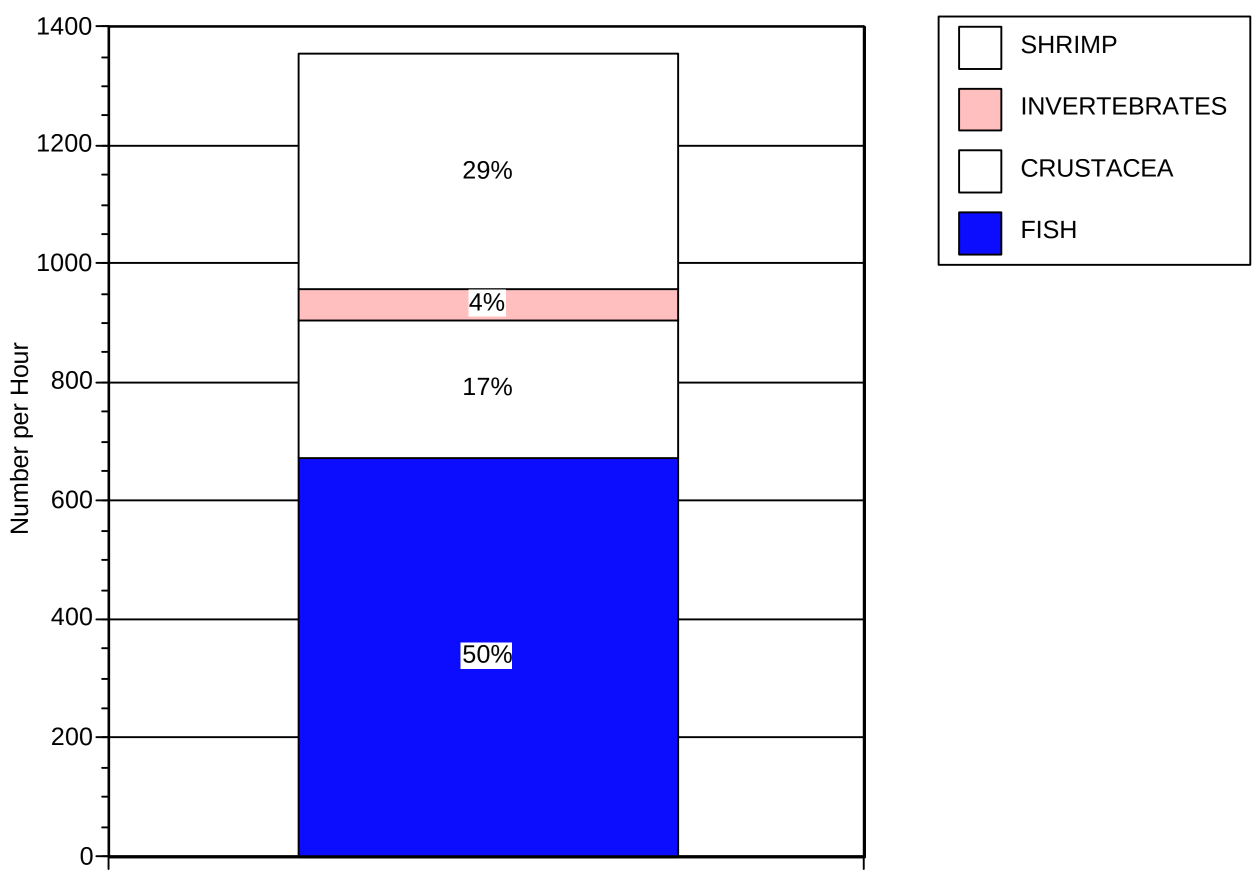


Figure 4. Overall catch composition in the Gulf of Mexico.

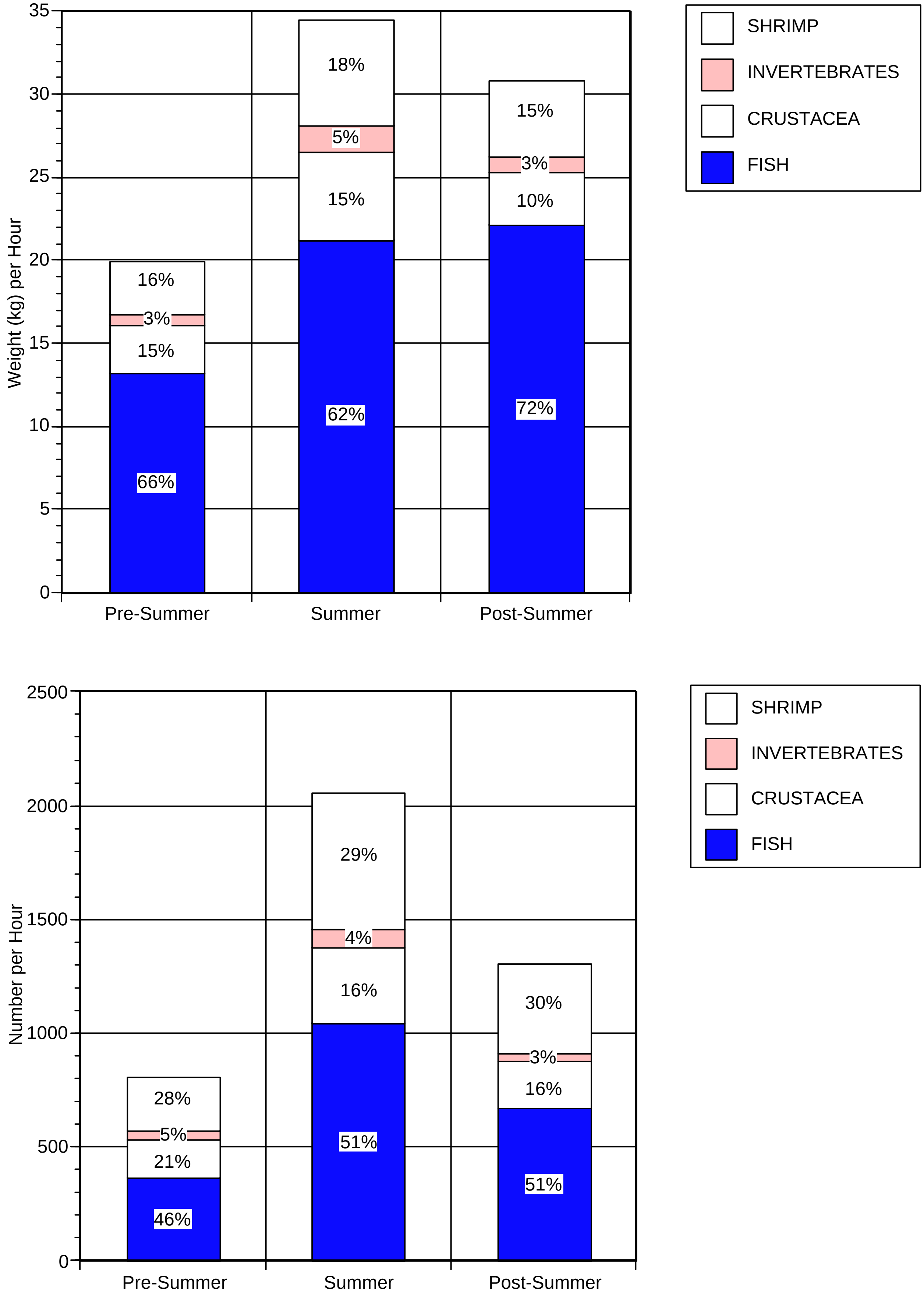


Figure 5. Seasonal catch composition in the Gulf of Mexico.

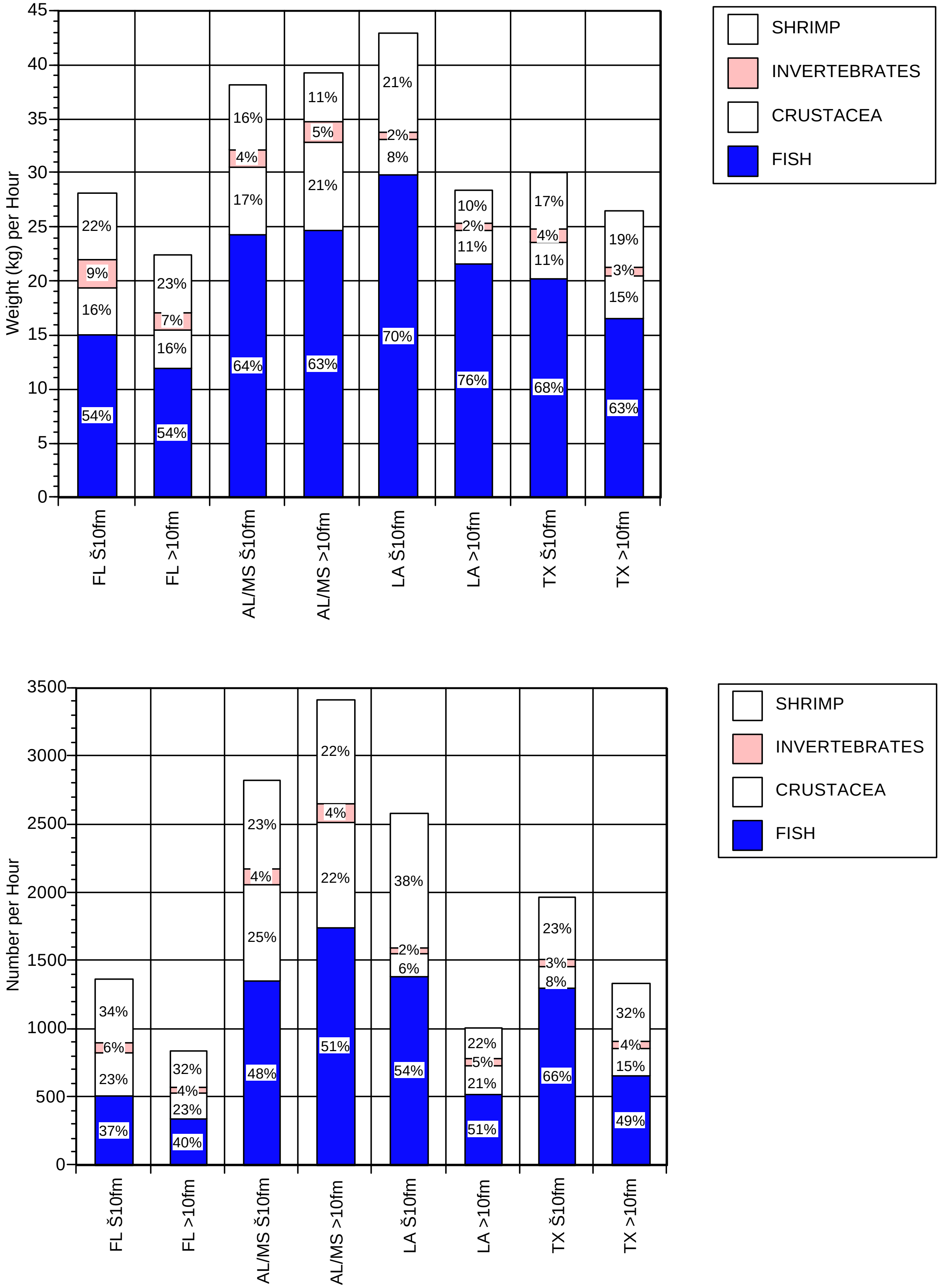


Figure 6. Area catch composition in the Gulf of Mexico.

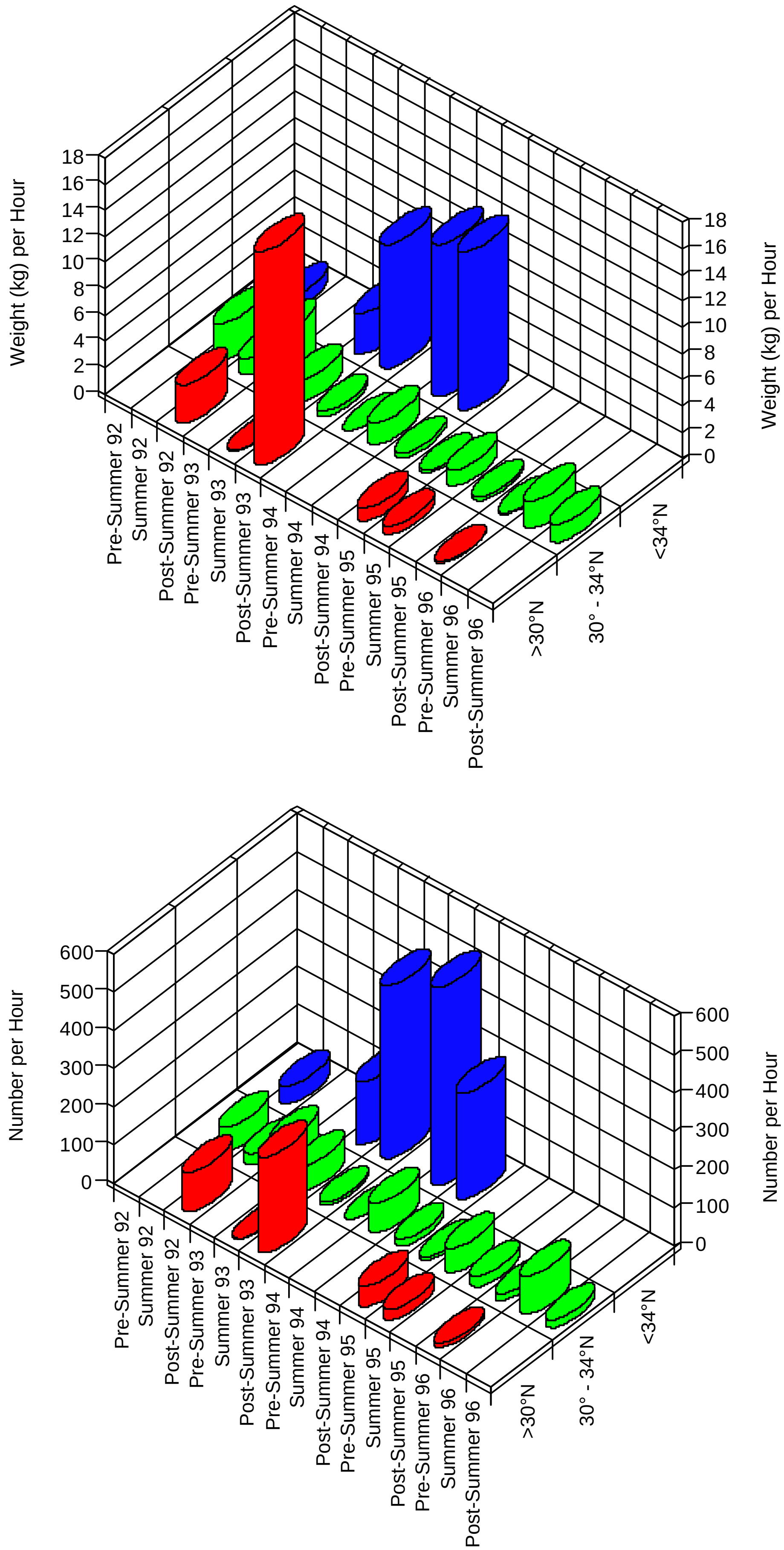
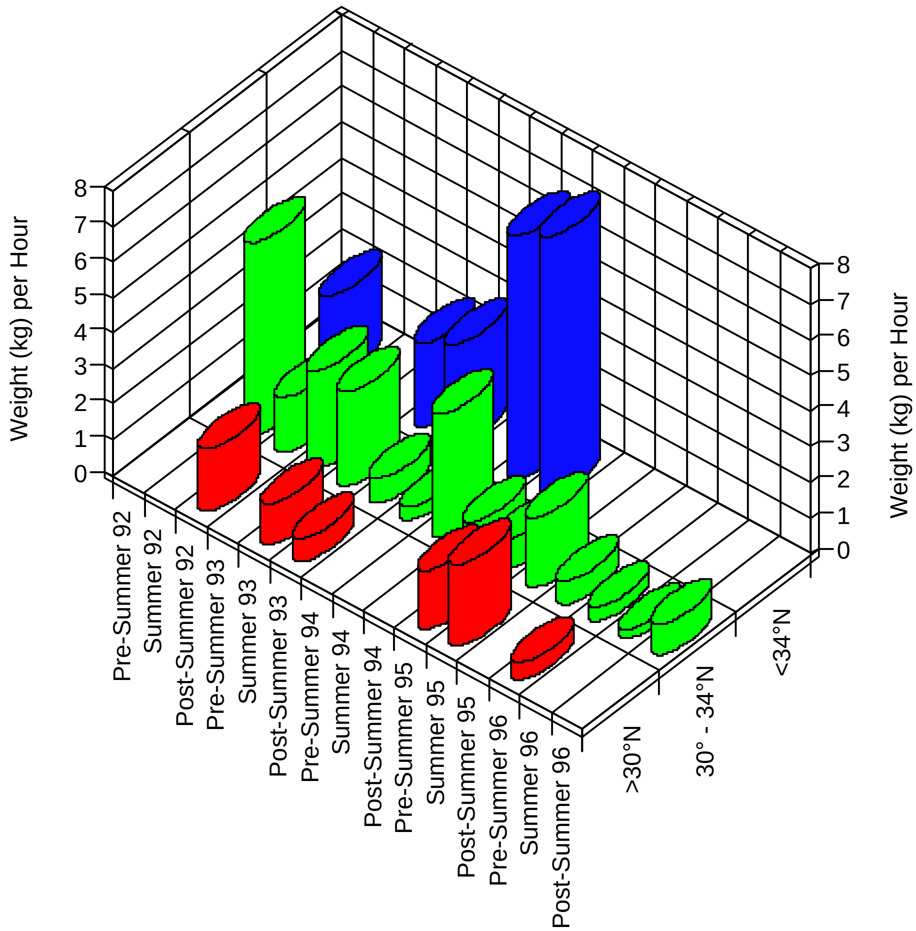


Figure 7. Atlantic croaker catch per hour rates in the south Atlantic.



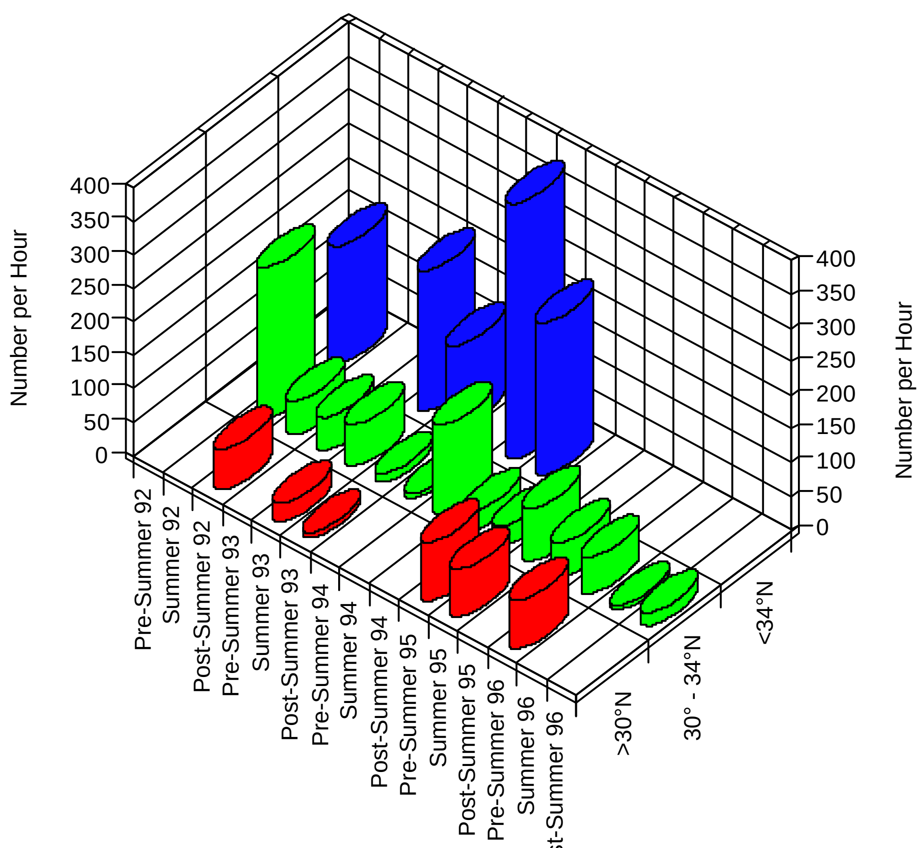


Figure 8. Spot catch per hour rates in the south Atlantic.

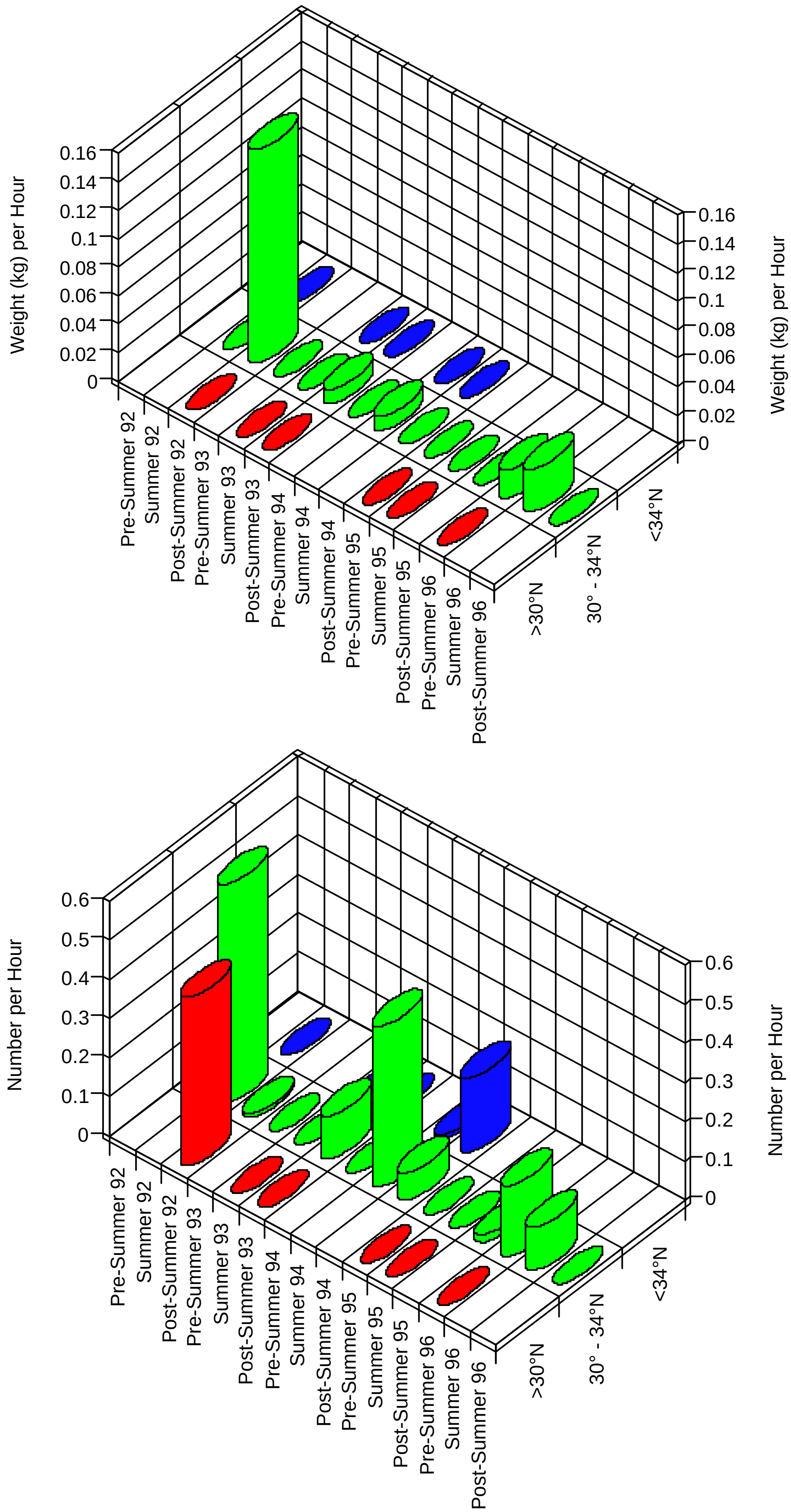
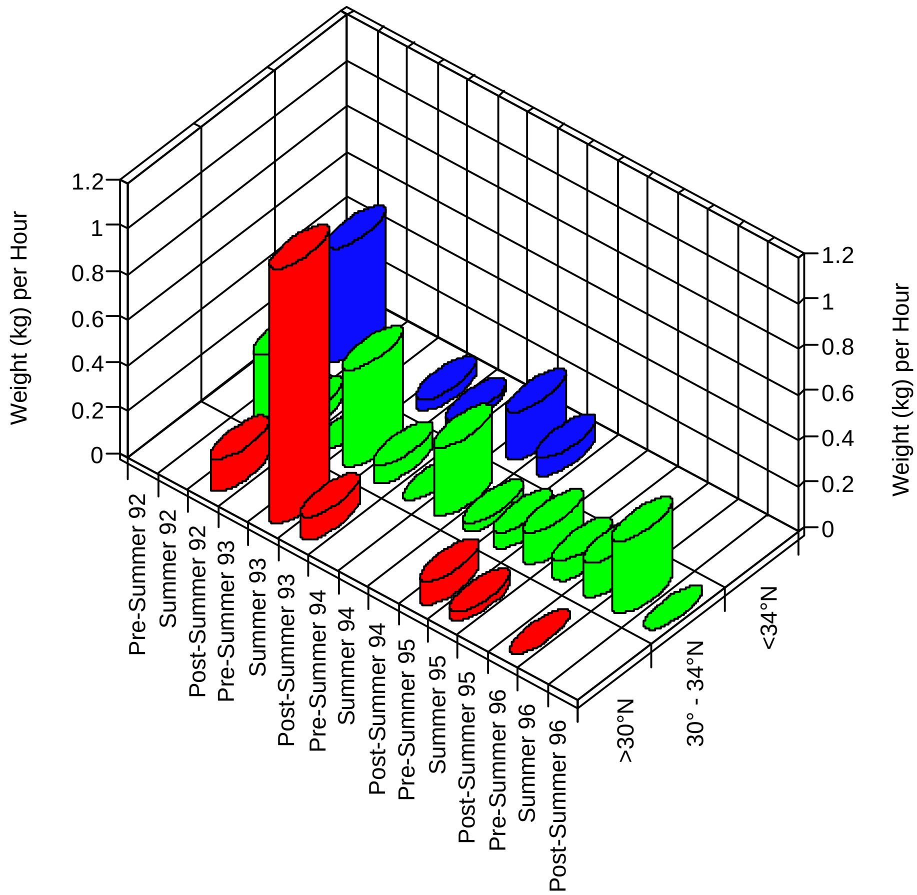


Figure 9. King mackerel catch per hour rates in the south Atlantic.



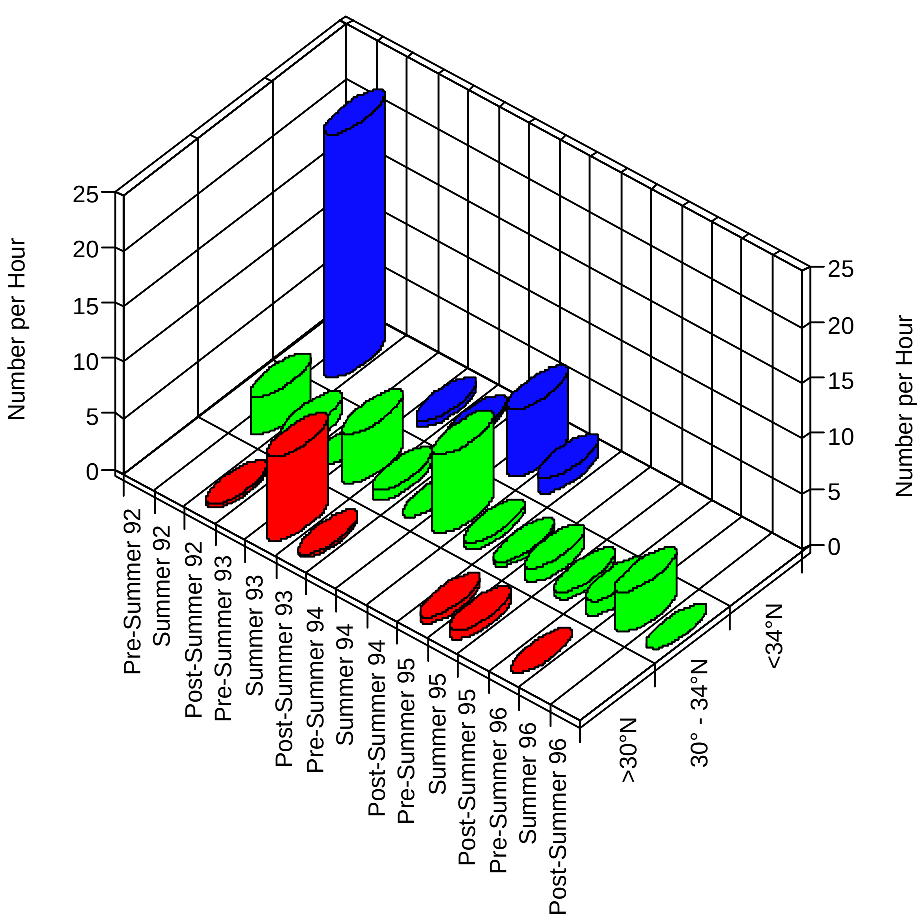


Figure 10. Spanish mackerel catch per hour rates in the south Atlantic.

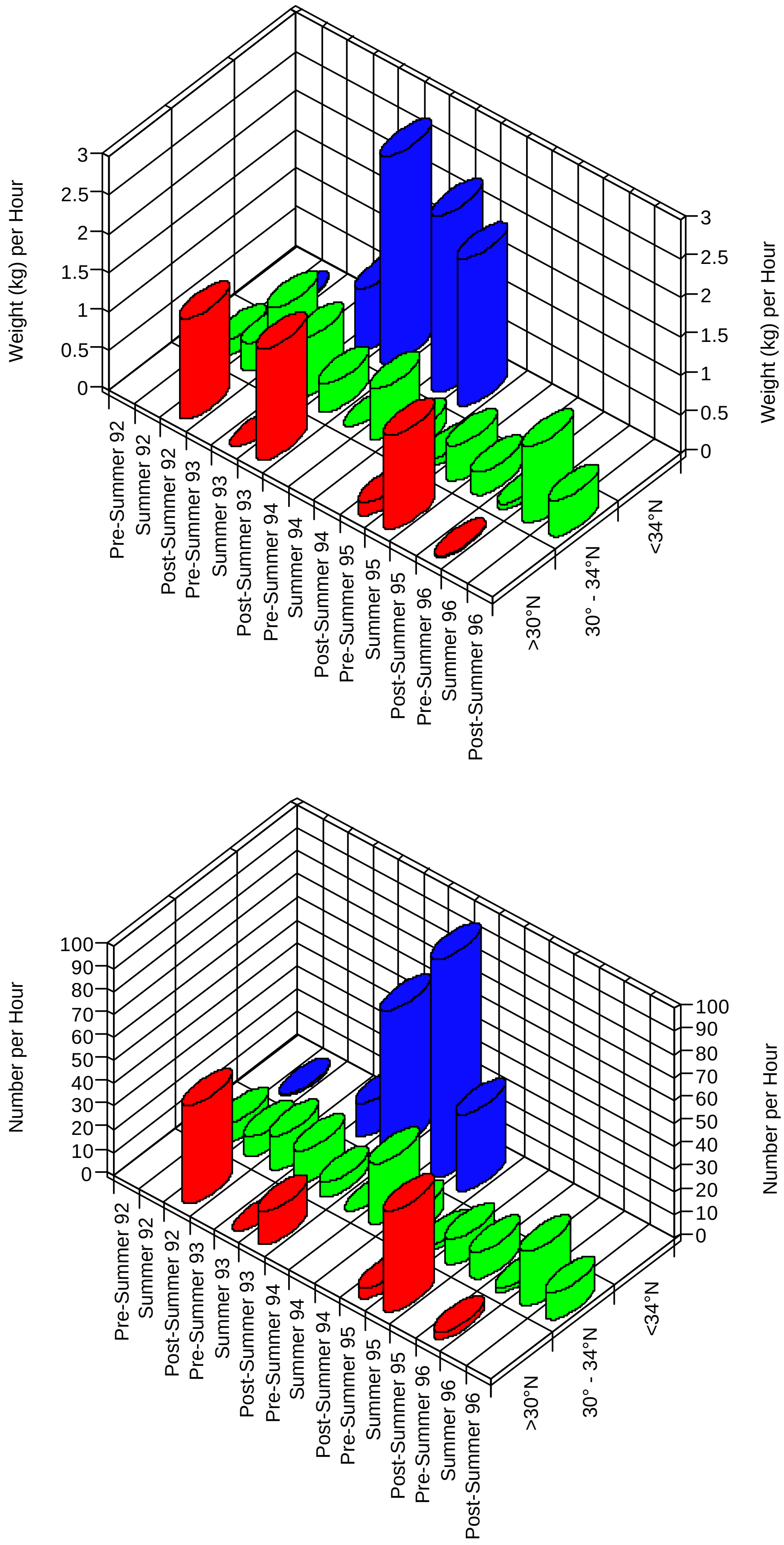
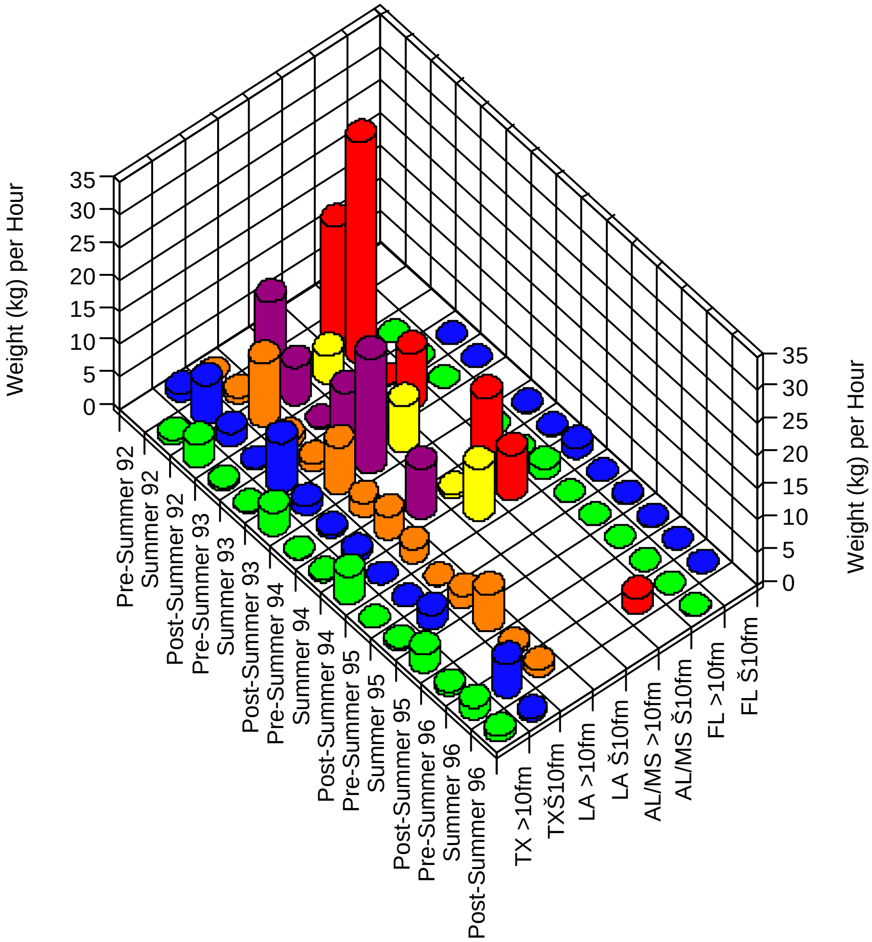


Figure 11. Weakfish catch per hour rates in the south Atlantic.



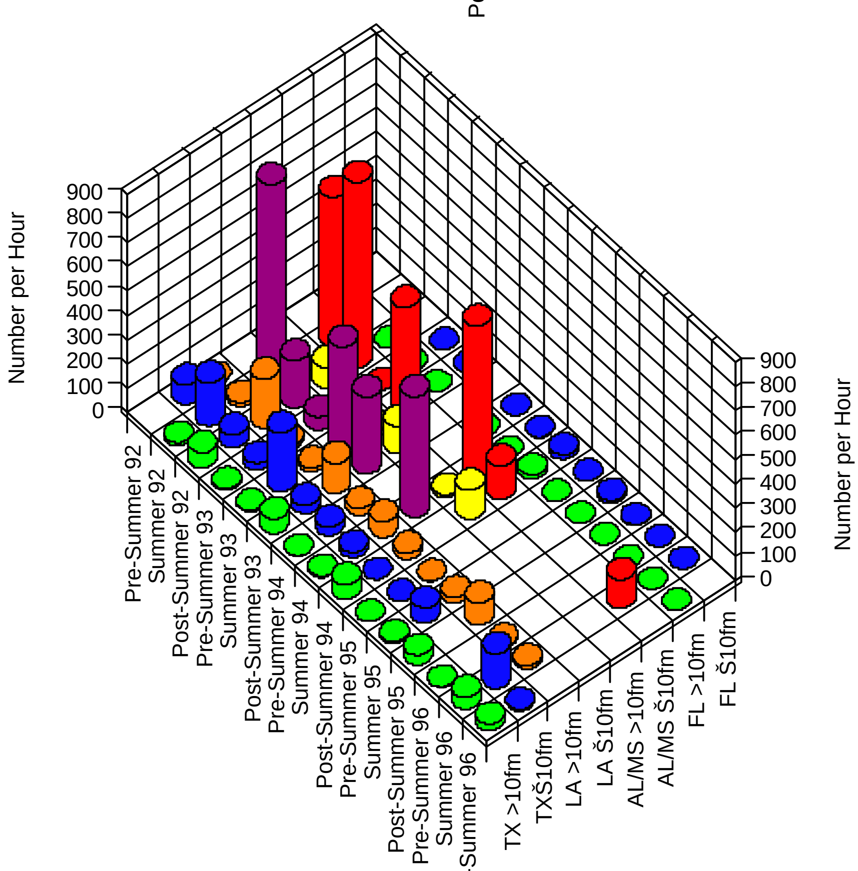


Figure 12. Atlantic croaker catch per hour rates in the Gulf of Mexico.

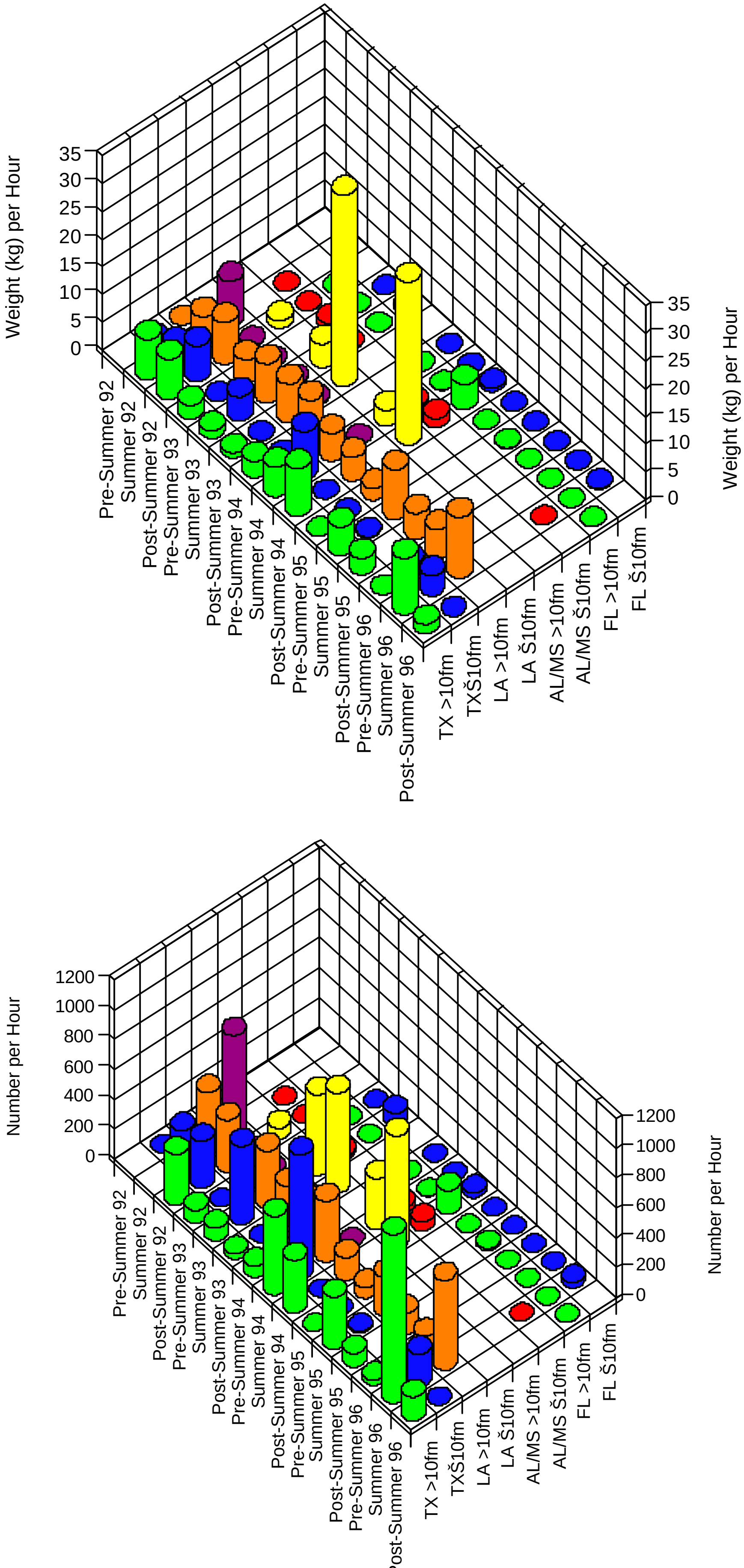


Figure 13. Longspine porgy catch per hour rates in the Gulf of Mexico.

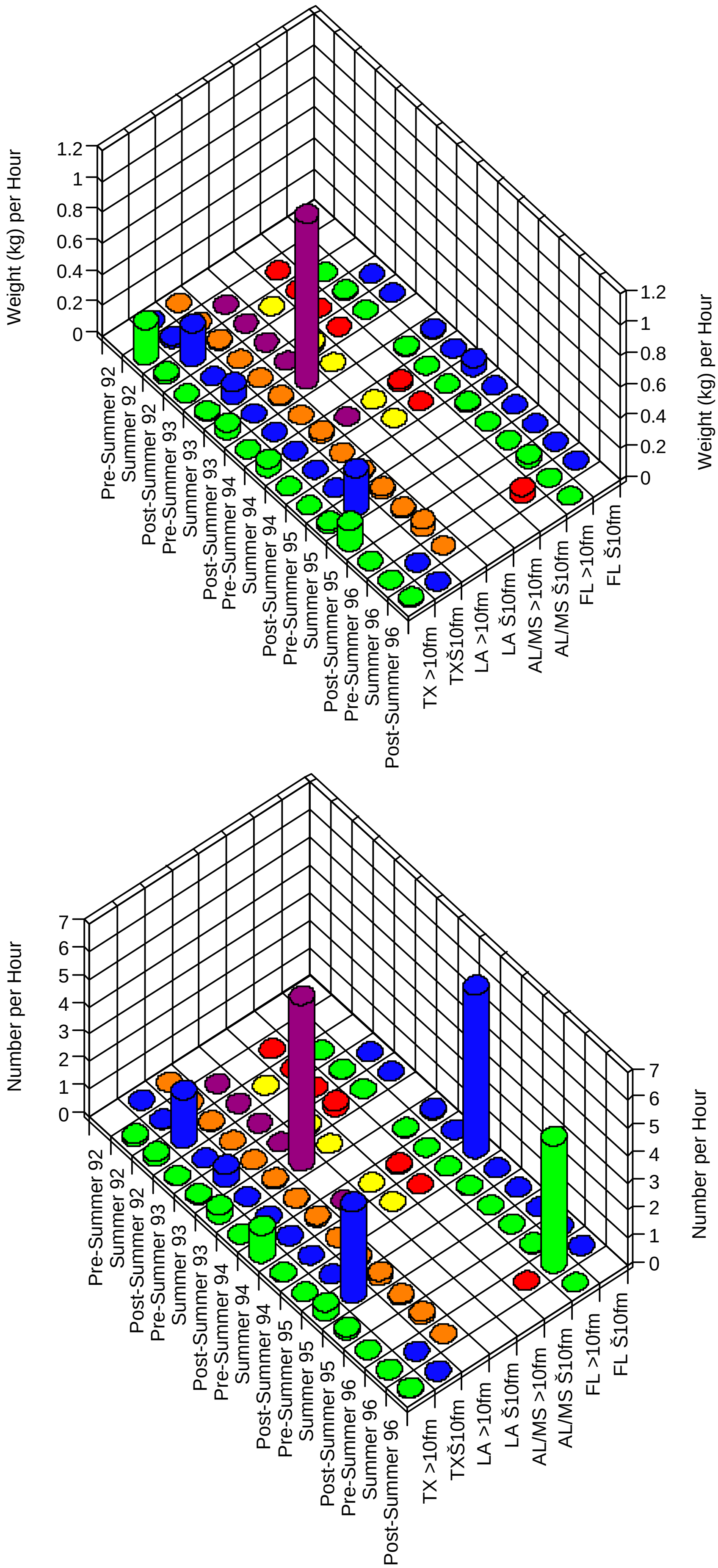
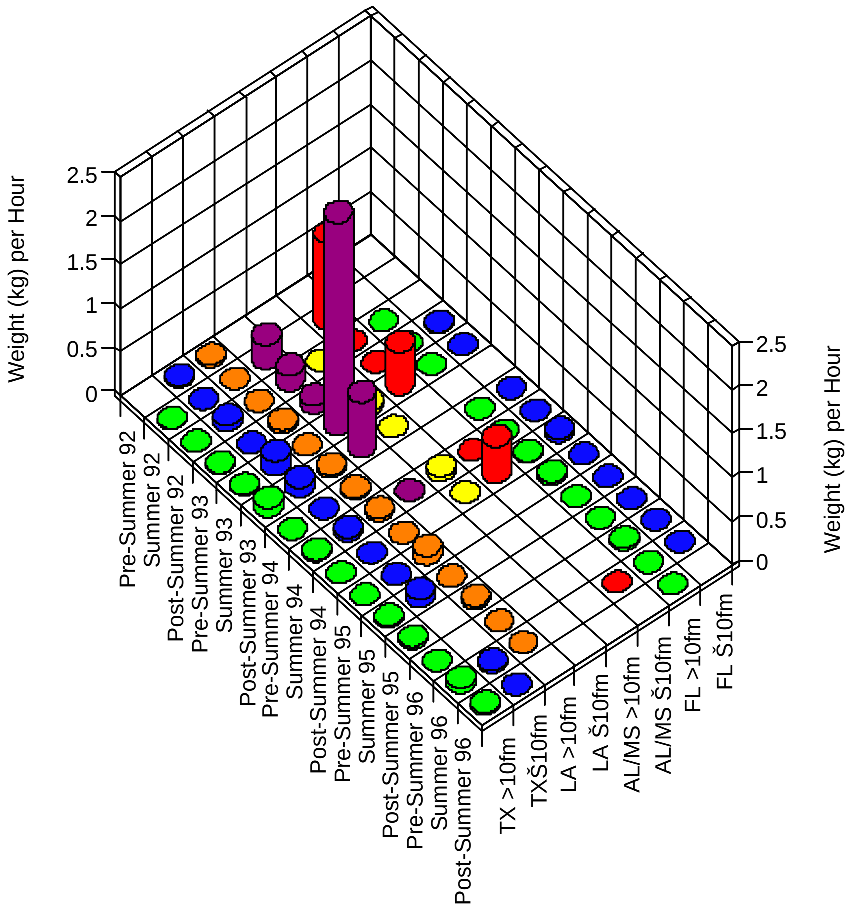


Figure 14. King mackerel catch per hour rates in the Gulf of Mexico.



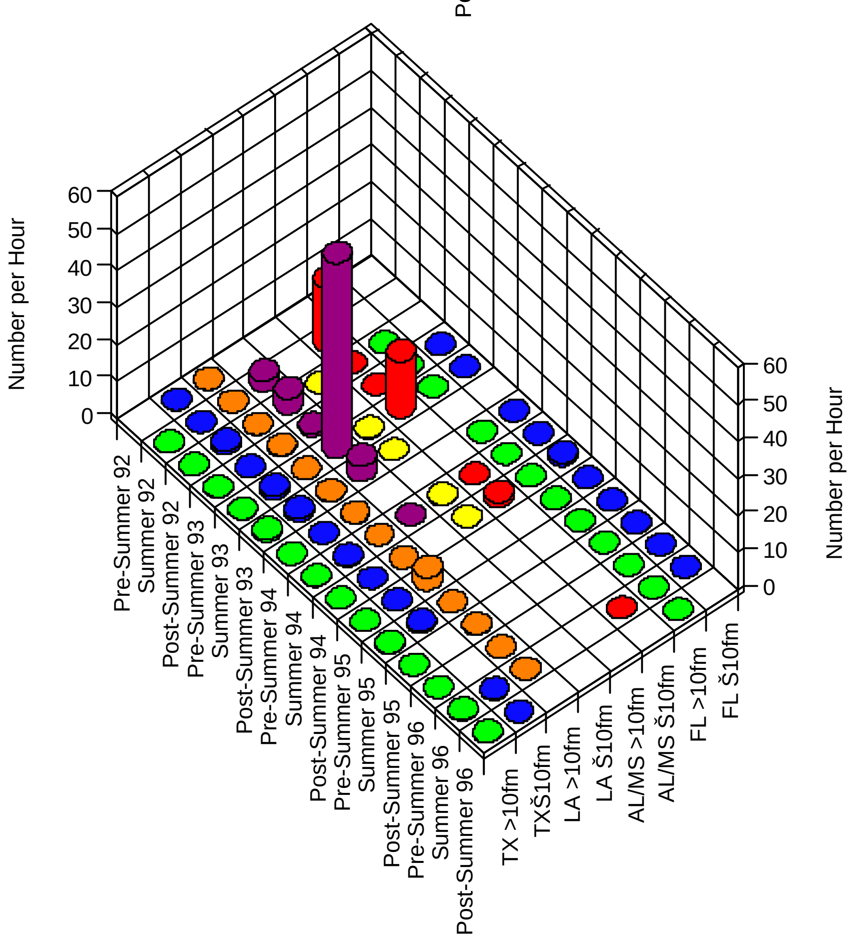


Figure 15. Spanish mackerel catch per hour rates in the Gulf of Mexico.

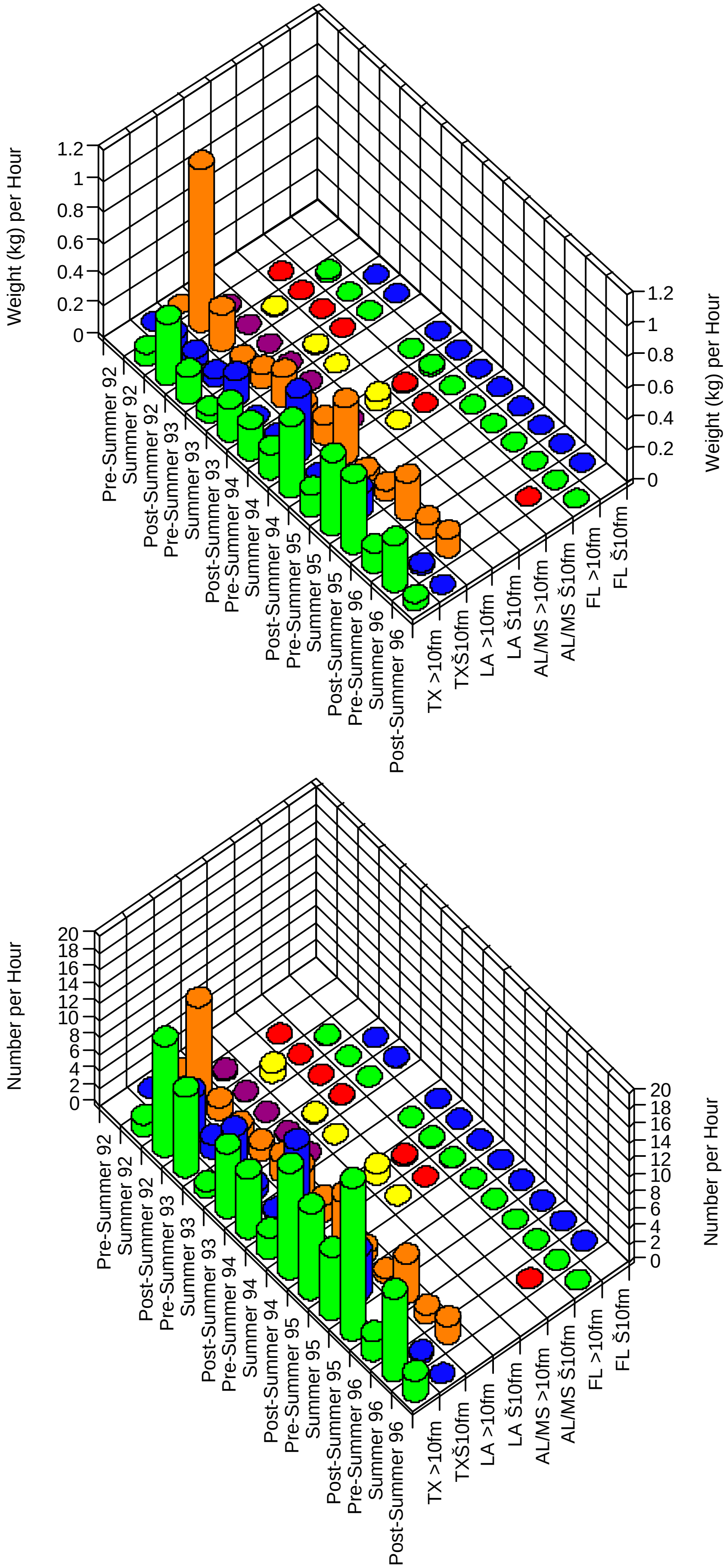


Figure 16. Red snapper catch per hour rates in the Gulf of Mexico.

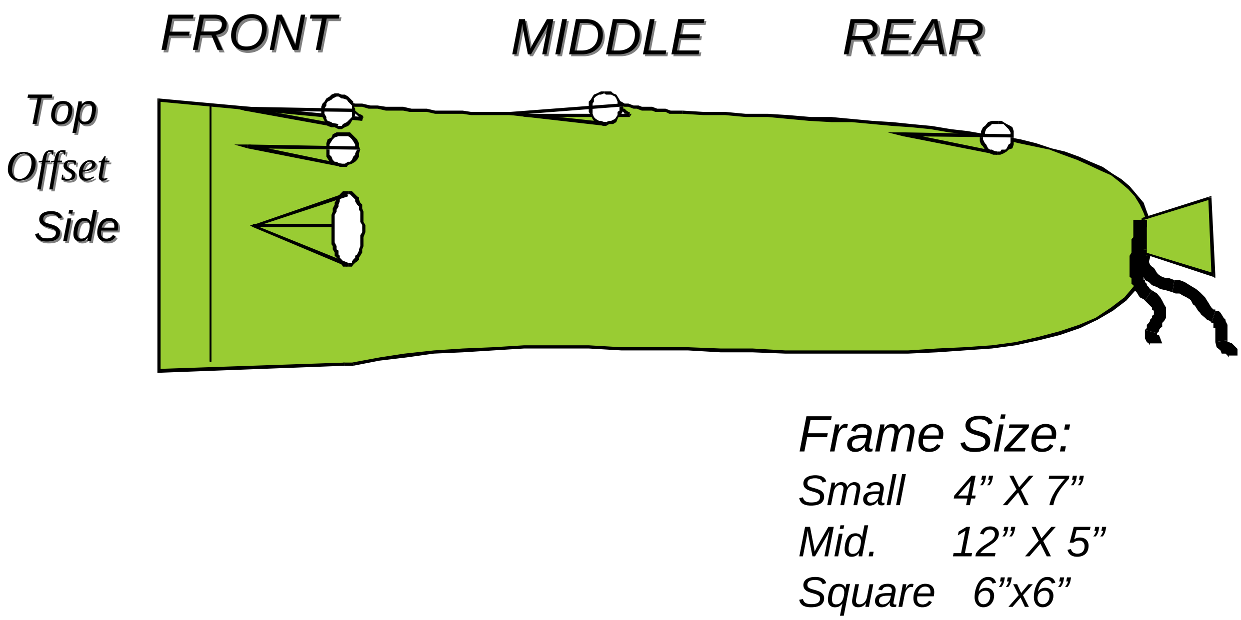


Figure 17. The various fisheye designs, with regards to position and size.

FUNNEL DESIGNS

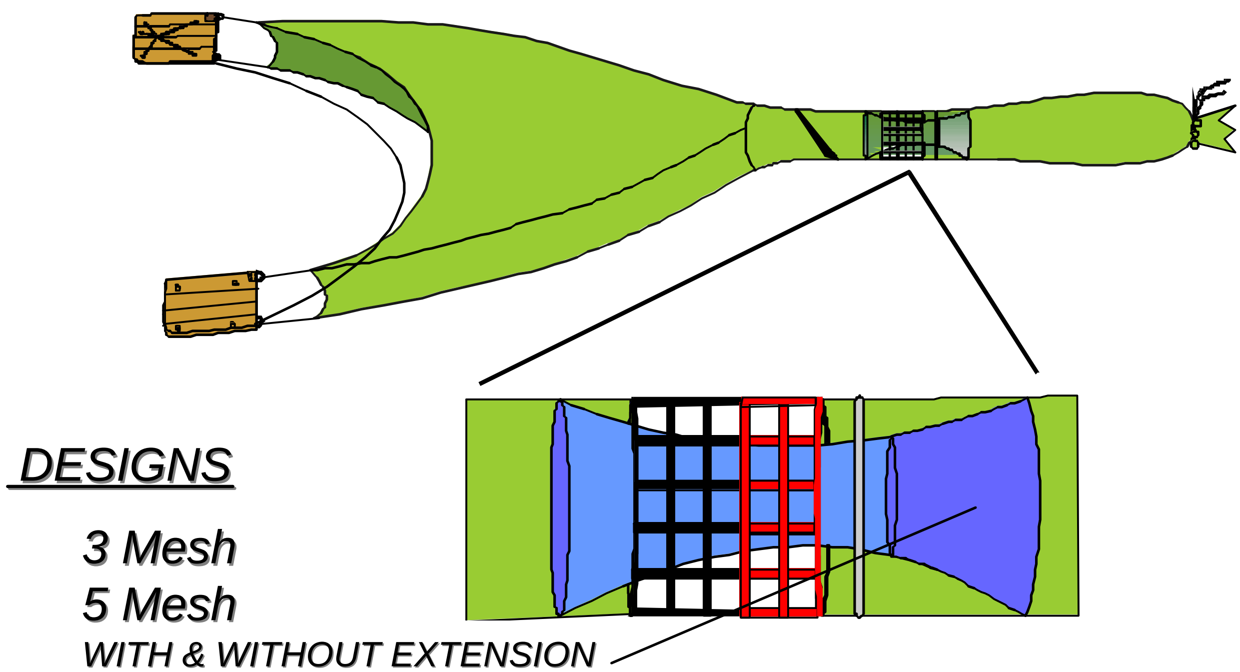


Figure 18. The various funnel designs, with regards to mesh number and extension modifications.

JONES/DAVIS WITH CONE STIMULATOR

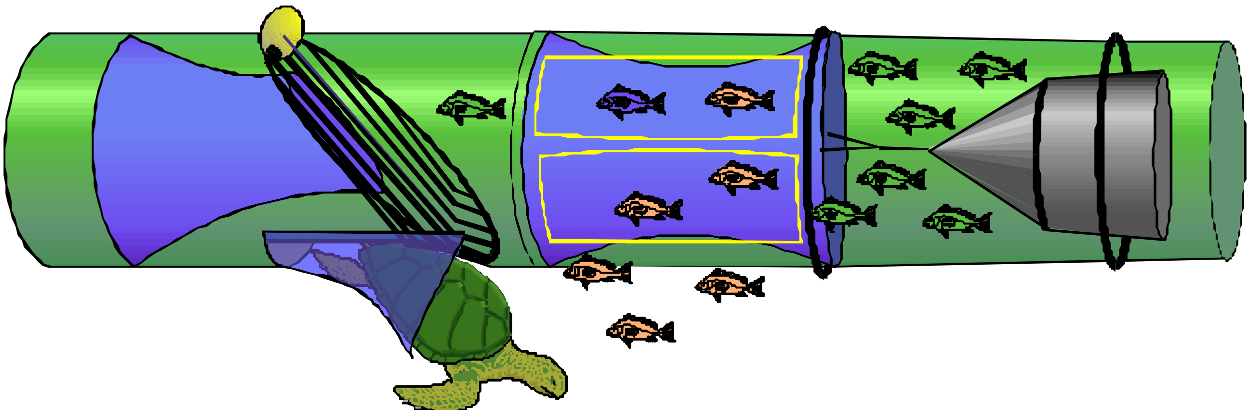


Figure 19. The Jones/Davis expanded mesh design.

12X5 FISHEYE (30 MESH), SS TED
REDUCTION RATES (GOM)

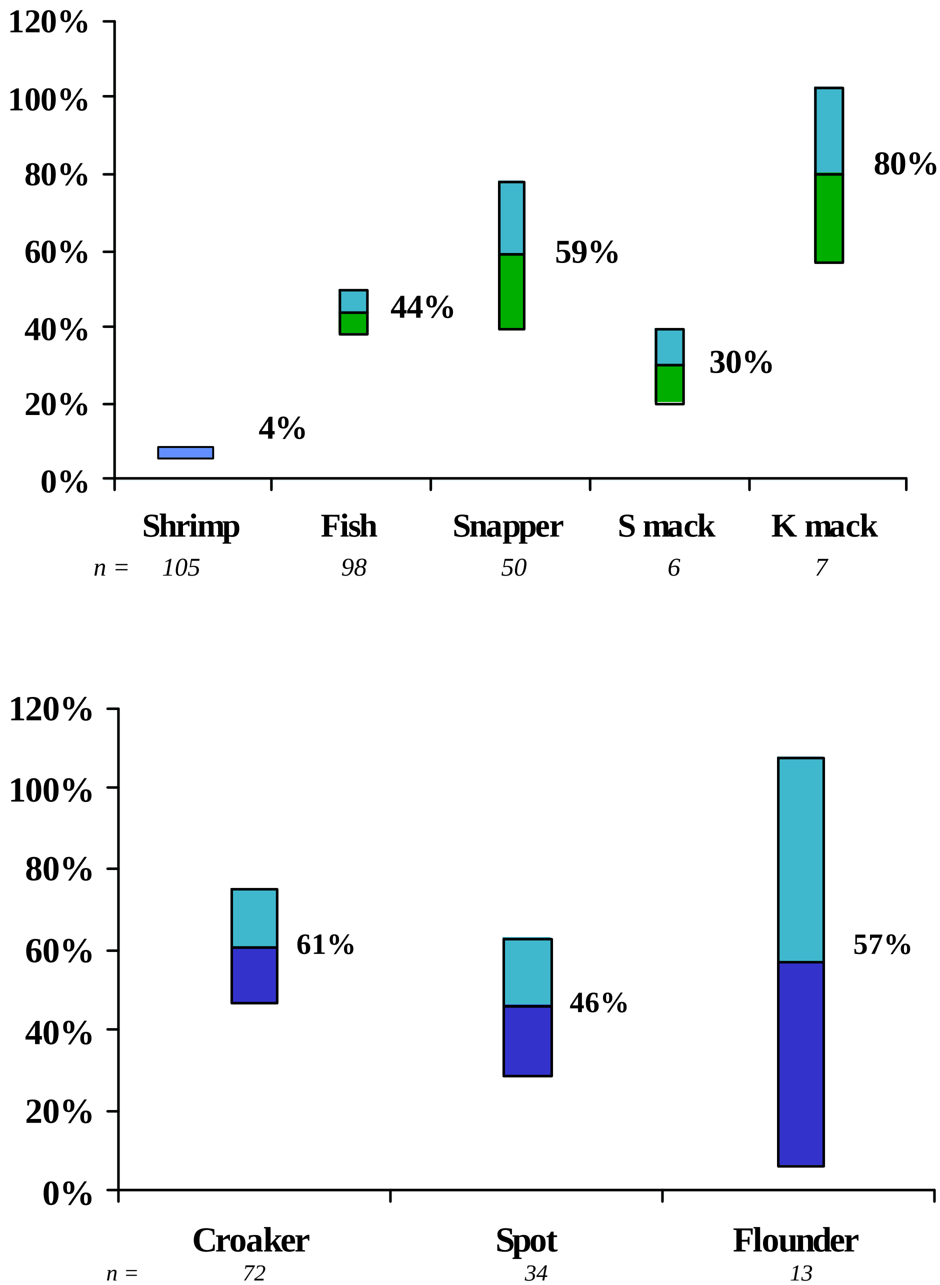
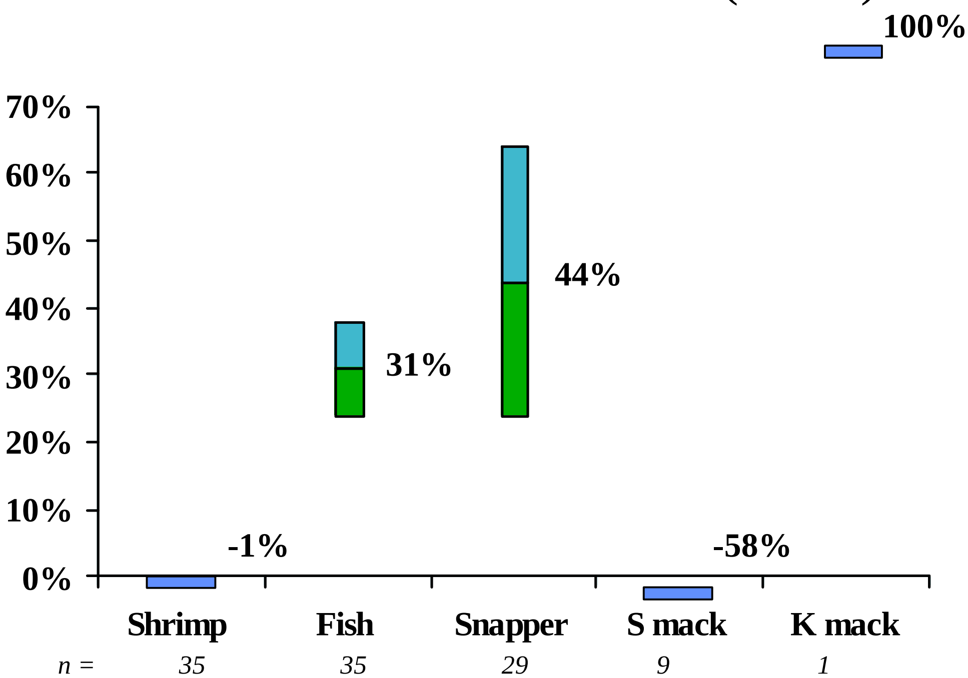


Figure 20. Reduction rates for the 12x5 (30 mesh position) fisheye design in the Gulf of Mexico, with a Supershooter TED.

12X5 FISHEYE (5 MESH), SS TED

REDUCTION RATES (GOM)



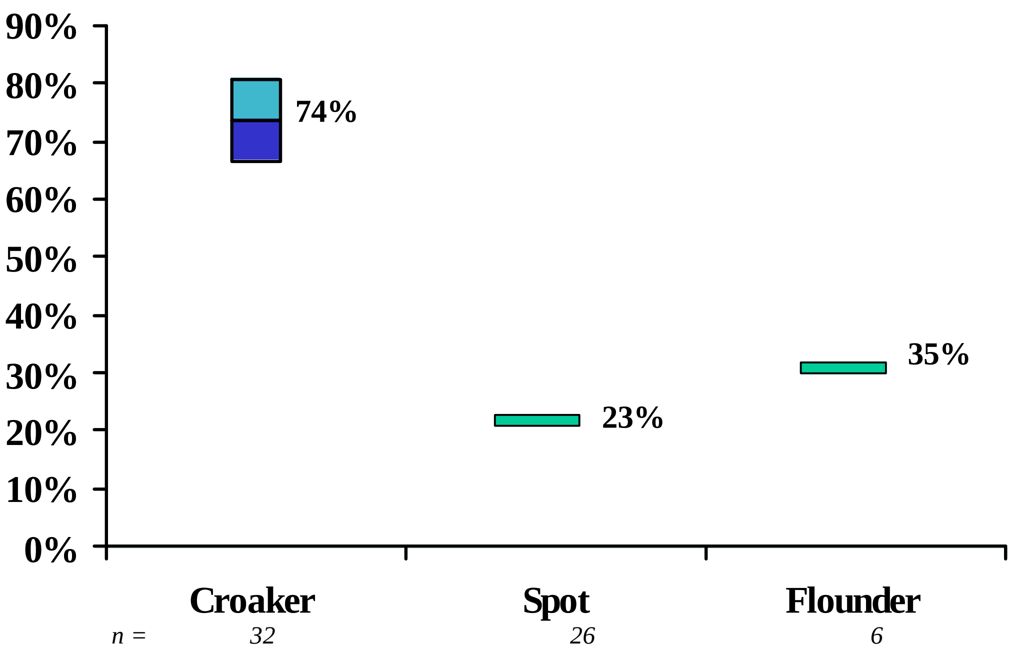
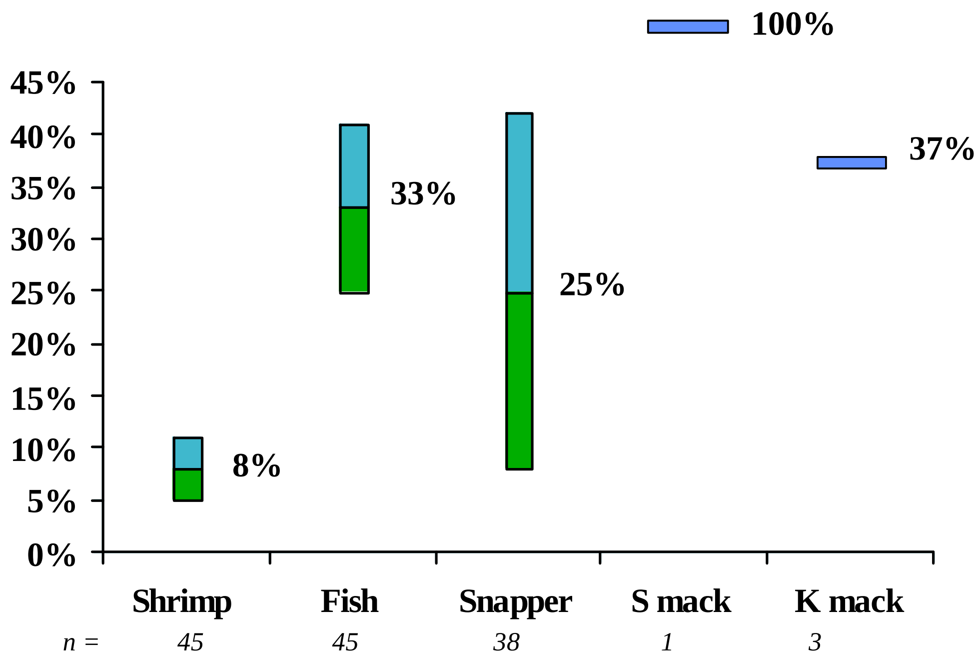


Figure 21. Reduction rates for the 12x5 (5 mesh position) fisheye design in the Gulf of Mexico, with a Supershooter TED.

12X5 FISHEYE (OFFSET), SS TED

REDUCTION RATES (GOM)



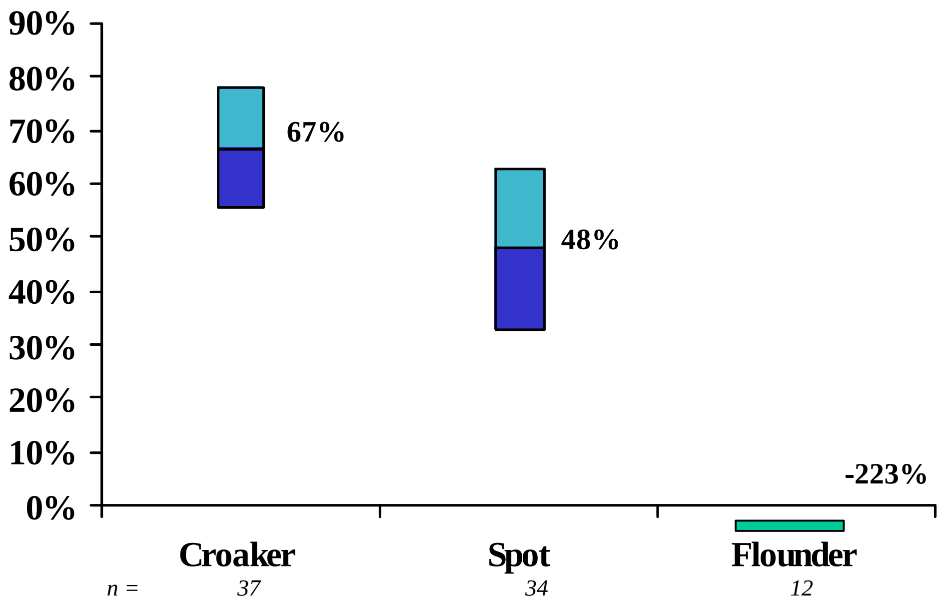
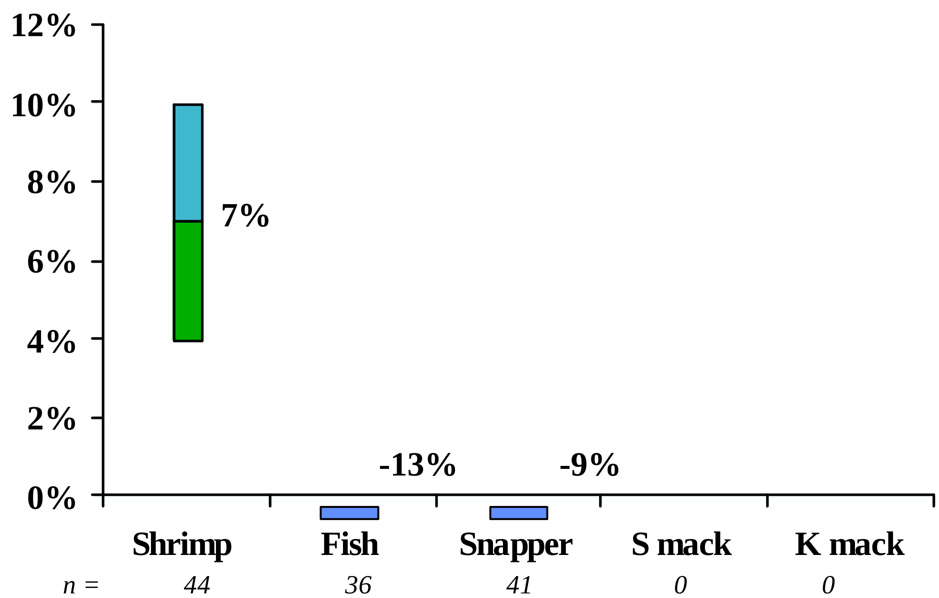


Figure 22. Reduction rates for the 12x5 (offset position) fisheye design in the Gulf of Mexico, with a Supershooter TED.

4X7 FISHEYE (30 MESH), AW TED
REDUCTION RATES (GOM)



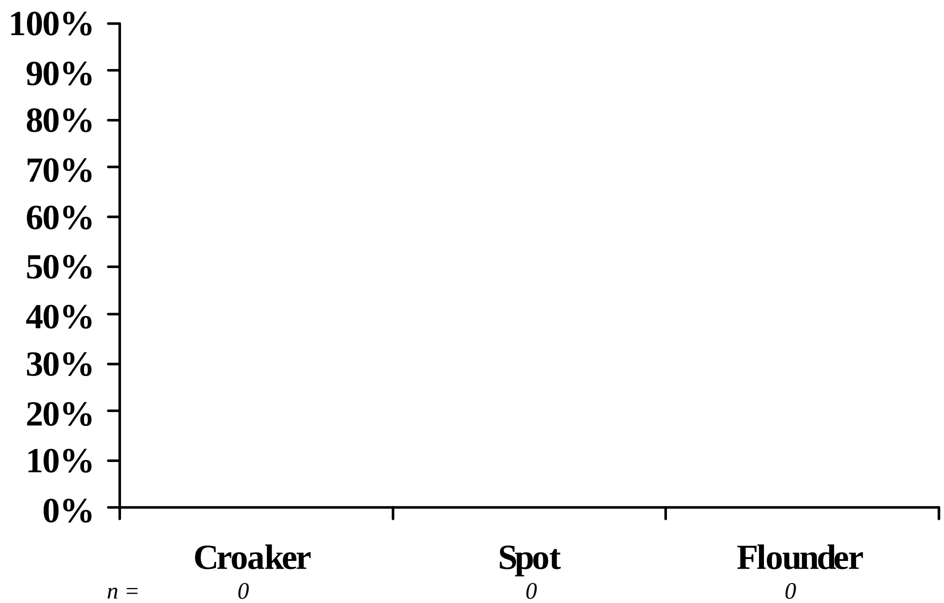
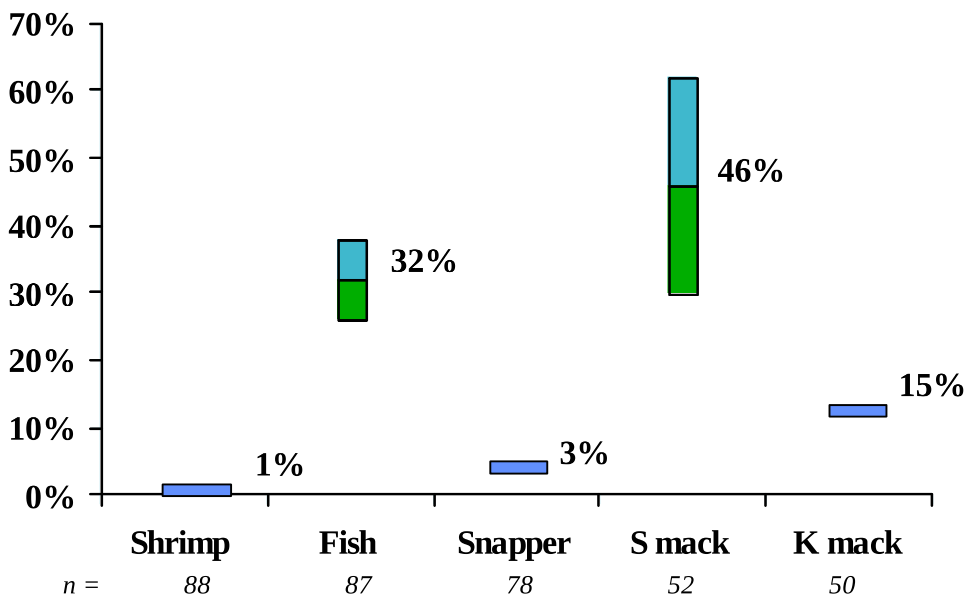


Figure 23. Reduction rates for the 4x7 (30 mesh position) fisheye design in the Gulf of Mexico, with an Anthony Weedless TED.

EXTENDED FUNNEL, SS TED
REDUCTION RATES (GOM)



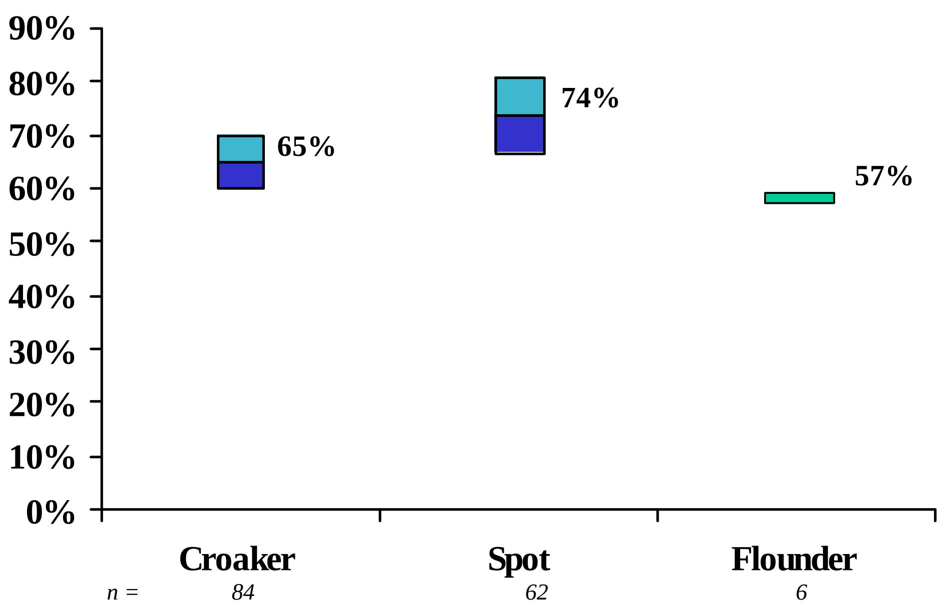


Figure 24. Reduction rates for the extended funnel design in the Gulf of Mexico, with a Supershooter TED.

3/5 EXTENDED FUNNEL, BUS TED
REDUCTION RATES (GOM)

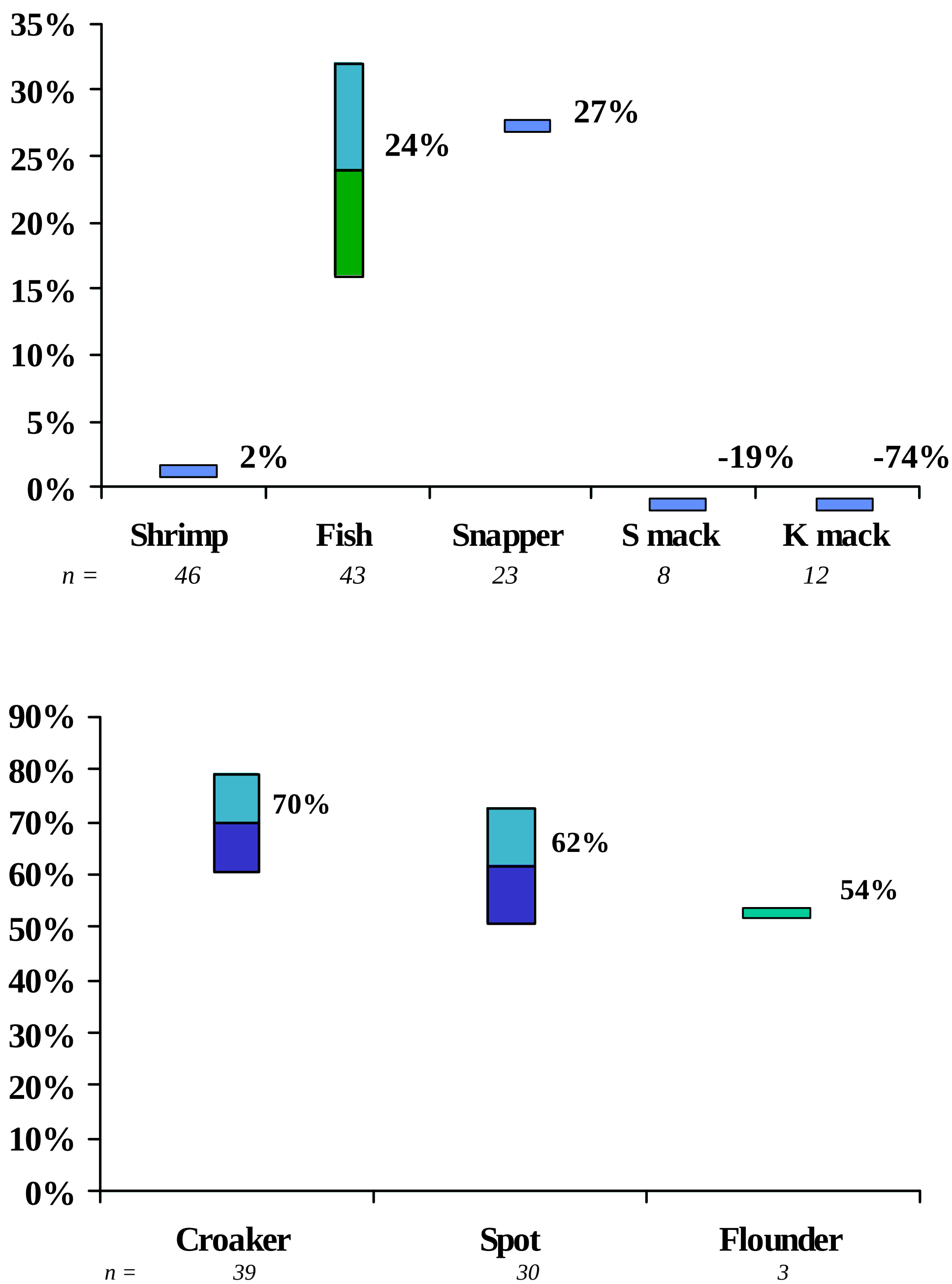
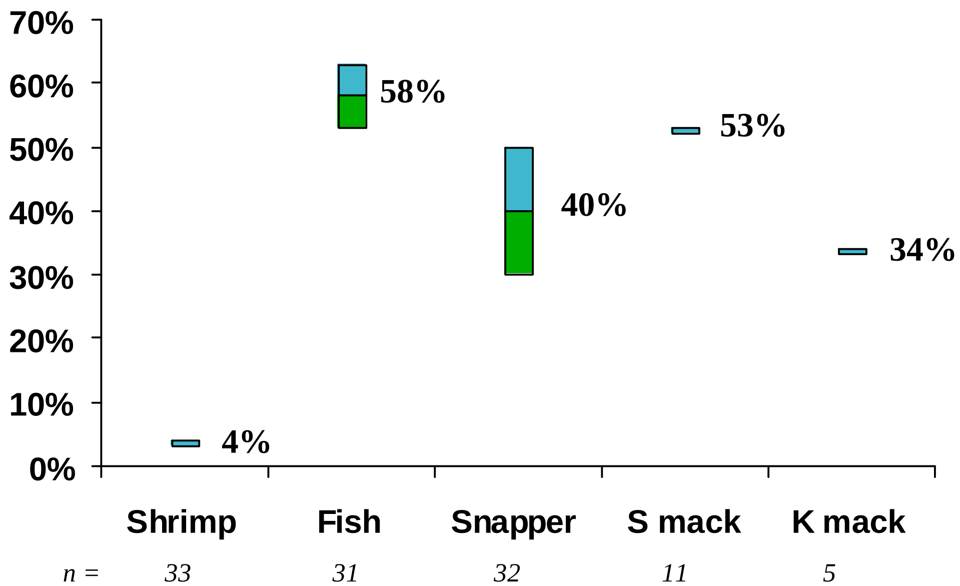


Figure 25. Reduction rates for the 3/5 extended funnel design in the Gulf of Mexico, with a Busken TED.

JONES/DAVIS BRD
REDUCTION RATES (GOM)



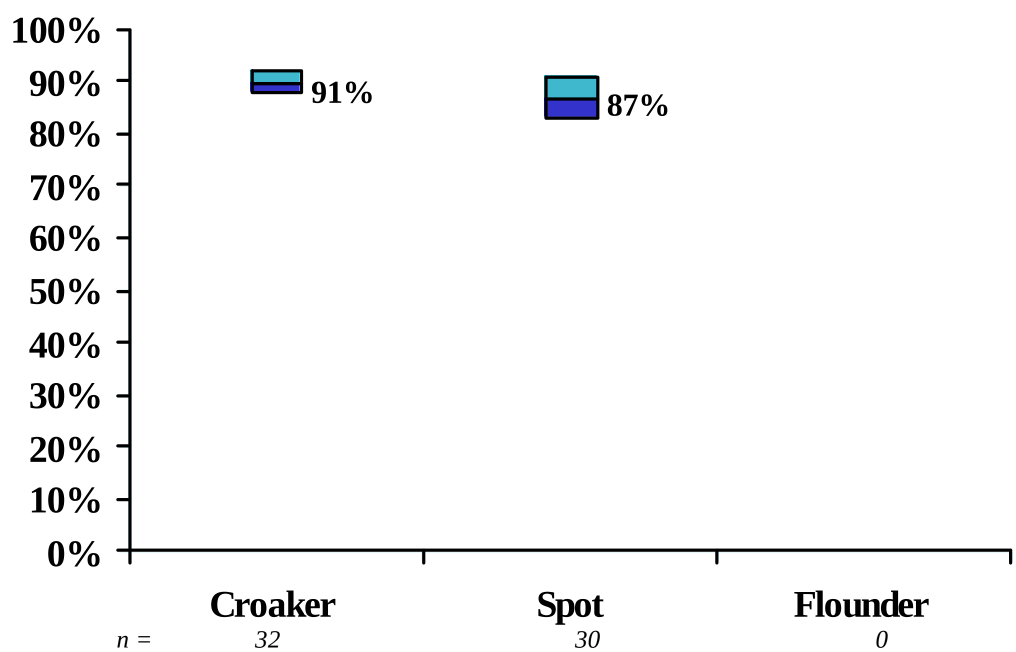


Figure 26. Reduction rates for the Jones/Davis extended funnel design in the Gulf of Mexico.

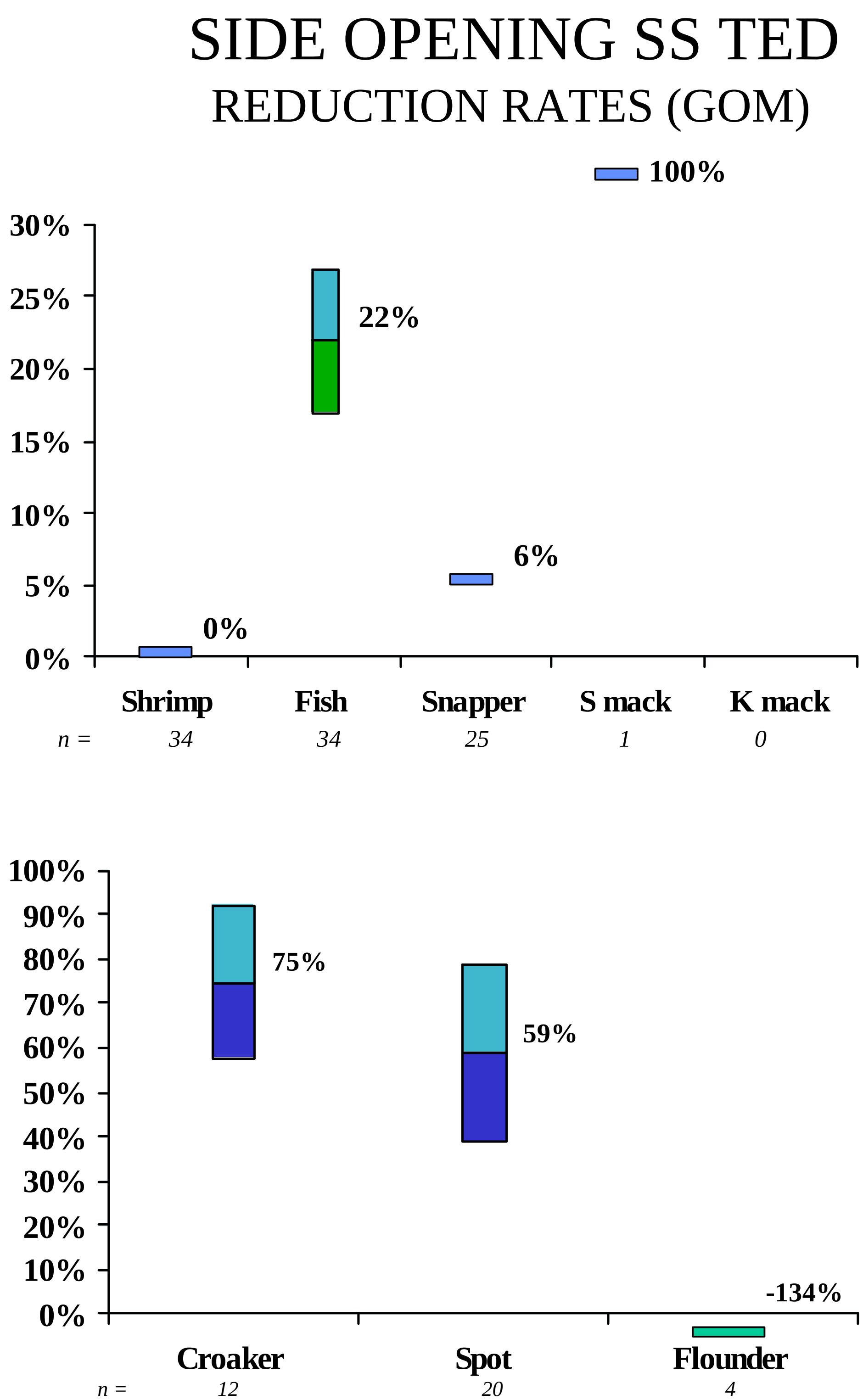


Figure 27. Reduction rates for the side opening Supershooter TED design in the Gulf of Mexico.

FRONT FISHEYE (12X5), BB TED

REDUCTION RATES (S. ATL)

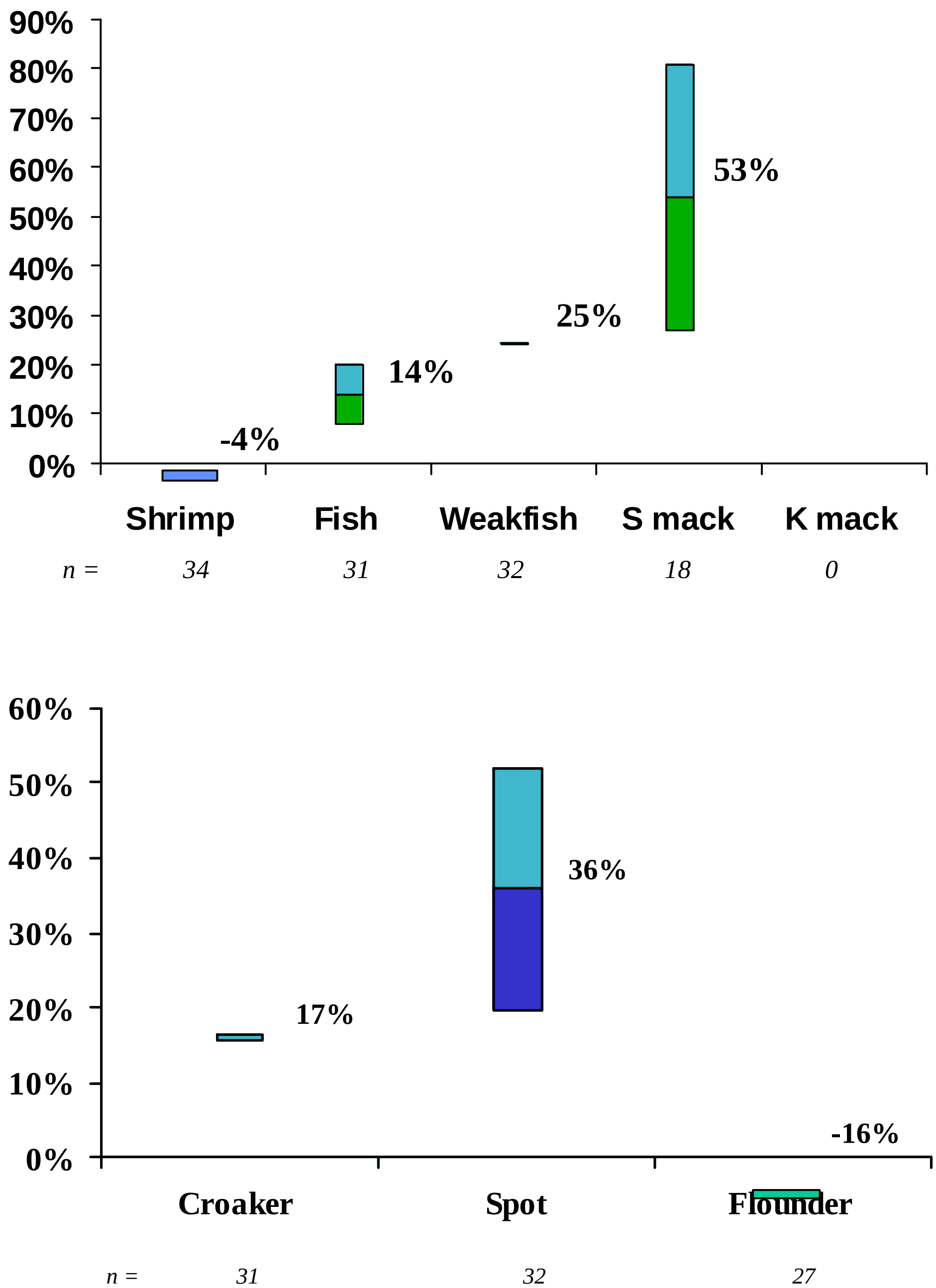
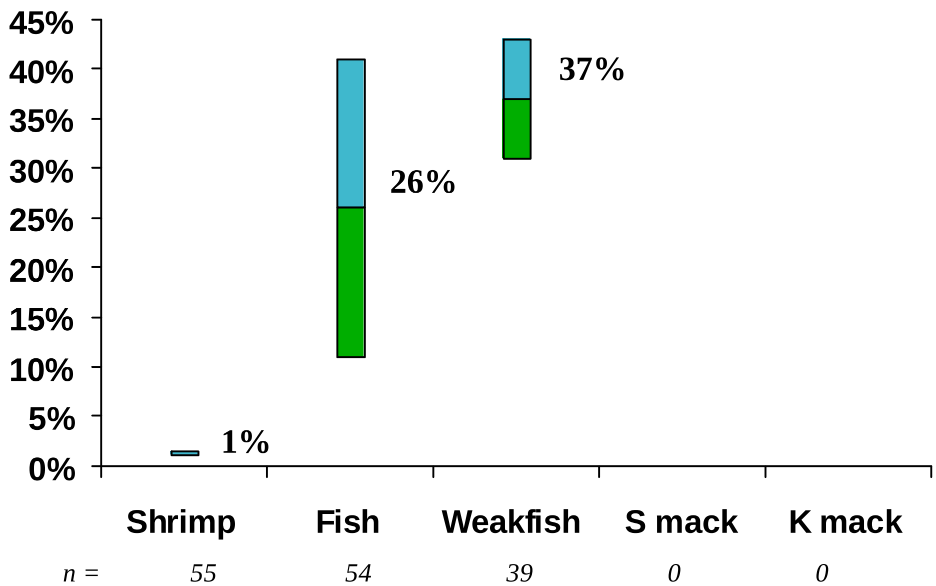


Figure 28. Reduction rates for the 12x5 (front position) fisheye design in the south Atlantic, with a Burbank TED.

OFFSET FISHEYE (12X5), BB TED
REDUCTION RATES (S. ATL)



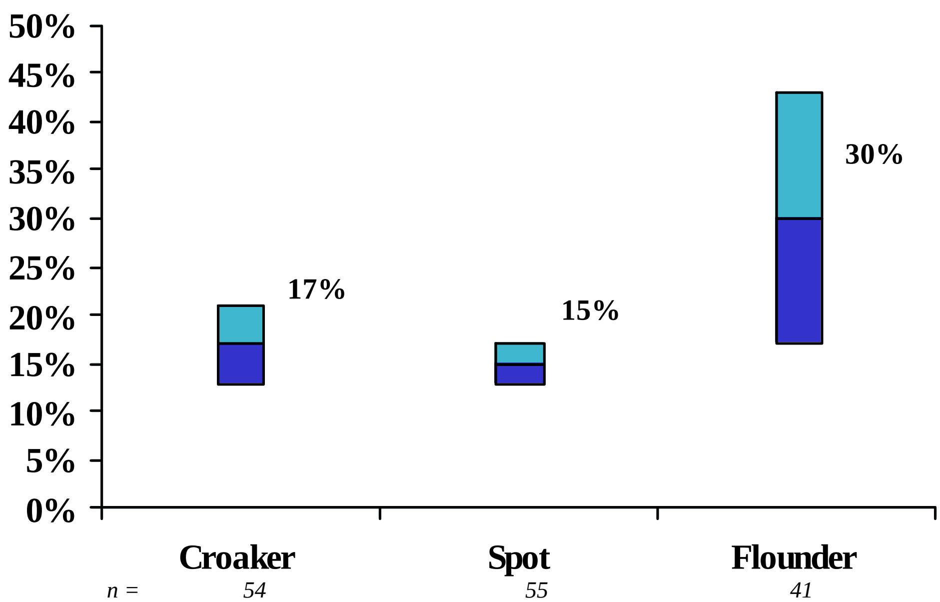
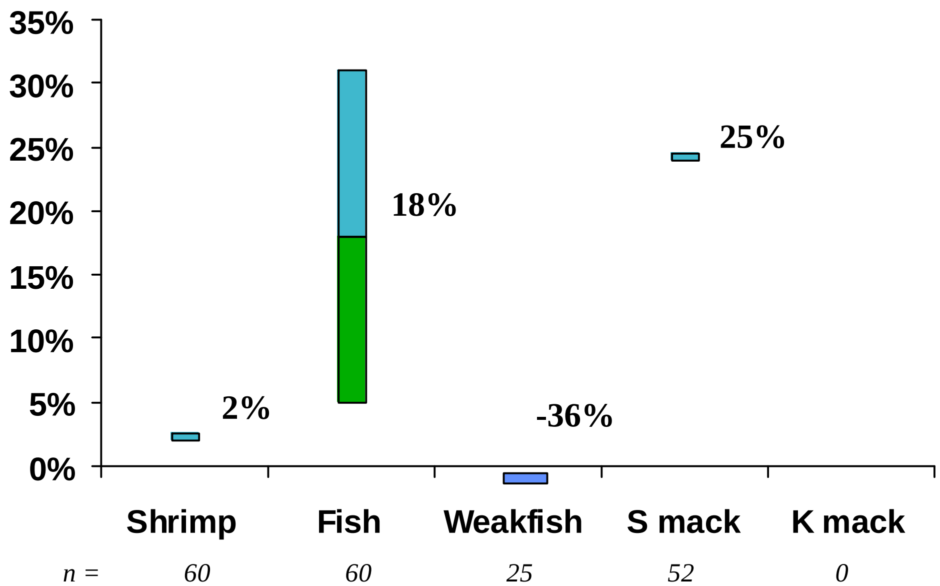


Figure 29. Reduction rates for the 12x5 (offset position) fisheye design in the south Atlantic, with a Burbank TED.

FRONT FISHEYE (4X7), NO TED

REDUCTION RATES (S. ATL)



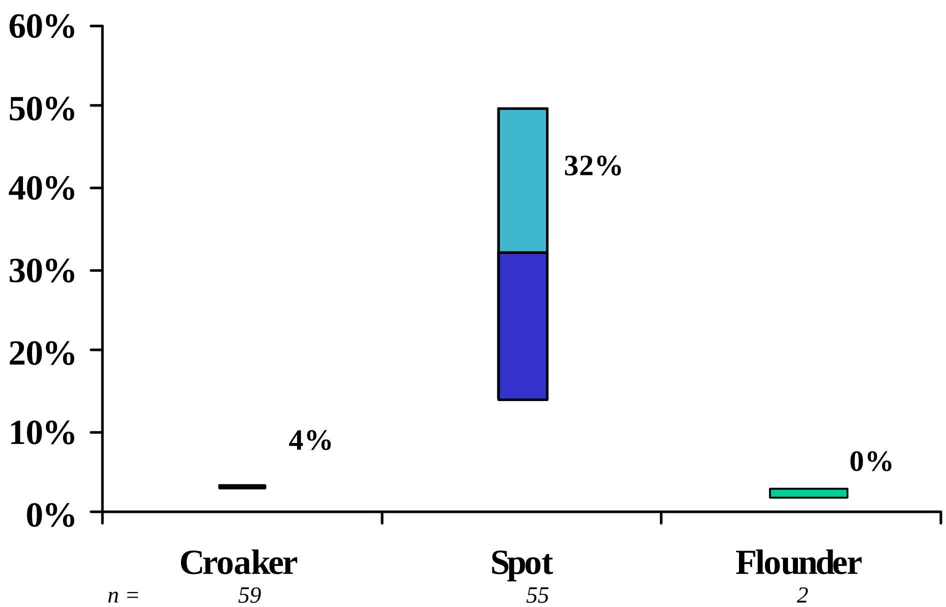


Figure 30. Reduction rates for the 4x7 (front position) fisheye design in the south Atlantic.

MIDDLE FISHEYE (6X6), NO TED
REDUCTION RATES (S. ATL)

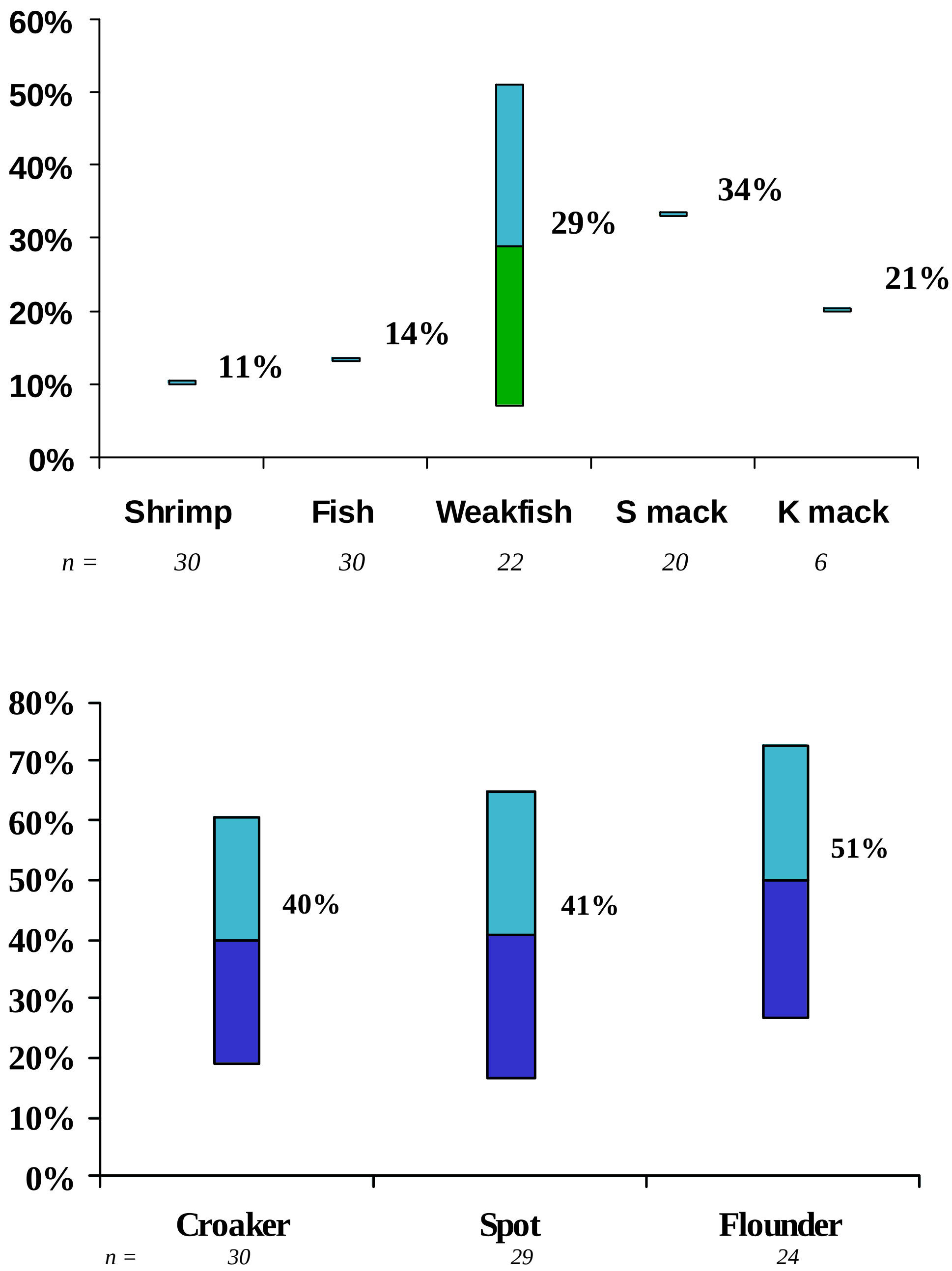
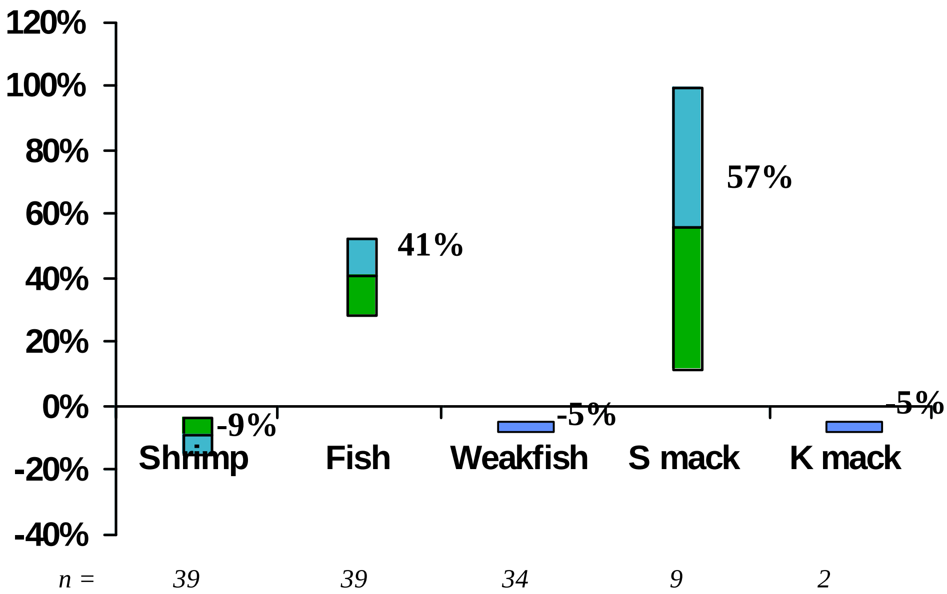


Figure 31. Reduction rates for the 6x6 (middle position) fisheye design in the south Atlantic.

EXTENDED FUNNEL, GA TED

REDUCTION RATES (S. ATL)



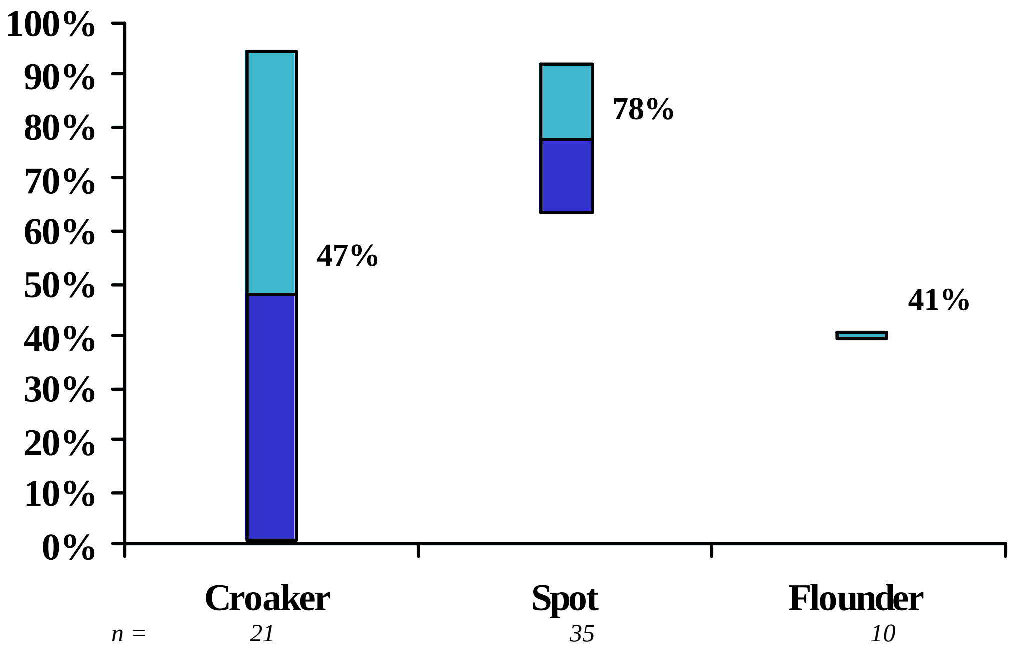
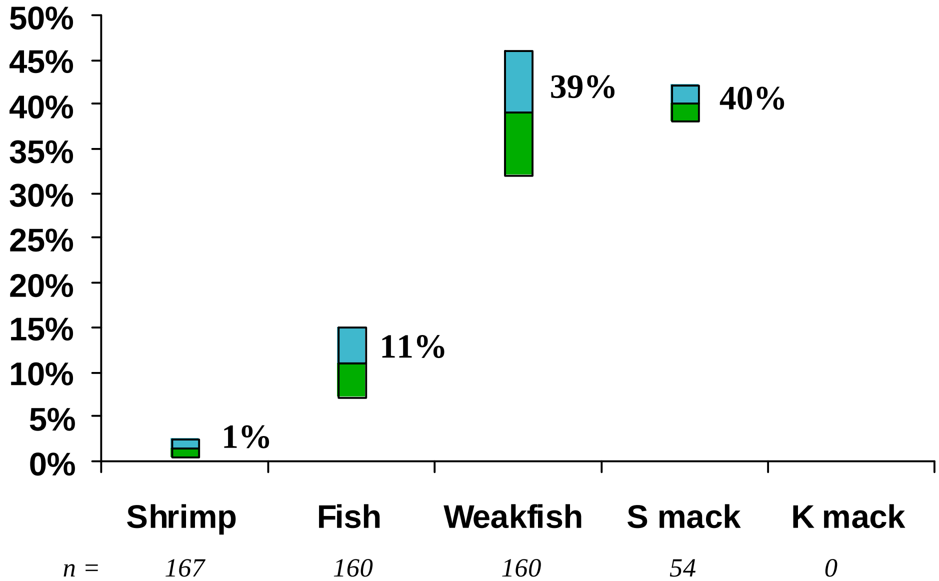


Figure 32. Reduction rates for extended funnel design in the south Atlantic, with a Georgia TED.

EXTENDED FUNNEL, BB TED

REDUCTION RATES (S. ATL)



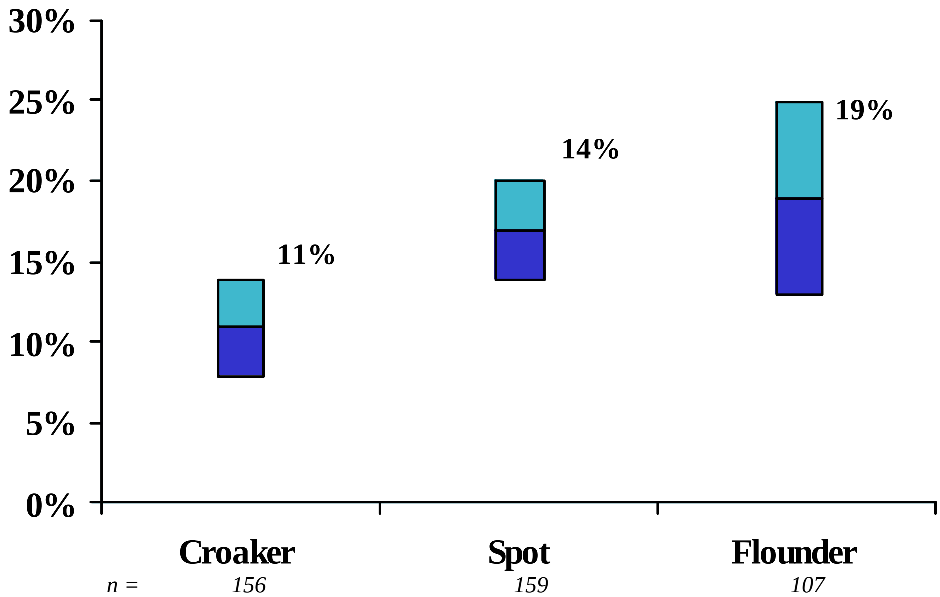
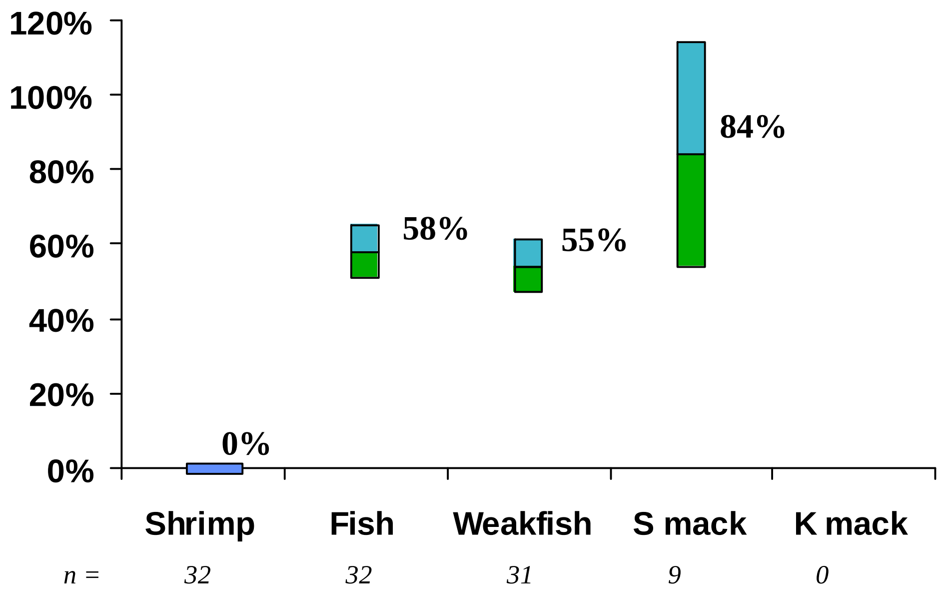


Figure 33. Reduction rates for extended funnel design in the south Atlantic, with a Burbank TED.

EXTENDED FUNNEL, SS TED

REDUCTION RATES (S. ATL)



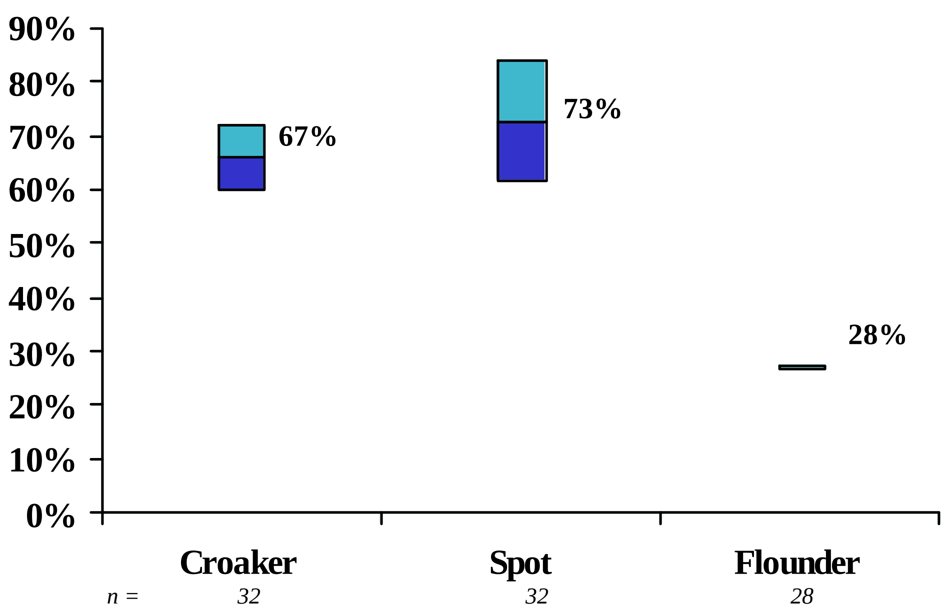
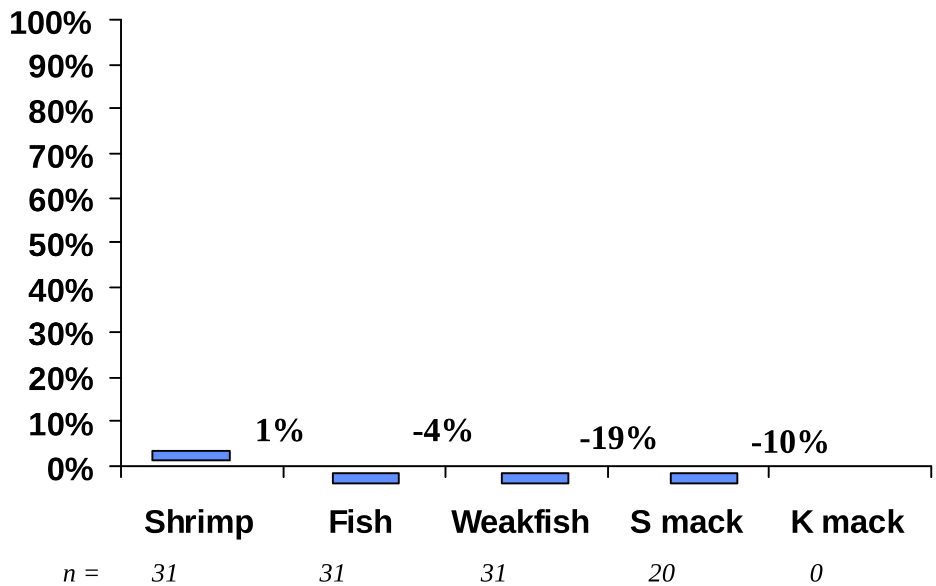


Figure 34. Reduction rates for extended funnel design in the south Atlantic, with a Supershooter TED.

SNAKE EYES, PAR TED
REDUCTION RATES (S. ATL)



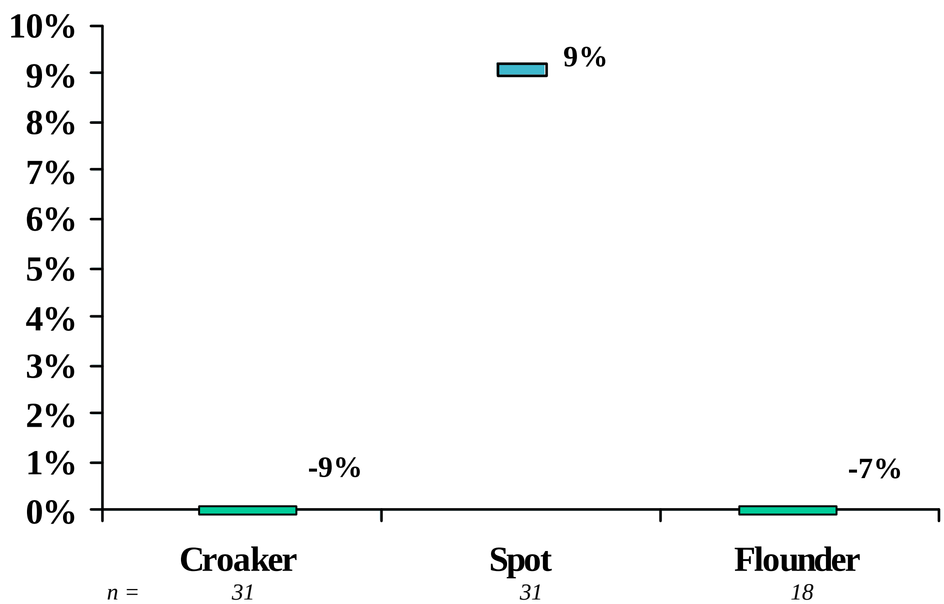


Figure 35. Reduction rates for snake eye design in the south Atlantic, with a Parker TED.

TOP POSITION FISHEYE

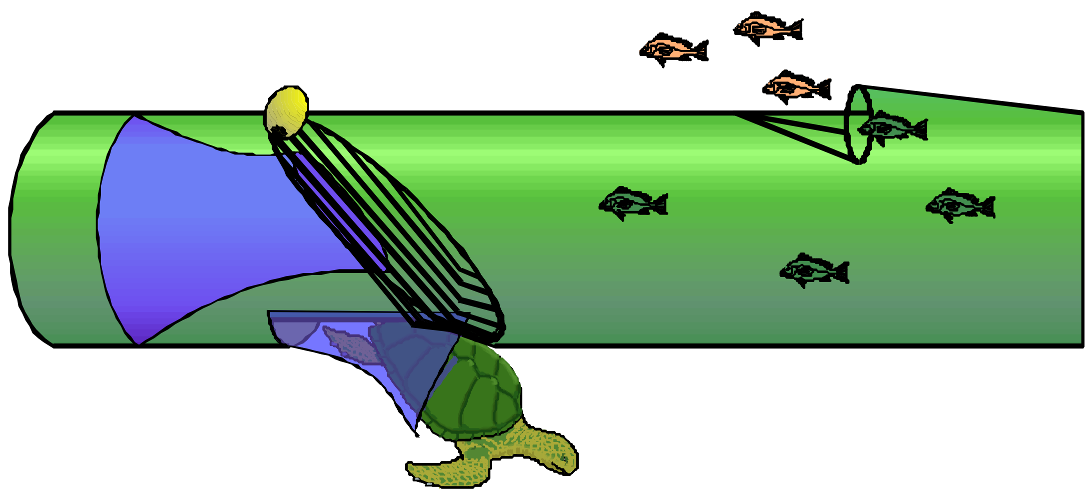


Figure 36. Fisheye design in the top position.

EXTENDED FUNNEL

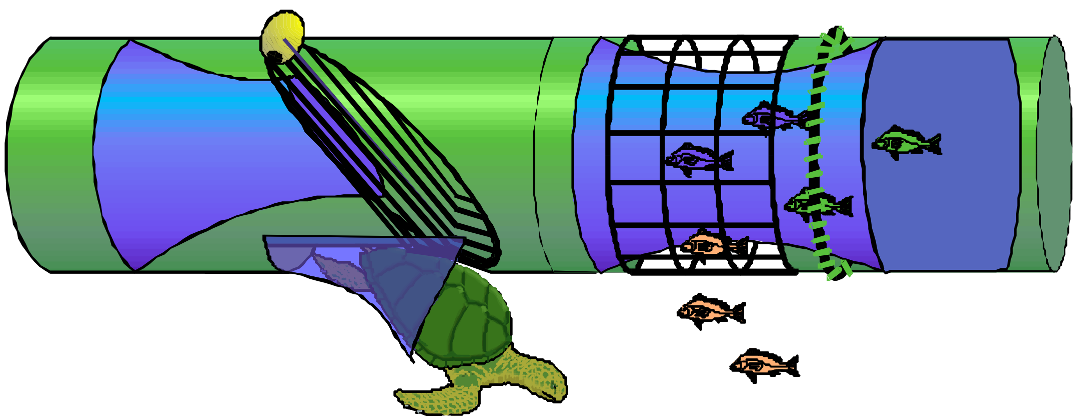


Figure 37. Extended funnel design.

EXPANDED MESH WITH CONE STIMULATOR

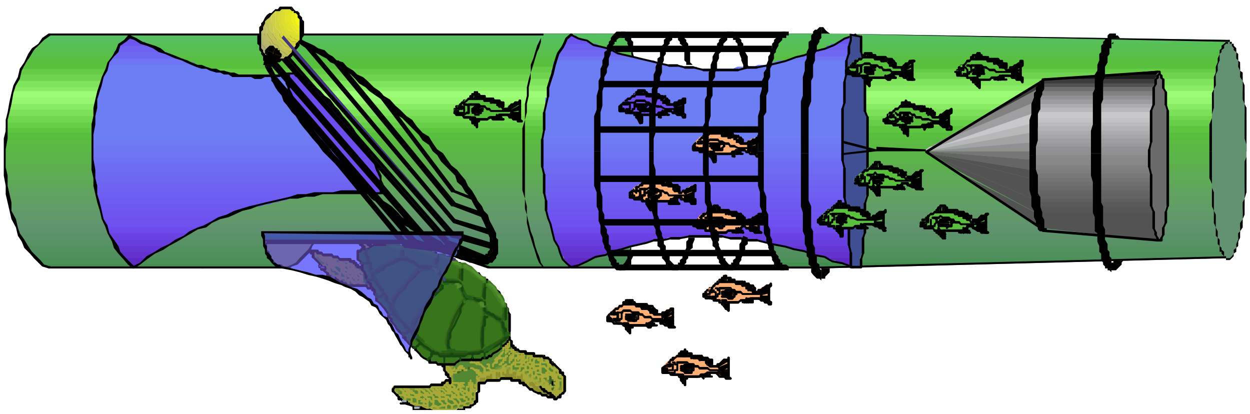


Figure 38. Expanded mesh design with a fish stimulator cone.

Parker TED

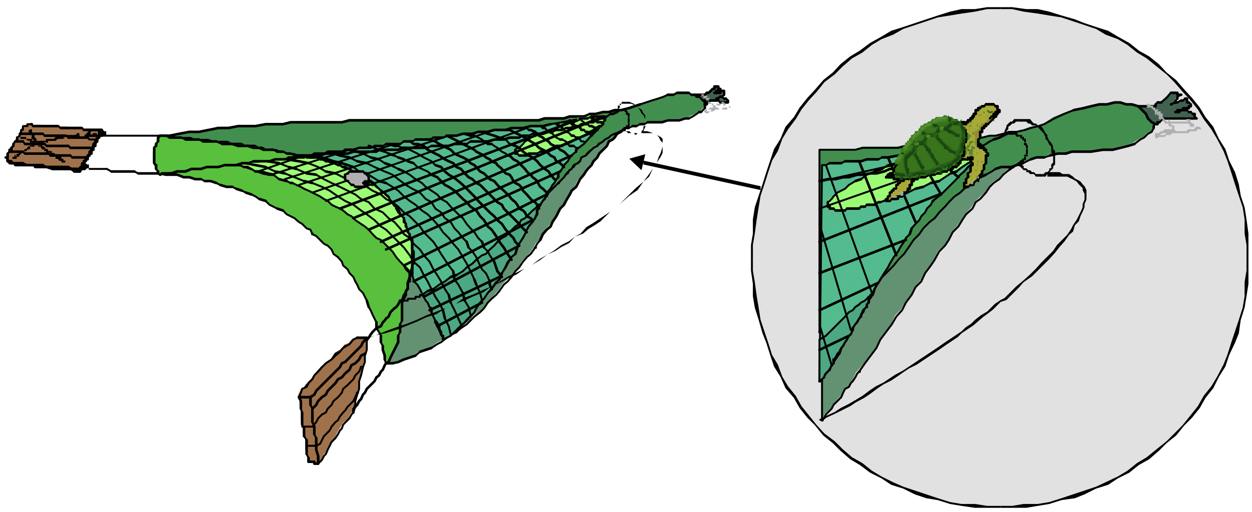


Figure 39. Parker TED design.

DIHN TED
(4 x 8 Andrews TED)

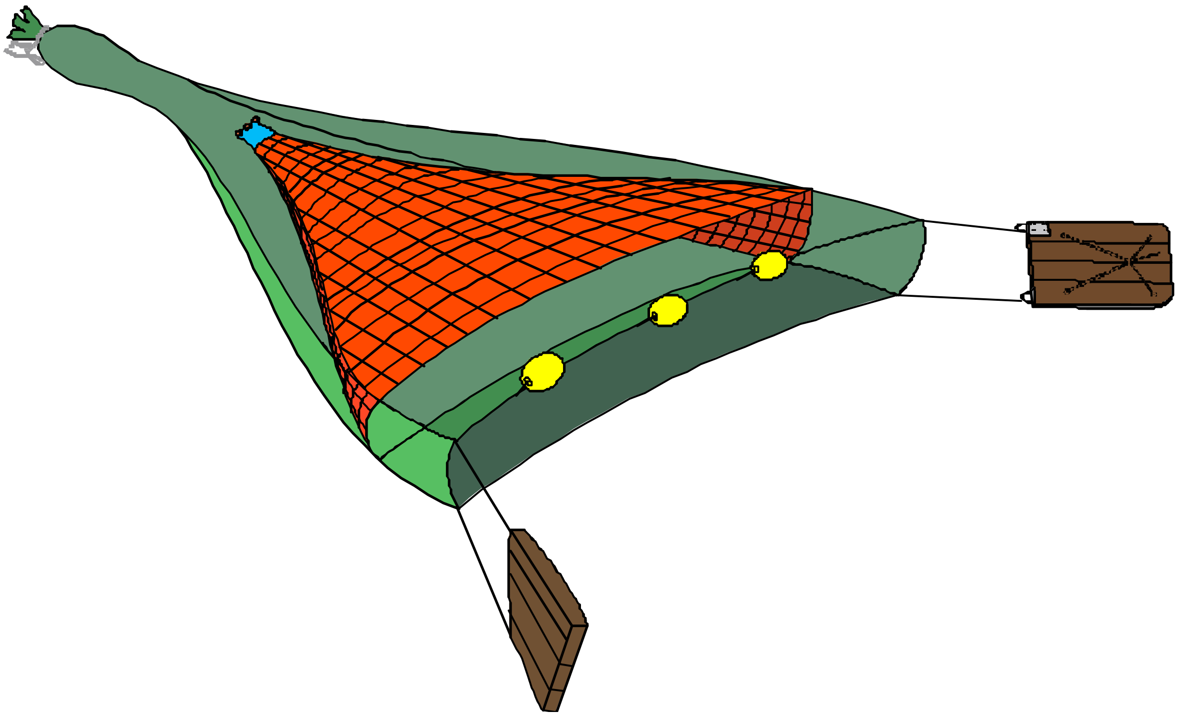


Figure 40. The DIHN TED design.

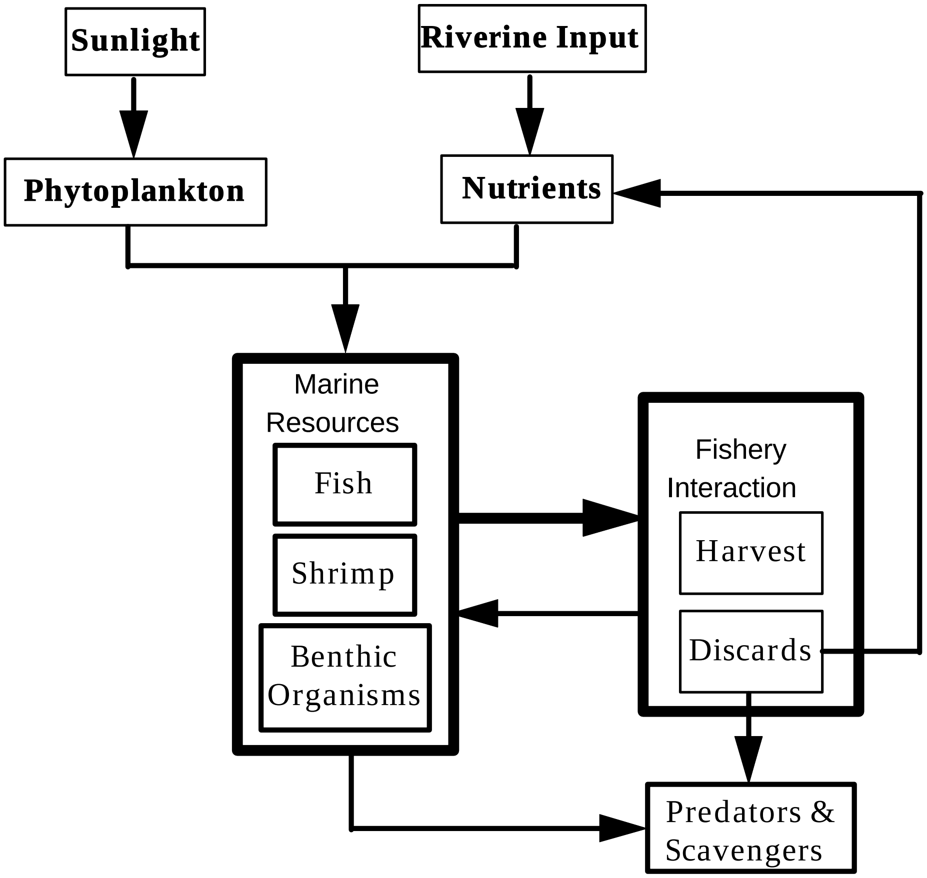


Figure 41. Generalized conceptual ecosystem model to evaluate impacts of shrimp trawl bycatch in the Gulf of Mexico.

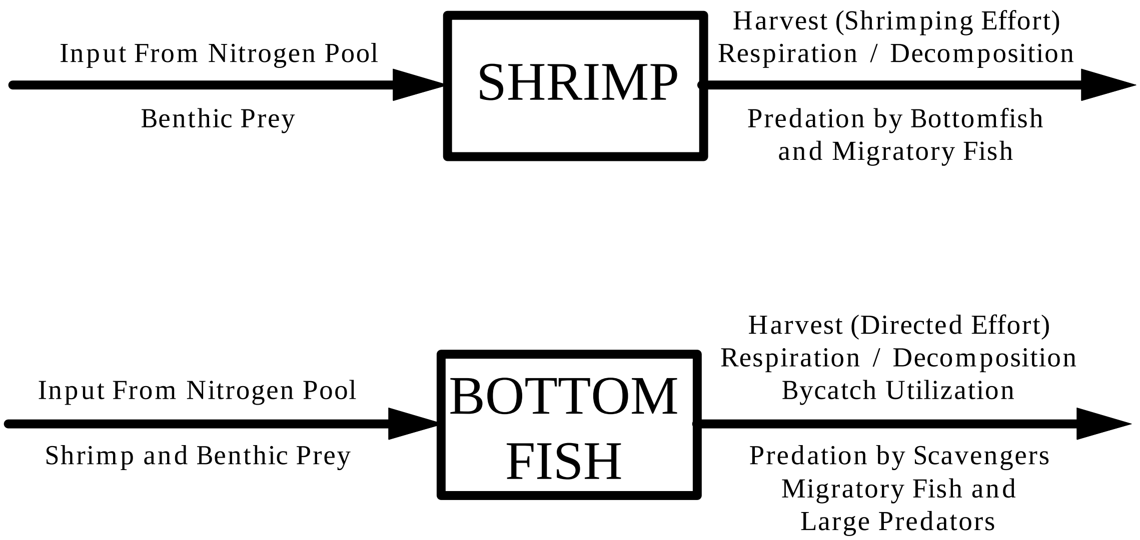


Figure 42. Input and removal of nitrogen from stocks of shrimp and bottomfish. The flows of nitrogen in components of all living marine resources follow the general pattern shown.

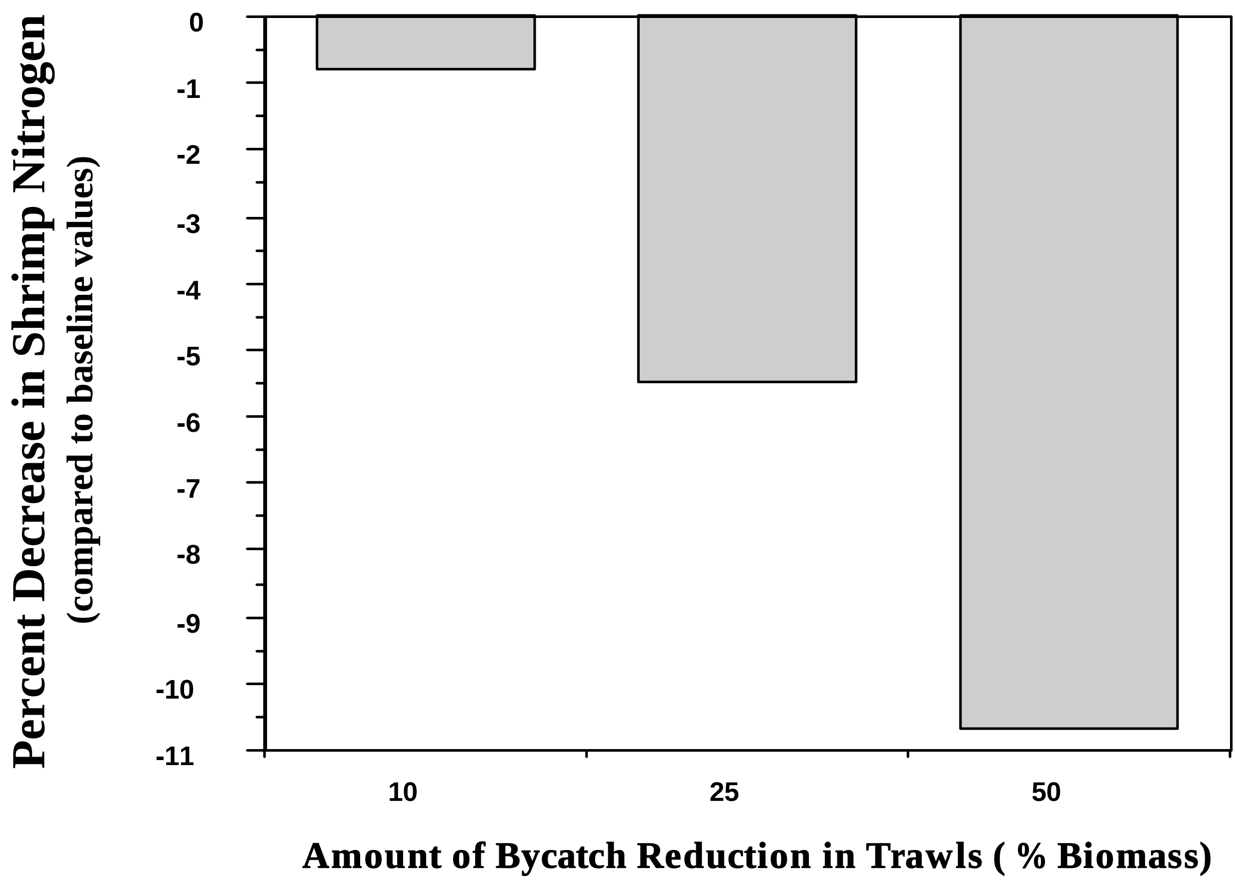


Figure 43. Decrease in size of shrimp stocks for simulation scenario 1 (predation increases due to greater numbers of fish in the ecosystem).

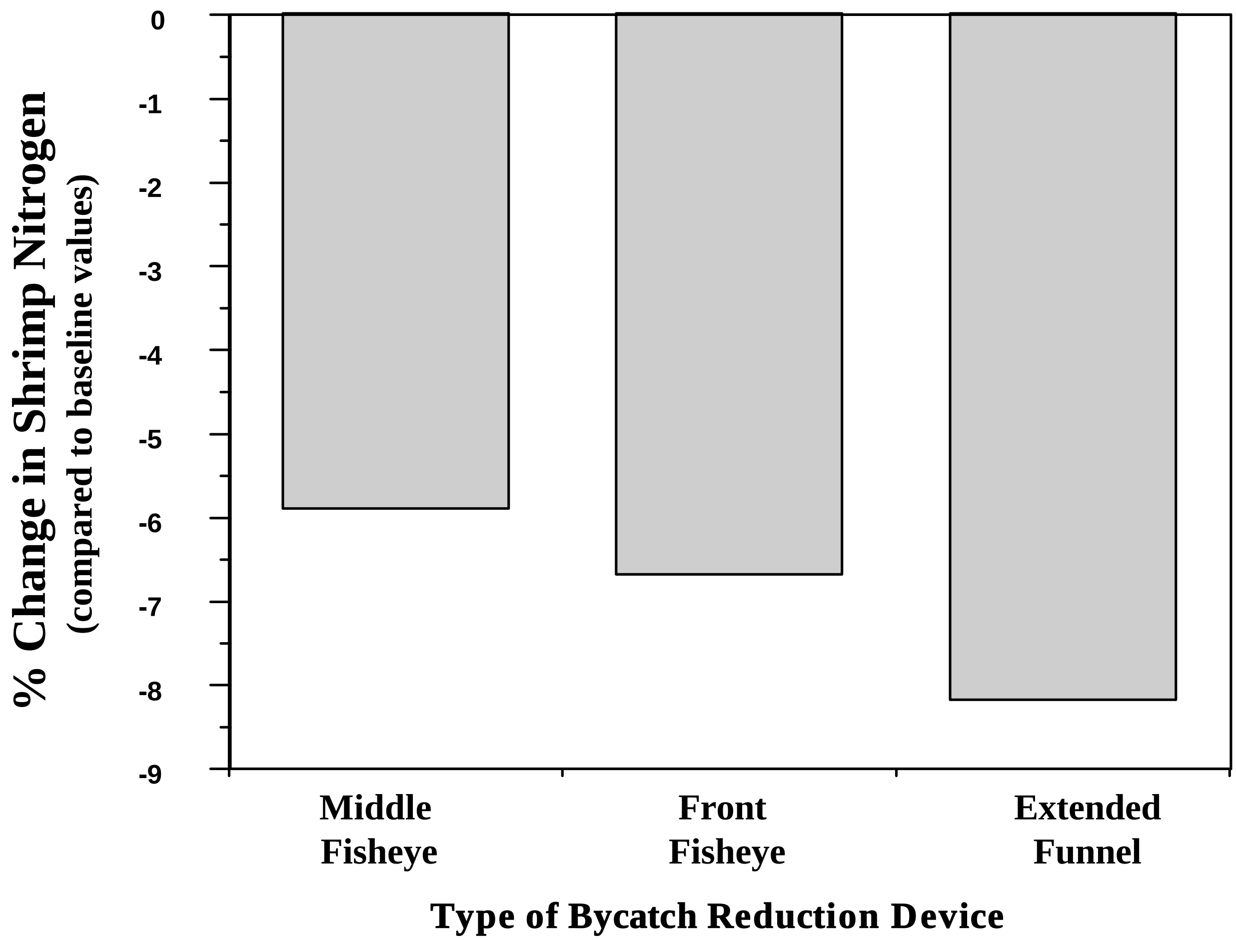


Figure 44. Decrease in size of shrimp stocks for simulation scenario 2 with three types of bycatch reduction devices (BRD's): predation increases only for excluded fish.

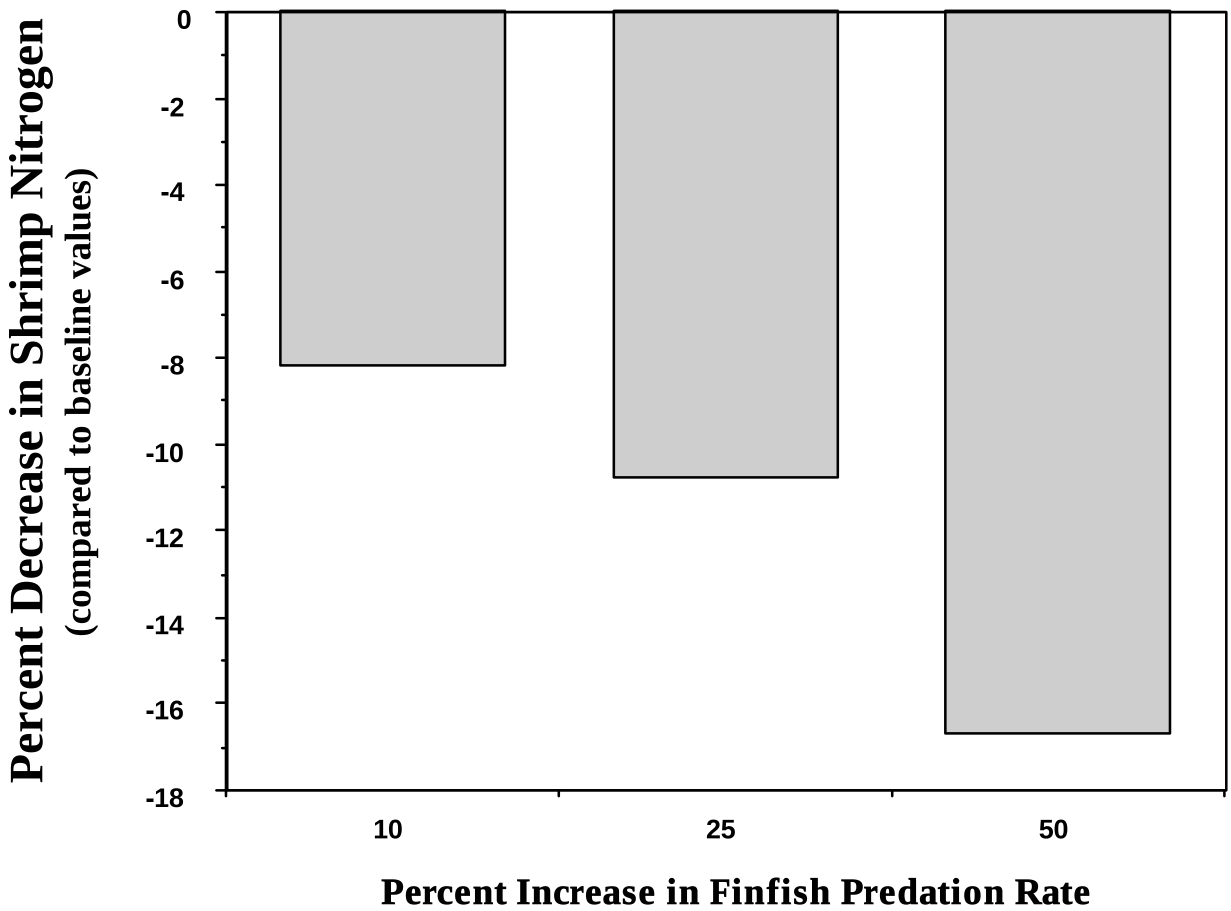


Figure 45. Decrease in size of shrimp stocks for simulation scenario 3 with average bycatch reduction: predation rates increase as the size structure of fish stocks change. As small fish are allowed to continue growing, they might attain a size at which they become predators on shrimp, thus increasing the overall predation rate.

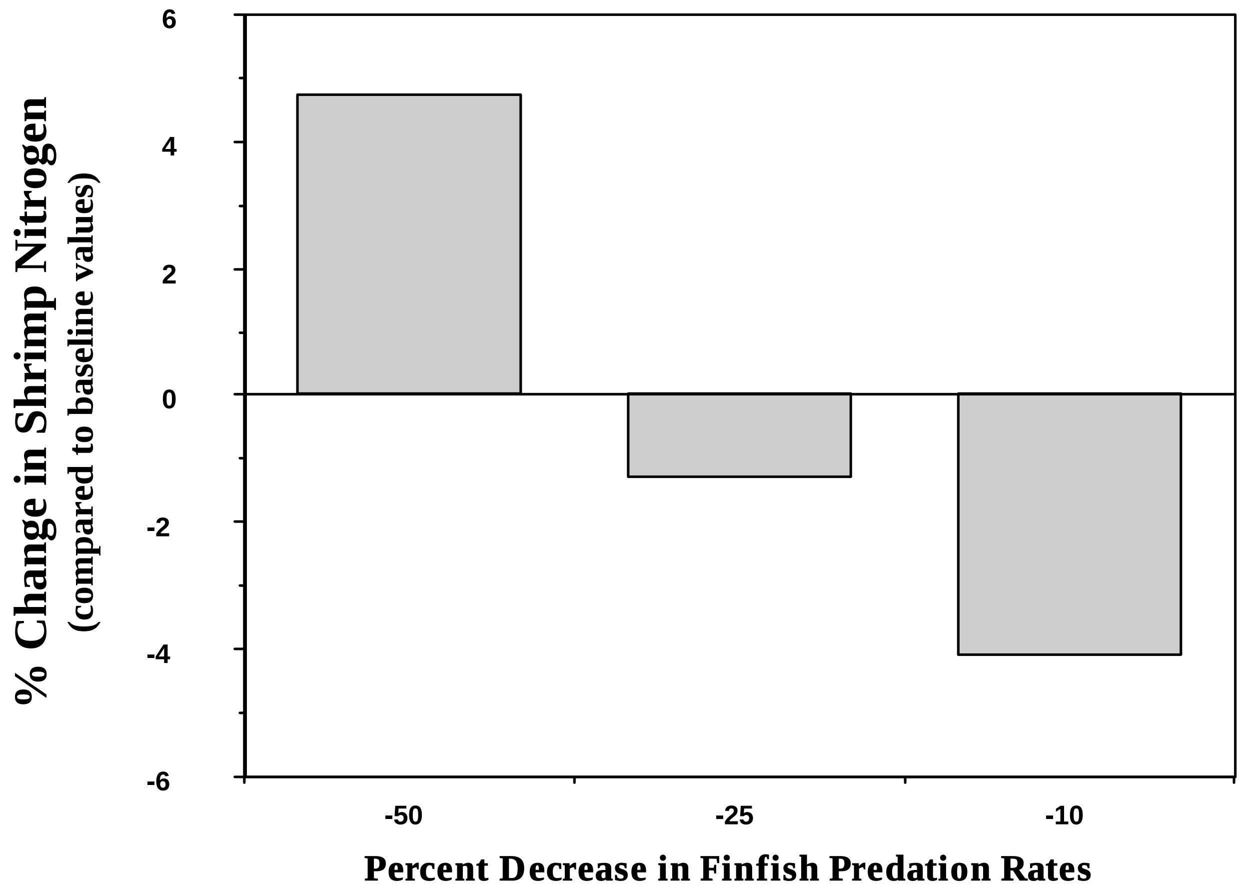


Figure 46. Change in size of shrimp stocks for simulation scenario 4 (with average bycatch reduction): predation rates decrease as the size structure of fish stocks change. This scenario assumes that as shrimp predators continue to grow, they will select for alternate prey items over shrimp.

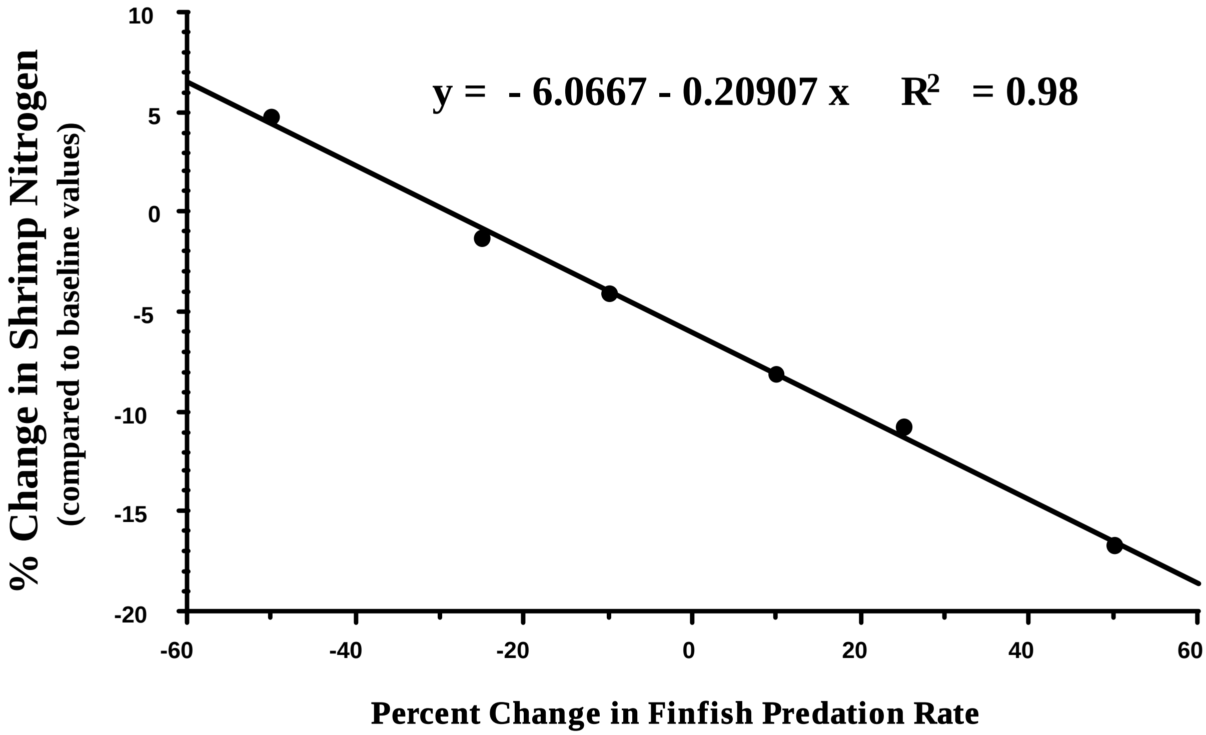


Figure 47. Effects of predation rate on shrimp nitrogen. Data reflect results from simulation scenarios 3 and 4 which utilized sensitivity analyses in the model to examine the impacts of increasing or decreasing predation rates on the shrimp nitrogen stock.