Research Accomplishments of the NMFS Southeast Fisheries Center

WILLIAM J. RICHARDS, Editor

The Southeast Fisheries Center (SEFC) of the National Marine Fisheries Service, NOAA was organized into its present structure in 1976 when the Magnuson Fisheries Conservation and Management Act (MFCMA) expanded the responsibilities of the NMFS. Research that had been conducted under four smaller laboratories was then placed within a single unit to provide more focused responses to fishery management issues. Presently, the Center consists of headquarters offices in Miami and major facilities in Beaufort, N.C.; Charleston, S.C.; Miami and Panama City, Fla.; Bay St. Louis and Pascagoula, Miss.; and Galveston, Tex.

Highly productive coastal waters of the southern United States have long been noted for shrimp, *Penaeus* spp., menhaden, *Brevoortia* spp., and a host of other commercial and recreational species. Prior to the MFCMA, relatively little attention was paid to managing fisheries because the short-lived shrimp and menhaden were not seriously impacted by fishing, and other stocks were generally subject to moderate pressure. The situation changed quickly in the last decade, however, as the demand for fishery products and recreational opportunities increased and as organized interest groups exerted their influences to obtain equitable allocations. The role of the SEFC was altered significantly during this time also as scholarly research gave way to fitting immediate information needs to resolve management and conservation problems in specific fisheries. The material that follows is a blend of accomplishments from these two periods in the history of the various laboratories comprising the Southeast Fisheries Center.

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Research programs have focused on the fisheries, the species assemblages, or the critical problems in the area. Since shrimp is the most valuable fishery to the region as well as the nation and likewise menhaden in weight (Thompson, 1987), major research efforts have been directed at these fisheries for many years. Estuaries play a critical role in the early life histories of shrimp, menhaden, and a number of other important species and, therefore, have received considerable study. In recent years, increasing attention has been given to species of recreational value, especially the bluefin tuna, *Thunnus thynnus*; swordfish, *Xiphias gladius*; and billfishes, Istiophoridae, which make up the oceanic pelagic species group, and to the king mackerel, *Scomberomorus cavalla*, and Spanish mackerel, *S. maculatus*, which are part of the coastal pelagic species group. Most species in these two groups are important commercially as well, and declining trends in abundance have raised serious concerns.

Endangered marine turtles and mammals found in the area have also come under our purview in recent years. Fisheries operating around reef areas have received added attention also because of increasing fishing pressure and resulting declines in abundance. Major programs are addressing marine contaminants in the environment and the quality and safety of fish products sold to the public. Progress in investigations of latent fishery resources in the region offers the potential for billions of pounds of added harvest. Finally, the use of remote sensing with satellites and aircraft ushers in new aspects to our research as we attempt to understand our complex ecosystems. This paper briefly reviews and highlights some of the research accomplishments made by the SEFC.

Shrimp Research

Harvests of brown, white, and pink shrimp in the southeast represent the greatest valued U.S. fishery. Landings for 1986 from the Gulf and South Atlantic had a combined value of $6.2 million which is nearly 24 percent of the total value of U.S. landings (Thompson, 1987). The distribution of catch in the Gulf of Mexico is shown in Figures 1, 2, and 3. The following sections review research related to this important resource.

Shrimp Mark-Recapture Studies

Large-scale tagging experiments were first conducted on white shrimp, *Penaeus setiferus*, during 1935-47 by Lindner and Anderson (1956). Growth rates and longshore movements were determined using Peterson tags in releases from North Carolina through the Gulf of Mexico to northern Tamaulipas, Mexico. Later researchers felt the Peterson disc restricted swimming efficiency and growth (Costello and Allen, 1962), so the use of biological stains that appeared long-lived and nontoxic was initiated (Costello, 1964). Klima (1963, 1974) employed stains to derive information on brown shrimp, *P. aztecus*, and white shrimp movements, growth, and mortality off Louisiana and Texas

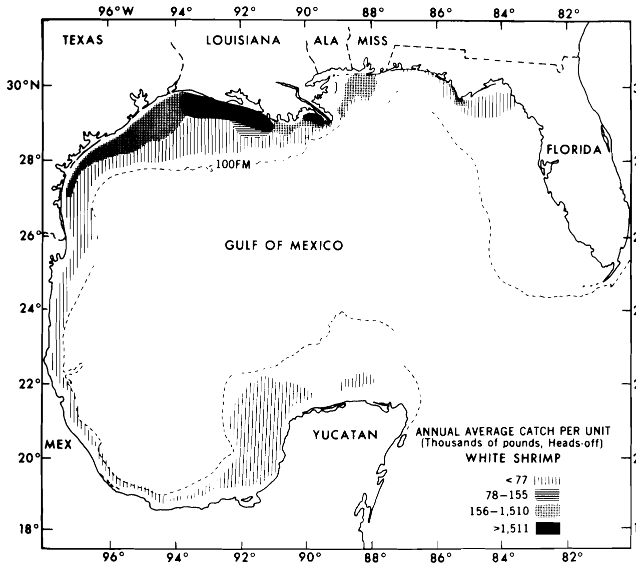

Figure 1.—Distribution of catch per unit (thousands of pounds) of white shrimp in the Gulf of Mexico (from Klima et al., 1987b).

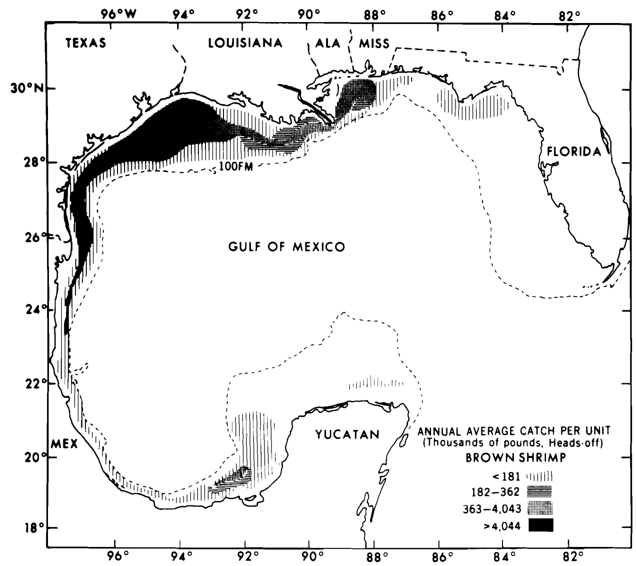

Figure 2.—Distribution of catch per unit (thousands of pounds) of brown shrimp in the Gulf of Mexico (from Klima et al., 1987b).

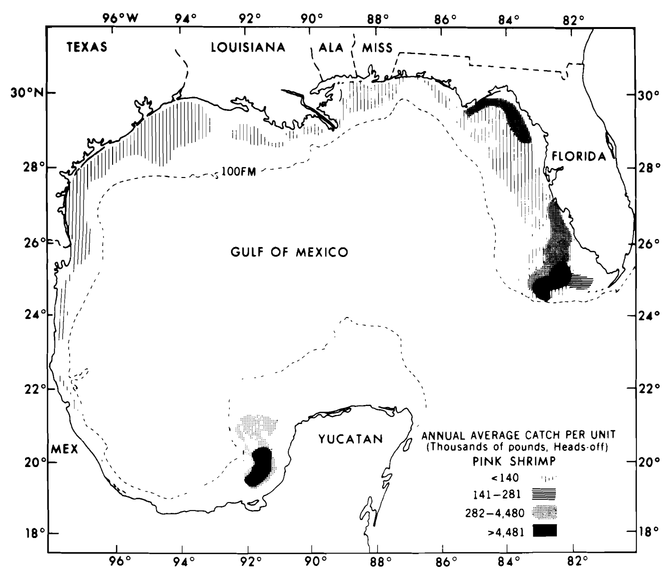

Figure 3.—Distribution of catch per unit (thousands of pounds) of pink shrimp in the Gulf of Mexico (from Klima et al., 1987b).

and within Galveston Bay. Costello and Allen (1966) used stained pink shrimp, *P. duorarum*, off south Florida to indicate timing and direction of shrimp movements, to delineate nursery grounds, and to outline geographic ranges of the Tortugas and Sanibel stocks. The use of stains continued into the 1980's as Sullivan et al. (1985) described their utility in estimating standing stocks of juvenile shrimp in estuarine nurseries.

Several drawbacks of biological stains, including high mortality of small shrimp, limited retention of stains, and lack of individual shrimp identification, led to the development of a numbered internal plastic tag (Neal, 1969) and, shortly thereafter, to the now prevalent numbered vinyl streamer tag (Marullo et al., 1976). The streamer tag has been found to have little effect on shrimp movement, behavior, or mortality, to be easily recognized and returned by fishermen, and to provide necessary growth and movement information for individual shrimp.

Cooperative shrimp mark-recapture studies have been conducted with the Louisiana Department of Wildlife and Fisheries, the Texas Parks and Wildlife Department, and Mexico's Instituto Nacional de la Pesca. These studies, continuing since 1977, have addressed issues such as biological components needed for stock assessments, movement of shrimp across international or sanctuary boundaries, and potential effects of offshore disposal of salt dome brine.

Forecasting Brown Shrimp and Pink Shrimp Landings

In response to requests from fishermen for advance information on potential landings in upcoming shrimp seasons, the SEFC has developed predictive models to forecast annual landings for the Texas and Louisiana offshore brown shrimp fisheries and the Tortugas pink shrimp fishery. Forecasts of the Texas brown shrimp fishery have been made since 1963. Forecasts for Louisiana were begun in 1985, while 1987 marked the first Tortugas forecast.

The Texas brown shrimp forecasts depends upon sampling in the Galveston Bay estuary to monitor 1) brown shrimp postlarvae moving through the entrance to Galveston Bay, 2) juvenile brown shrimp in salt marsh habitats, and 3) juvenile and subadult brown shrimp in the April-June bait shrimp fishery. Since 1965, 15 of the 20 predictions of annual Texas landings derived from the bait shrimp index have fallen within ±5 percent of the subsequent actual catch.

The Louisiana brown shrimp forecast is based on inshore and offshore landings data for May of each year provided by the Louisiana Department of Wildlife and Fisheries and the SEFC's Economics and Statistics Office (Klima et al. 1987). The Tortugas pink shrimp forecast is based on data collected by the Everglades National Park, the National Weather Service, and SEFC (Sheridan and Sikkema[1]).

Texas Closure

Implementation of the Gulf of Mexico shrimp fishery management plan in May 1981 permitted closure of the brown shrimp fishery from the coastline to 200 n.mi. off the Texas coast (Fig. 4) to increase the yield of shrimp. According to the plan, shrimp yield would be increased by protecting shrimp from fish during the period when they were growing rapidly. Discards would be reduced by allowing all shrimp caught to be landed. For the past 7 years (1981-87) the Gulf of Mexico Fishery Management Council has agreed to continue this seasonal closure of the brown shrimp fishery off the Texas coast. The 1986 and 1987 Texas Closures were unlike the other 5 years since the area closed was only from the coastline to 15 n.mi. off the Texas coast.

[1]Sheridan, P. F., and D. A. Sikkema. Prediction of Tortugas pink shrimp (*Penaeus duorarum*) landings. Manuscr. in prep.

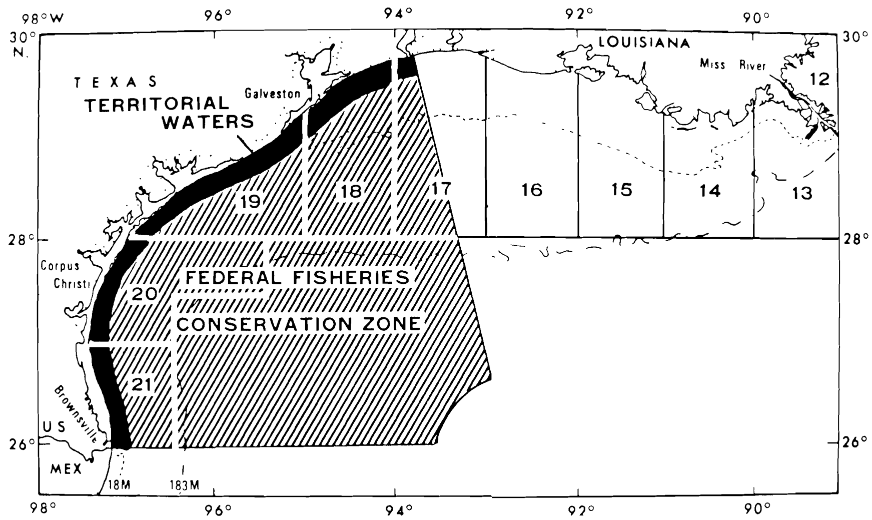

Figure 4.—Locations of statistical subareas (no. 12-21); The Texas territorial waters (solid black band); and the Federal Fisheries Conservation Zone (striped area) (from Klima et al., 1982).

Each year the closure has been in effect, SEFC personnel have utilized commercial landing and effort data, as well as scientific investigations to evaluate the effect of the closure on the Gulf of Mexico brown shrimp fishery and determine if benefits are being achieved. Klima et al. (1982) reviewed the 1960-80 offshore brown shrimp fishery and determined the effects the closure had on the fishery during the first year. It was resolved that fishing motality on small brown shrimp was significantly reduced during the closure period and that the closure had a positive impact on increasing the relative abundance of shrimp as well as total production off the Texas coast.

Each year the entire 200-mile closure was in effect (1981-85). Gulf-wide yield was estimated to have increased from 4.2 to 9.8 million pounds (Klima et al., 1987a, b). Nichols (1987) determined a small loss in yield in 1986 because the closure was only out to 15 n.mi. from shore.

Tortugas Sanctuary

The Gulf of Mexico Shrimp Fishery Management Plan established an area commonly known as the Tortugas shrimp sanctuary off south Florida in May 1981 to increase yield from the fishery. This decision was based on evidence that

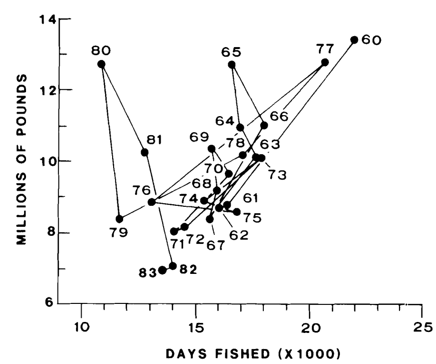

Figure 5.—Catch of pink shrimp versus fishing effort in biological years 1960-1983 for the Tortugas grounds (subareas 1-3) (from Klima et al., 1986).

showed the sanctuary area to be the nursery ground for the Tortugas stock of the pink shrimp. Since May 1981, the sanctuary has been closed to trawling, with the exception of a small region which was reopened for a brief period (April 1983 through August 1984) to evaluate the effects (Fig. 5).

Roberts (1986) sampled areas both in and out of the sanctuary to establish size differences of shrimp between the two sites. Results indicated that small shrimp (>69 tails per pound) were more abundant inside the sanctuary than outside.

The finding was reinforced when a significant drop in size of commercially landed shrimp was observed when fishing was allowed in part of the sanctuary (Klima and Patella, 1985). Mark-recapture studies determined that most of the shrimp in the closed area move to the north into trawlable waters and only a small percentage remain in the sanctuary (Gitschlag, 1986). Nichols (1987) updated the yield-per-recruit information on the Tortugas pink shrimp fishery and determined a 14-20 percent gain in yield was possible with the sanctuary compared to unregulated conditions. Gains in ex-vessel revenue due to the closure would be from 45-55% during peak season. Annual assessments provide information to the Council and allow them to determine the effects of the closure (Nance et al., 1986; Nance and Patella, 1987). All reports thus far have shown a benefit to the Tortugas fishery from the closure.

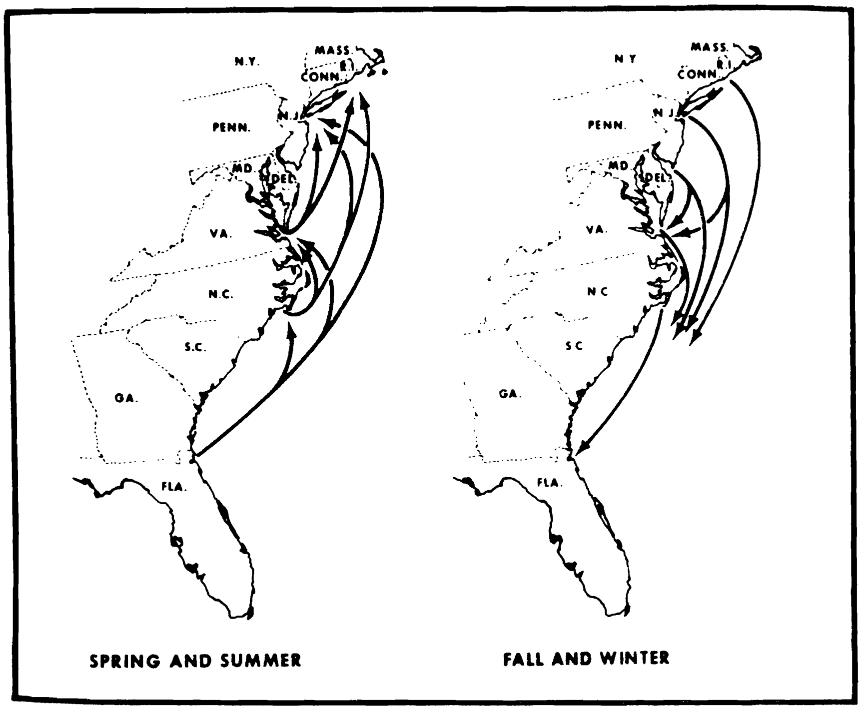

Figure 6.—Generalized movements of tagged Atlantic menhaden (from Dryfoos et al., 1973).

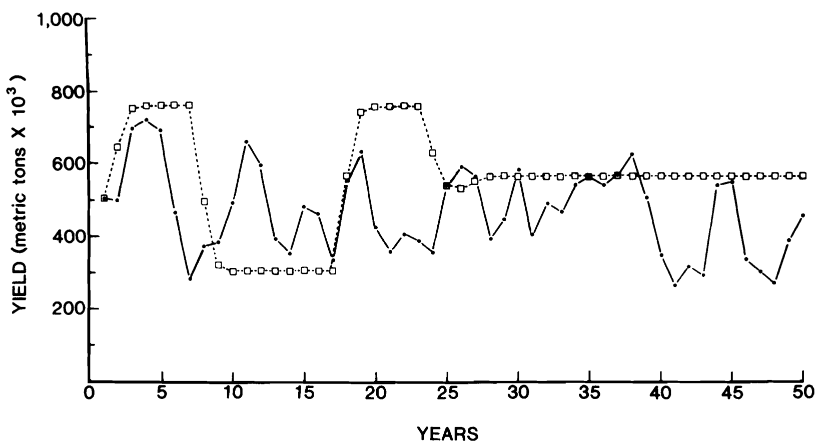

Figure 7.—Annual yield of the Gulf menhaden fishery projected by the population simulation model when upper and lower values of recruitment from the 1964-77 year classes are inserted (dashed line) and when recruitment varies randomly within limits of observed recruitment for the same data set (solid line) (from Nelson and Ahrenholz, 1986).

Menhaden Research

The NMFS initiated research on menhaden in 1952, and has monitored the Atlantic menhaden, *Brevoortia tyrannus*, fishery since 1955 and the Gulf menhaden, *B. patronus*, fishery since 1964 for biostatistical, landings, and fishing effort data (Smith et al., 1987a, b). Reintjes (1969) and Reintjes and Pacheco (1966) summarized much of the early NMFS effort and their papers continue to serve as benchmarks for fishery researchers. Since the purse seine fisheries span much of the year and geographic ranges of the species, definition of the seasonal movements and recruitment patterns of the fishes were essential to understanding the dynamics of the populations and effects of the fishery. These were defined in one of the nation's largest fish tagging programs (internal ferromagnetic tags) on the Atlantic and Gulf menhaden. Tagging of juvenile menhaden continues on the Atlantic coast. Recoveries of tags from magnets within reduction plants on the Atlantic coast detailed seasonal migration patterns (Fig. 6) (Dryfoos et al., 1973) and differential distribution by age and size (Nicholson, 1978). No coastwide migration pattern was evident for adult Gulf menhaden (Pristas et al., 1976; Ahrenholz, 1981). Tagging results also allowed fishery independent estimates of natural mortality rates for use in stock assessment analyses of Atlantic menhaden (Ahrenholz et al., 1987, Vaughan and Smith, 1988) and Gulf menhaden (Fig. 7) (Nelson and Ahrenholz, 1986; Vaughan, 1987).

Studies to develop relative abundance indices of coastwide prerecruits were initiated in the early 1960's on the Atlantic and Gulf coasts. These surveys made substantial contributions to our knowledge of the estuarine phase of the menhaden life cycle and basic estuarine ecology; however, the relative abundance indices lacked the precision necessary for making real time forecasts of prerecruit year class size. Environmental factors affecting recruitment were investigated in a benchmark paper on Atlantic menhaden (Nelson et al., 1977).

Recent stock assessments (Vaughan, 1987, Vaughan and Smith, 1988) attempt to address such questions as: 1) Do current landings exceed maximum sustainable yield? 2) Is there sufficient recruitment to the fishable stock to support current landings? 3) Does recruitment depend more on spawning stock size or more on environmental conditions? 4) Should the age at entry to the fishery be raised to increase fishing yields? Results of such stock assessments serve as input to the Atlantic and Gulf States Marine Fisheries Commissions in recommending specific management actions (AMMB, 1986; Christmas et al., 1983).

Estuarine Systems Research

Estuarine Systems Research is a multidisciplinary program concerned with estuarine habitats from North Carolina to Texas. This large and varied program emphasizes a balanced mixture of field and laboratory studies with goals of: 1) Determining the key functional relationships that regulate resource production and 2) developing the capability to assess impacts of environmental alterations and contaminant additions on fishery organisms and their habitats. Specific objectives are to determine the distribution and relative values of estuarine nursery areas (including marshes, seagrasses, and nonvegetated habitats); measure larval fish recruitment to estuaries and determine factors influencing their survival; evaluate uses of detrital material; evaluate impacts of freshwater inflow and temperature; determine the functional value of mitigated and created wetland habitats; and to synthesize information on wetland acreages and fishery species life history.

Estuarine Systems

Research on the structure and function of seagrass and marshes and their contribution to survival and growth of fishery organisms has been underway for many years. Currently, the adverse impacts of turbidity (due to boat traffic) on seagrass distribution, abundance, and growth is being studied in Florida. We continue to examine how the production, standing crop, and density of temperate and tropical seagrasses are limited by nutrients and therefore are impacted by reduction of nutrient input by reduced freshwater inflow or increased nutrients through eutrophication in Florida Bay.

Since there are virtually no data as to whether artificially propagated seagrass beds and salt marshes provide fishery habitat values equivalent to the habitats they are to replace, research is being conducted to develop and evaluate habitat creation techniques (Fonseca et al., 1985). Studies are also underway to determine the actual fishery contribution of 1) substituting transplanted seagrass beds for natural beds, and 2) substituting one seagrass species for another. Because of their important ecological function, microorganism abundance in transplanted seagrass bed sediments has also been measured in studies in Florida and North Carolina. We have continued studies at two salt marsh mitigation sites in North Carolina to determine how these sites compare with natural marshes as habitat for fishery organism production (Lewis and Peters, 1984). In Texas, we have initiated a study to determine whether the construction of access channels in transplanted marshes will increase utilization of the inner marsh surface by fishery organisms. In North Carolina we are studying three recontoured dredge material islands to ascertain whether faunal abundances, faunal composition, and trophic dynamics compare with natural counterparts of these systems.

We are compiling data on the life history, distribution, and abundance of 35 selected fish and invertebrate species in each of 13 estuaries from Florida Bay to Mobile Bay (Thayer et al., 1987). The completed data base will be part of the National Estuarine Inventory. We are also estimating acreages of coastal wetland habitats from National Wetland Inventory habitat maps and mapping submerged aquatic vegetation in North Carolina sounds from Cape Lookout to the northern tip of Currituck Sound.

Trace metal studies have focused on four areas: 1) Determination of total dissolved and ionic copper and zinc in estuarine waters, 2) bioassay of trace metal pollution in estuaries, 3) monitoring levels of contaminants in 17 estuaries in the Southeast Region, and 4) determining mechanisms of metal regulation in shellfish. Measurements of copper and zinc in estuarine waters indicated that existing levels of these trace metals in some contaminated estuaries are sufficiently high to adversely affect estuarine fishery organisms (Cross and Sunda, 1985). This hypothesis was tested in laboratory experiments using the larvae of the copepod *Acartia tonsa*. Monitoring levels of trace metals in sediment and Atlantic croaker, *Micropogonias undulatus*, from estuaries from North Carolina to Texas is a part of NOAA's National Status and Trends Program. Trace metal regulation in shellfish is concerned with the determination of the physiological and biochemical processes involved in the metabolism of the metals. This study has been primarily concerned with the sources of natural variability in both whole animal and tissue concentration of metals as a function of normal growth and reproductive cycles.

Mortality of Juvenile Shrimp in Estuaries

Mortality of postlarval and juvenile penaeid shrimp in estuarine nurseries appears to be highly variable and, for the most part, regulated by predation. Food availability and physical factors such as temperature may control distributions and growth but do not appear to directly affect survival except under extreme circumstances (Zein-Eldin and Aldrich, 1965; Gleason and Zimmerman, 1984). Environmental and habitat conditions, however, can regulate mortality by modifying predation rates. The major fish predators on penaeid shrimp in the bays along the northern Gulf of Mexico include southern flounder, *Paralichthys dentatus*; spotted seatrout, *Cynoscion nebulosus*; and red drum, *Sciaenops ocellatus*. Many other fish species also feed on shrimp to a lesser extent. The accessibility of emergent

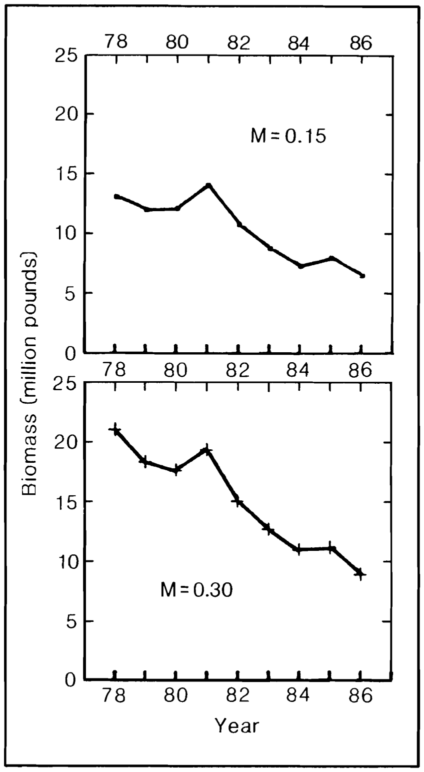

Figure 8.—Estimated female spawning stock biomass of U.S. Gulf Migratory Group king mackerel, 1978-86, using two alternative values for the natural mortality rate M: M = 0.15 and M = 0.3 (from Powers, 1986).

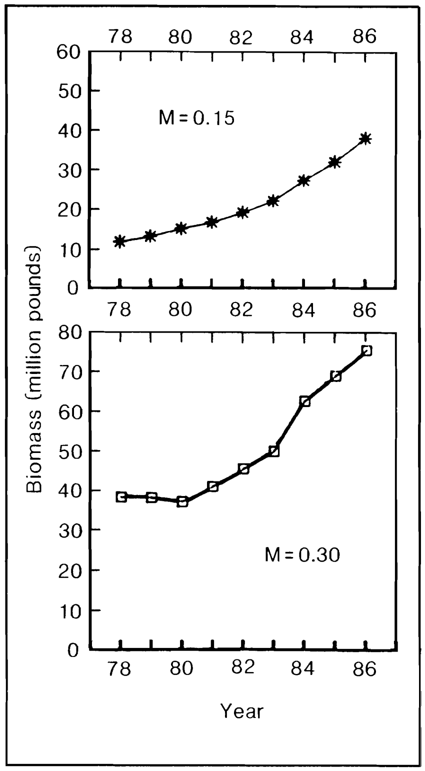

Figure 9.—Estimated female spawning stock biomass of Atlantic Migratory Group king mackerel from 1978-86 using two alternative values for the natural mortality rate M: M = 0.15 and M = 0.3 (from Powers, 1986).

vegetation and the density of shrimp affect fish predation rates and interact with tidal fluctuations and seasonal changes in water levels (Minello and Zimmerman, 1983; Zimmerman and Minello, 1984). In addition, water turbidity and the burrowing behavior of shrimp, which is controlled by a suite of environmental variables, have been shown to alter predation rates of estuarine fishes (Minello et al., 1987). Predator-prey interactions are also affected by shrimp size, shrimp species, and the presence and type of alternative prey (Minello and Zimmerman 1984, 1985). Progress toward understanding the processes regulating survival of penaeid shrimp in estuaries is obstructed by our overall lack of information on the many interacting factors which modify predation rates. This information on predation and survival is needed to determine causes of natural fluctuations in populations of penaeid shrimp.

Coastal Pelagics

Stock identification has been an important component of the SEFC research in the Coastal Pelagics Program, which has been concerned principally with king mackerel and Spanish mackerel. Early tagging work initiated cooperatively with the Florida Department of Natural Resources in the 1970's showed migration patterns that allowed the king mackerel resource to be partitioned into two management units: The Atlantic Migratory Group and the Gulf of Mexico Migratory Group. Recent electrophoretic analyses have revealed that the Gulf Migratory Group can be further subdivided into two segments with mixing in the northern Gulf during the warm months.

Annual assessments have been conducted on mackerel stocks to determine stock status (Powers, 1986). Collection of landing statistics, basic age and growth studies, plus development of data bases on size and age frequencies have permitted analyses of yields and estimates of the biomass of spawning stocks. Analyses have shown that the biomass of the spawning stock of the Gulf Migratory Group of king mackerel has been declining since the late 1970's, while that of the Atlantic Migratory Group has remained stable (Fig. 8, 9).

Biological studies indicate that king and Spanish mackerels are basically piscivorous (Saloman and Naughton, 1983a, b), that spawning may occur over several months (Finucane et al., 1986), that larvae and post-larval forms are more abundant along oceanic discontinuities. Several king mackerel tagged in south Florida, Texas, and Louisiana have been recovered in Mexico, and one fish released in Mexico has been recovered in U.S. waters.

Many of the coastal pelagic species are heavily fished by recreational anglers, and surveys of headboat and charterboat fisheries have been conducted throughout the southeast. For these surveys, headboats have been defined as any for-hire vessel that carries 15 or more anglers per trip, whereas charterboats have been defined as for-hire vessels that are 25 feet long or longer and carry less than 15 anglers per trip. The headboat survey, which was initiated in North and South Carolina in 1972 and later expanded to cover the entire coast from North Carolina to Texas, also obtained biological data from the catches. These studies have produced descriptions of various aspects of the life history and population dynamics of about 25 species of reef fish. Charterboat surveys were initiated in 1982 to obtain information on distribution and relative abundance primarily of coastal pelagic fishes and secondarily of reef fishes (Fig. 10) (Brusher et al., 1984). Data on king and Spanish mackerels from charterboat surveys have been analyzed and used in annual assessments of stock status. Data from both headboat and charterboat surveys have been used in the development of fishery management plans and for

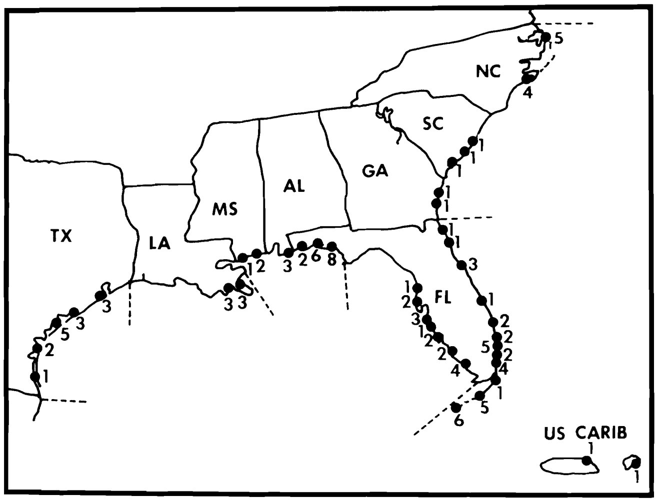

Figure 10.—1983 charterboat survey ports showing initial number of contracted vessels in each port (from Brusher et al., 1984).

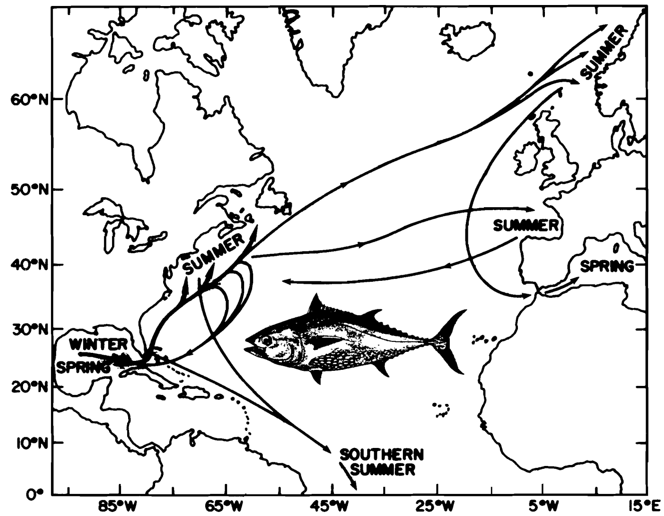

Figure 11.—Movements of bluefin tuna based on tag returns (from Beardsley and Scott, 1987).

developing management measures for reef fishes and coastal pelagic fishes.

Oceanic Pelagics

Bluefin Tuna

Migratory patterns derived from tagging data combined with other relevant information (Brunenmeister, 1980) were essential elements in establishing the currently accepted hypothesis that two separate stocks of bluefin tuna exist in the Atlantic Ocean: One in the west and the other in the east and Mediterranean Sea. The SEFC sponsored additional research on bluefin tuna stock structure, which developed new methodology for analyzing chemical composition of fish vertebrae, reaffirmed the two-stock hypothesis, and provided estimates of mixing rates (Calaprice, 1986). Recaptures of marked fish were used to develop the growth equation currently used for bluefin tuna in the western Atlantic Ocean (Fig. 11) (Parrack and Phares, 1980). Additional work on growth of bluefin tuna conducted at or sponsored by SEFC includes studies of otoliths from young-of-the-year (Brothers et al., 1983), comparison of aging from otoliths and vertebrae (Lee et al., 1983), and development of an alternative aging procedure for vertebrae (Prince et al., 1985).

The mark-recapture data provided some of the first indications that marks observed in hard parts from large pelagic fish may be formed annually (Prince et al., 1985). Information on the reproductive biology of bluefin tuna was presented by Baglin (1982). Methodology for identifying bluefin tuna larvae were established by Potthoff and Richards (1970), Potthoff (1974), and Richards and Potthoff (1974). Ichthyoplankton surveys in the Gulf of Mexico during the bluefin tuna spawning season have provided extensive information on spawning areas and estimates of larval abundance (Richards, 1976; Richards and Potthoff, 1980; Richards et al., 1981; McGowan and Richards, 1986) since 1977; those estimates have been used as indices of adult abundance in recent assessments of the west Atlantic stock (Fig. 12).

There has been concern about the status of the bluefin tuna population in the western Atlantic Ocean since the middle 1970's. Assessments of the resource were presented to the International Commission for the Conservation of Atlantic Tunas (ICCAT) from 1975 to 1982 (Parks, 1976, 1977; Parrack et al., 1979; Parrack, 1980, 1981, 1982; Powers et al., 1983) were instrumental in the establishment of international management measures by ICCAT. Since 1984, assessments have been conducted at annual ICCAT meetings with the participation of all concerned nations; as a result the focus of SEFC research on bluefin has been primarily on assessment analysis methodology as well as derivation of information for input into the assessments.

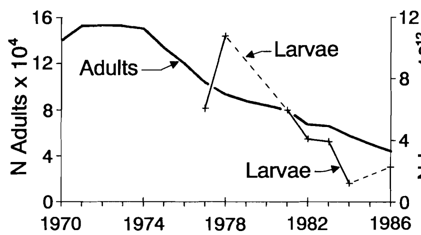

Figure 12.—Adult population size and larval abundances of the western Atlantic bluefin tuna showing population declines.

Swordfish

The SEFC has been involved in research on Atlantic swordfish for the past decade, providing advice and analyses on the status of the resource to ICCAT and the Regional Fishery Management Councils. In 1977, the SEFC sponsored a workshop to review available information on the biology, ecology, and population dynamics of swordfish, and to identify potential management problems and develop research recommendations (Beardsley, 1978). The catalyst for that workshop was the rapid development of a commercial and recreational swordfish fishery off the southeast coast of Florida and the revival of the traditional U.S. longline fishery which had been restricted by FDA mercury regulations in 1970.

As a result of a successful legal challenge of the FDA mercury guideline, the standard was increased from 0.5 ppm to 1.0 ppm in 1978. As the unrestrained fishery expanded, reports of declining catch rates and average sizes combined with increased landings of small fish raised concern as to the status of the resource and prompted the Regional Councils to develop a swordfish management plan. Preliminary work by SEFC scientists, in support of Council activities, attempted to address the question of declining abundance on an Atlantic-wide basis through the analysis of Japanese longline data (Beardsley, 1979; Farber and Conser, 1983).

Subsequent work was directed towards database building activities, especially with respect to the U.S. fishery and the collection of size frequency data which could be used in virtual population analyses. Descriptive reports on the size frequency data were presented periodically to the Regional Fishery Management Councils and their swordfish working group (Hoey et al., 1985).

In 1985, the first analytical assessment utilizing VPA methodology with equilibrium yield per recruit analyses was conducted by SEFC scientists and presented to ICCAT and the Councils (Conser et al., 1986). To support Council management activities, SEFC scientists evaluated the effect of seasonal closures and minimum size regulations on swordfish yield per recruit (Conser et al., 1985). In 1986 through 1985, hard-part and mark-recapture growth curves were compared, sex-ratio size data was reviewed, indices of abundance based on catch and effort data were evaluated, and least squares techniques were used to calibrate virtual population analyses.

These results, which were similar to the 1985 assessment, were presented to ICCAT (Anonymous, 1987). Growth overfishing of northwest Atlantic resource was documented, but evidence of recruitment overfishing was not found. The VPA results indicated recent increases in recruitment, numbers of older fish, and stock biomass. Although some uncertainty exists about the precision of estimates for recent years, peer reviews supported the general trends identified for the northwest Atlantic stock. The evidence indicated that management to reduce the catch of small fish and increase the number of older fish in the stock was desirable. The ICCAT standing committee on research and statistics (SCRS) recommended that the Commission support the need for an international workshop to evaluate data from swordfish fisheries on an Atlantic-wide basis.

Continued Council concern over the status of the resource prompted additional analyses on forward projections of allowable swordfish catches (Conser and Hoey, 1987), and potential effects of alternative minimum sizes on yield and spawning stock biomass (Goodyear[2]). In preparation for the ICCAT workshop, SEFC scientists updated size frequency (over 440,000 fish), sex ratio size, and CPUE data along with comprehensively reviewing and correcting U.S. landings from 1962 through 1986 (Hoey and Bertolino, In press; Hoey and Casey, In press).

Cooperative research between SEFC and Spanish scientists examined the available size frequency data from the U.S. and Spanish fleets operating in the Atlantic north of lat. 40°N from the Tail of the Grand Banks to the Azores (Hoey et al., In press). This document along with a review of Japanese longline data and mark-recapture data and size frequency and reproductive data from the Spanish fisheries, led the ICCAT committee to favor the single-stock hypothesis for the North Atlantic as a working hypothesis for stock management purposes. Although the two stock hypothesis could not be discarded, the committee indicated that any analyses based on a two-stock assumption would have to take into account the mixing of fish from the east and west in the North Atlantic. Although catch-at-age tables were developed for 5 areas including the Mediterranean, time did not allow for analytical assessments. At present, SEFC scientists were preparing for an intersessional ICCAT swordfish workshop scheduled for summer 1988 and continuing to evaluate trends in the U.S. fishery with particular emphasis on changes within the U.S. Exclusive Economic Zone.

[2]Goodyear, C. P. 1987. Yield and spawning stock biomass for swordfish - potential effects of alternative minimum size. NMFS Southeast Fish. Cent., Miami, Fla., manuscr.

Billfish

Billfish research has been mostly international in scope since those species come under the auspices of ICCAT. The U.S. fishery is recreational, but both domestic and foreign longline fishery operations have sizeable catches. Our work has concentrated on making population assessments of the three principal species—sailfish, *Istiophorus platypterus*; white marlin, *Tetrapturus albidus*; and blue marlin, *Makaira nigricans*. Conser (1984) made an in-depth yield per recruit analysis of sailfish in the western Atlantic Ocean and found that the rapid growth of sailfish and the relatively late age at which they are recruited to the fishery produces a healthy situation by the Y/R criterion (i.e., the population is not "growth overfished," although it may be somewhat "growth underfished") (Fig. 13). The U.S. recreational billfish fishery was analyzed by Beardsley and Conser (1981) who found that catch and effort statistics from the recreational fishery coupled with longline data show a consistency of trends for white marlin, but data sources for blue marlin did not show the same consistency. Due to low recreational catches of blue marlin, cooperative tagging by recreational fishermen has resulted in detailing movements (Fig. 14, 15).

Sampling for catch, effort, and biological data from billfish tournaments as well as from daily, nontournament fishing was begun in the early 1970's. This study has grown from about 10 tournaments and 8,000 hours of fishing effort to over 100 tournaments and over 80,000 hours sampled in 1987. In 1977 and 1985, special surveys were conducted to ascertain the total catch of blue marlin, white marlin, and sailfish by U.S. recreational fishermen along the U.S. Atlantic and Gulf coasts. These data have been made available to the Regional Fishery Management Councils to assist in their formulation of the Billfish Management Plan and have also been instrumental in deliberations on billfish

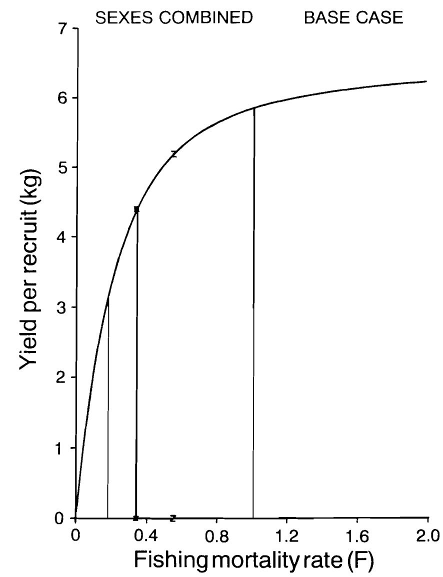

Figure 13.—Yield per recruit for sailfish (sexes combined) and various estimates of the instantaneous fishing mortality rate (F). The outer vertical lines represent the range of F values from the literature (assuming M = 0.34), the line labelled with an asterisk (*) represents the best estimate of F (F = 0.34), and the point labelled Z represents $F_{0.1}$ (where the slope of the curve is one tenth the slope at the origin) (from Conser, 1984).

conservation and management by the International Commission for the Conservation of Atlantic Tunas.

The Cooperative Game Fish Tagging Program (begun in 1954 at the Woods Hole Oceanographic Institution and later transferred to the SEFC) has over 500 cooperating fishermen in over 13 different countries and has recorded over 100,000 tagged and released game fish including 60,000 billfishes and 30,000 tunas (Fig. 16). In 1987, the program was expanded to include king mackerel and red drum in response to increasing interest by recreational anglers in these species.

Difficulty in aging billfishes has hampered analyses and this is further compounded by differential sexual growth rates. Consequently, substantial research effort is devoted to this problem. Key publications highlighting the progress on age and growth of oceanic pelagic fishes during the last decade include the following: 1) Proceedings of the International Workshop on Age Determination of Oceanic Pelagic Fishes—Tunas, Billfishes, and Sharks, Prince and Pulos, editors (1983); 2) Internal zonations in sections of vertebrae from Atlantic bluefin tuna, *Thunnus thynnus*, and their potential use in age determination (Prince et al., 1985); 3) Longevity and age validation of a tag-recaptured Atlantic sailfish, *Istiophorus platypterus*, using dorsal spines and otoliths (Prince et al., 1986); 4) An inexpensive microcomputer-based system for making rapid and precise counts and measurements of zonations in video displayed skeletal structures of fish (McGowan et al., 1987).

Early life histories of these fishes have been investigated for many years. Basic research on identification, distribution, and abundances of the early life stages of tunas, billfishes, and swordfishes have been done. The Potthoff and Kelley (1982) study on swordfish development was judged the best paper to appear in the *Fishery Bulletin* that year. Other fundamental studies were made on tunas by Richards and Potthoff (1974) and on billfishes by Richards (1974). These works culminated in 1984 with the publication of the highly acclaimed book "Ontogeny and systematics of fishes" (Moser et al., 1984) coauthored by several SEFC scientists.

Latent Resources

There are a number of latent resources in the southeast region which offer considerable commercial potential. The coastal herring and associated species complex alone has been estimated to have a yield potential of up to 5 million metric tons. Beginning in 1983, the SEFC initiated a series of research cruises to develop an effective survey

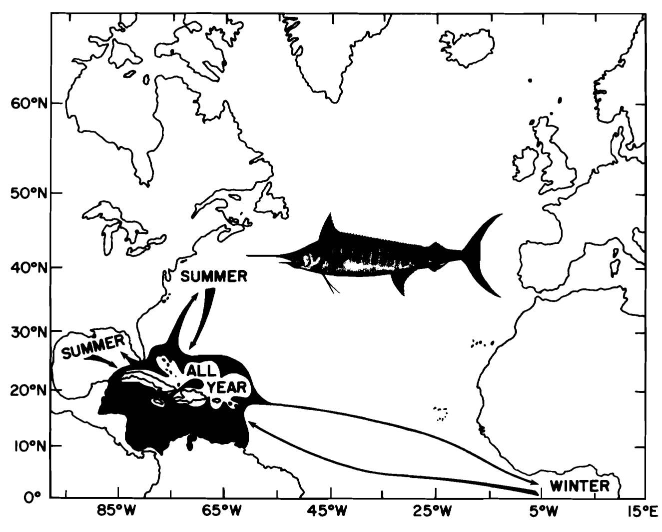

Figure 14.—Movements of blue marlin based on tag returns (from Beardsley and Scott, 1987).

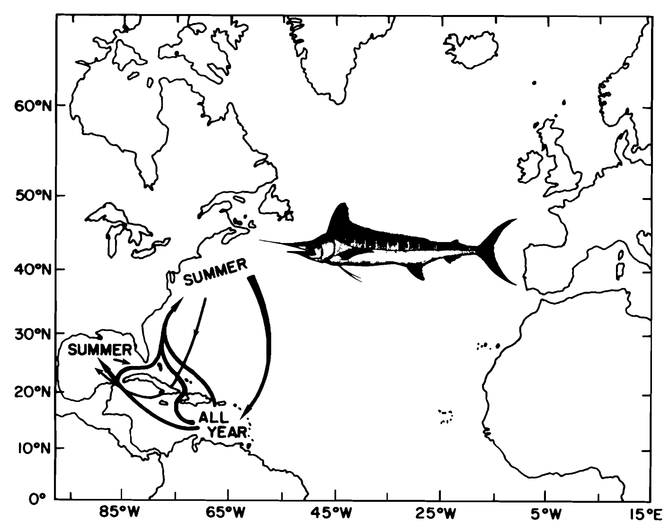

Figure 15.—Movements of white marlin based on tag returns (from Beardsley and Scott, 1987).

Figure 16.—Tagging a billfish.

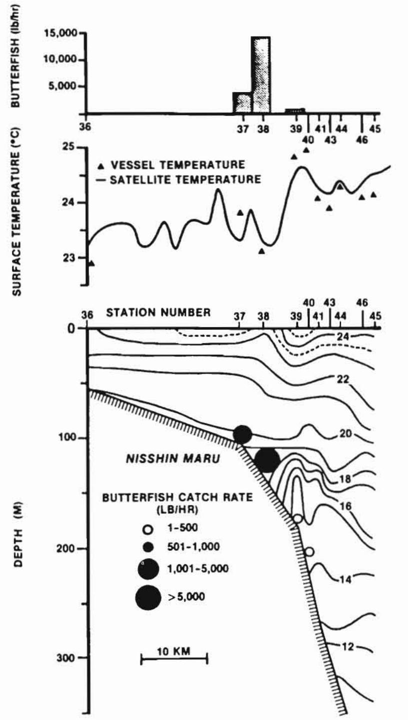

Figure 17.—Data from a sampling transect on April 25-26, 1985 in the northeastern Gulf of Mexico indicating butterfish catch rates, SST taken from the vessel and via satellite, and vertical thermal structure along the transect (from Latent Resources Annual Report for 1986, SEFC; unpubl.).

strategy for latent resources. The cruises focused on the use of large mesh midwater and high opening bottom trawls for sampling aggregations of fish in offshore waters. This research has directly aided in establishing a new Gulf fishery for butterfish, *Peprilus* sp., with an estimated annual potential of over $100 million and has shown potentials for squid and several coastal herrings. Research on butterfish involves fishery oceanography with satellite assistance (Fig. 17). The goal of research efforts directed at latent resources is to be to provide information for accelerating commercial development while at the same time ensuring adequate information for management based on an understanding of fishery dynamics and ecology.

Remote Sensing

Remote sensing applications to fisheries research in the SEFC have continued since 1974 when Kemmerer et al. (1974) found significant relationships between water color and Gulf menhaden. Research has concentrated on the potential role of remote sensing for delineating and monitoring of the spatial-temporal variability of environmental fishery habitats. The program has emphasized the applications of remote sensing technology to all life history stages and developed the analytical techniques required to utilize the technology (Fig. 18).

The LandSat menhaden experiments of 1975 and 1976 showed that the distribution and abundance of adult Gulf menhaden were related to water color as measured by the LandSat Multi Spectral Scanner (MSS) (Brucks et al., 1977). Results from this investigation also suggested a diurnal onshore-offshore migration pattern by adult menhaden (Kemmerer, 1980). Using Coastal Zone Color Scanner satellite measurements of pigment concentration and sea-surface temperature, Leming and Stuntz (1984) demonstrated that bottom water hypoxia off the Louisiana coast in summer could be mapped from space (Fig. 19).

Estuarine dependent species require some method to transport offshore spawned larvae and postlarvae to the juvenile estuarine grounds. The most

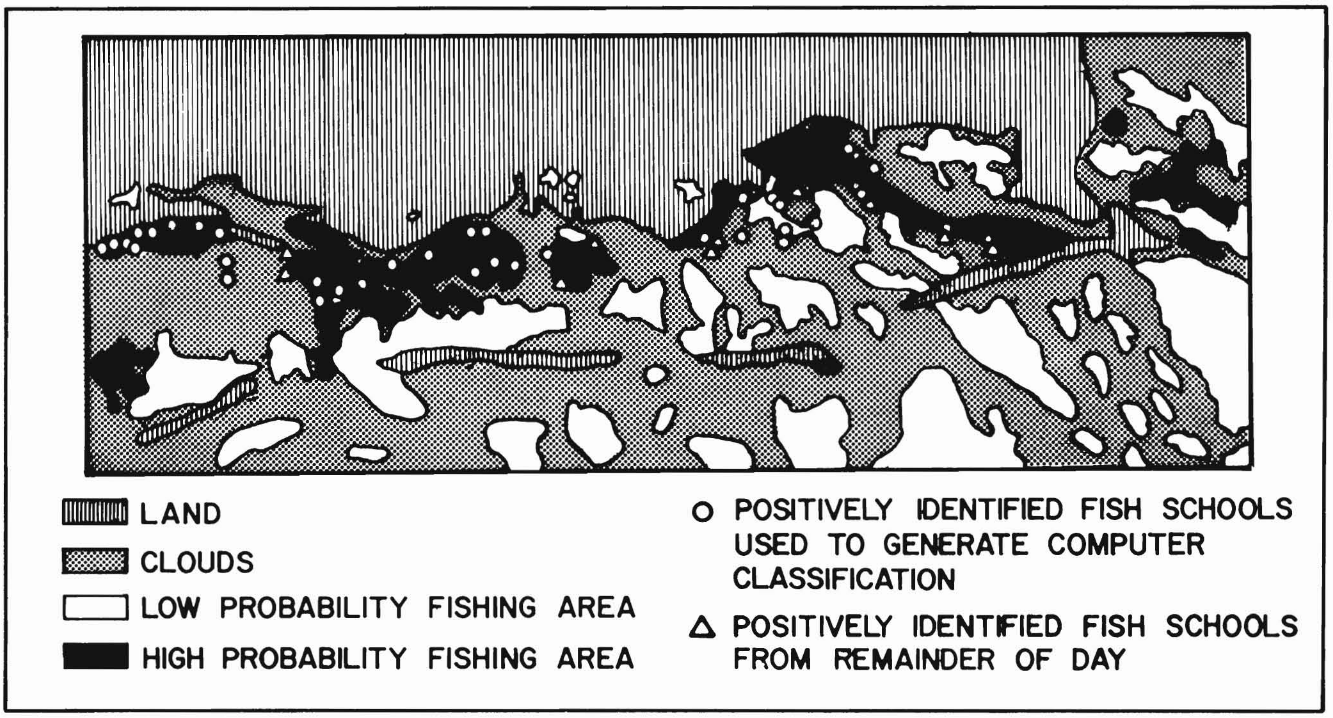

Figure 18.—Classification of LandSat MSS data from May 20, 1975, into high and low probability menhaden fishing areas for the eastern half of the Mississippi Sound (from Kemmerer, 1980).

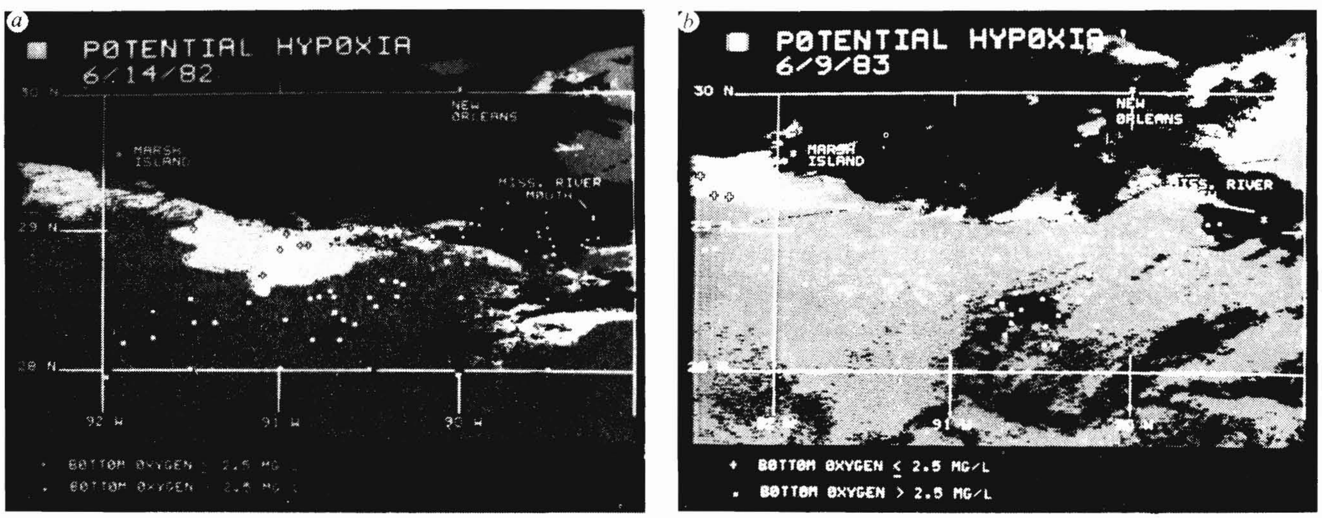

Figure 19.—a, Discriminant function classification of 14 June 1982 CZCS image showing area (light grey) of predicted potential hypoxic bottom water. White dots and crosses are vessel locations (15-24 June 1982) with bottom water oxygen concentrations greater and less than or equal to 2.5 mgl^{-1}, respectively. b, Discriminant function classification of potential hypoxia on 9 June 1983 using function coefficients from 14 June 1982. Station symbols are the same as a (vessels 13-20 June 1983) (from Stuntz and Leming, 1984).

obvious transport mechanism is wind-driven coastal currents. The potential for using satellite-borne scatterometers to measure wind stress and to model ocean currents was investigated at the SEFC Mississippi Laboratories during the flight

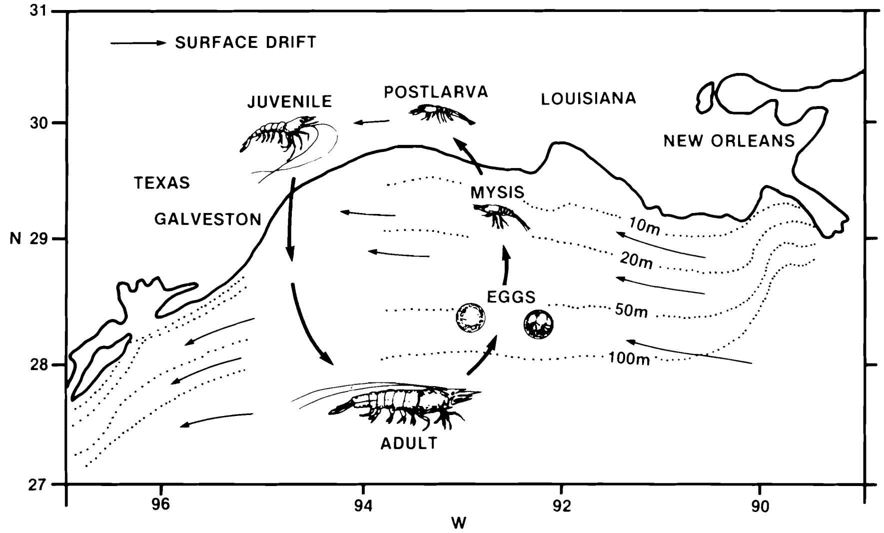

Figure 20.—General surface circulation schematic of northwestern Gulf of Mexico with life cycle migration and larval drift pattern for brown shrimp (from Leming and Johnson, 1985).

of the SeaSat instruments in late 1978 (Brucks et al.[3]). Although the scatterometer proved the concept was feasible, the satellite ceased functioning after only 90 days. Leming and Johnson (1985), however, showed that with proper wind data potentially supplied by satellite scatterometers, simple analytical coastal circulation models are capable of successfully predicting both postlarval shrimp numbers off Galveston (Fig. 20) and blue crab, *Callinectes sapidus*, larvae off Chesapeake Bay. Implementation of these research results awaits the next satellite scatterometer flight, scheduled for 1989.

Remote sensing studies aimed primarily at assessment of juvenile habitats include aerial mapping of submerged seagrass beds (Savastano et al., 1984) and an ongoing project to assess the utility of LandSat Thematic Mapper (TM) and MSS to monitor changes in coastal wetlands. Coastal wetlands are the primary juvenile habitat in the Gulf of Mexico and are being lost at a rapid rate. May (1986) has shown that the LandSat instruments can be used to monitor these changes over large areas for potential predictions of fishery impact. Seagrass beds are also important juvenile (and adult) fishery habitats because of their high organic productivity, and hence are a vital food pathway for the estuarine and nearshore ecosystem. Savastano et al. (1984) successfully demonstrated that submerged seabeds could be mapped from aircraft color sensors with accuracy sufficient for routine monitoring and change detection of beds on a wide scale.

Oceanic pelagics, both adult and larvae, have been found to be strongly associated with major oceanographic frontal features, such as the Loop Current, as measured from satellites (Leming et al., 1987; Leming[4]). The role for remote sensing may be in the potential for developing a stock abundance index from satellite data for oceanic pelagics such as bluefin tuna, and for the use of satellite data to guide research vessel larval sampling. The latter was initiated in 1987 and the former has been submitted as a formal research proposal. Similar applications of remote sensing have been found for a newly developing fishery for Gulf butterfish, *Peprilus burti*, in the northern Gulf of Mexico. Statistically significant relationships have been found between satellite measured sea-surface temperature gradients and butterfish catch rates (Leming and Herron, 1986; Herron et al., 1987). Recent research with an expert system approach to using satellite data as a guide to butterfish distribution is a first step toward adopting this powerful new technology (Leming, 1987).

Reef Resources

A combination of coral reef areas and irregular rocky substrates allow occupancy of a community of primarily Caribbean reef fishes throughout the Gulf of Mexico, along the southeastern U.S. coast, and in Puerto Rico and the Virgin Islands. These communities are characterized by groupers, *Myctoperca* and *Epinephalus* spp.; snappers, *Lutjanus*, *Rhomboplites*, and *Ocyurus* spp.; and grunts, *Haemulon* spp. In the northern parts of the Gulf and southeastern coast, a more temperate fauna occupies coastal reefs characterized by sea basses, *Centropristis* spp., and porgies, *Pagrus* spp. In the southern parts around coral reefs, the spiny lobster, *Panulirus* sp., is very important. All of these species are highly sought by both commercial and recreational interests.

Interactions of these multispecies communities present challenging problems to scientists charged with assessing the stocks. Huntsman et al. (1983) developed yield per recruit models for the major species found along the southeastern U.S. coast and set the pattern for reef fish management by the Gulf of Mexico and South Atlantic Fishery Management Councils. A basis for much of our knowledge has been the rigorous age and growth studies on many of these fishes that had long been considered unagable (Manooch and Huntsman, 1977). In shallow reef areas where so many species abound, estimating numbers of fish presents difficulties, but visual census techniques have been developed which provide reliable estimates of population sizes (Bohnsack and Bannerot, 1986). An example of the results of these studies in Florida reefs is shown in Fig. 21).

Artificial reef structures in the region range from oil platforms in the northern Gulf to a conglomerate of products including tires, cars, and vessels, as well

[3]Brucks, J. T., T. D. Leming, and S. B. Burkett. 1984. A model investigation using high resolution SASS wind stress measurements to derive wind driven surface layer transport properties in the Gulf of Mexico. NOAA/NMFS internal rep.

[4]Leming, T. D. 1981. Oceanic pelagics remote sensing applications. NMFS/SEFC interim rep.

Table 1.—Biological and physical factors impacting the recruitment dynamics of reef fishes. Predicted relative effects upon potential for cohort survivorship are represented as follows: L = large, M = moderate, S = small, N = none, U = unknown. These designations approximate order of magnitude intervals of mortality per life stage (from Richards and Lindeman, 1987).

	Biological dynamics					Physical dynamics			
						Atmospheric		Oceanic	
Life stages	Growth	Starvation	Predation	Behavioral responses	Disease, parasites	Wind effects	Temperature	Water dynamics (currents, vertical shear, many others)	Habitat (water column or demersal)
Egg									
Nested/Brooded	S?	N	S-L	N	M	N	M	S-M	L
Planktonic	S?	N	L	N	U	L	M	L	L
Larva									
Yolk-sac	M-L	N	L	N-S	U	L	M	L	L
Planktotrophic[1]	L	L-S	L	M-L	U	L	M	L	L
Juveniles[2]	M-L	S-N?	L	M-L	S-N	S	S-M	S-M	M
Adult[2]									
Suboptimal fecundity	M-S	S-N	M-L	M-L	S-N	S	S-M	S	M
Optimal fecundity	S-N	S-N	M	M-L	S-N	S	S-M	S	M-L

[1]Some taxa have specialized (e.g., prejuvenile) life stages.
[2]Depending on taxa, several life history stages may exist here.

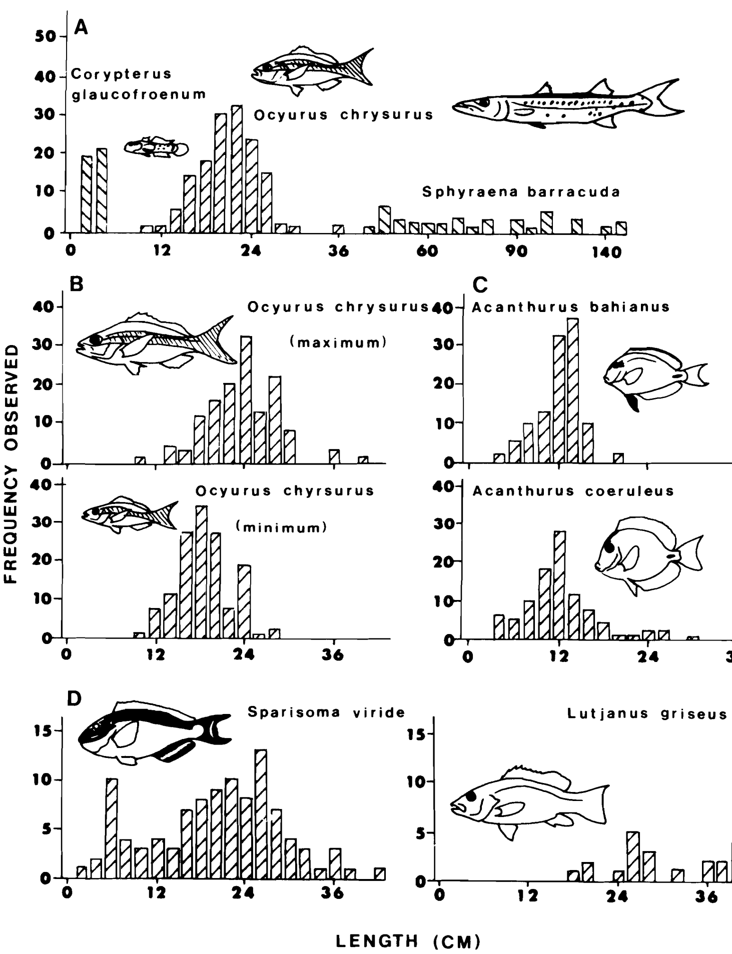

Figure 21.—Length/frequency histograms of selected species showing size distributions of individual species based on stationary sampling data. A. Mean lengths per sample for representative small, medium, and large species; B. Comparison of minimum and maximum lengths for *Ocyurus chrysurus*; C. length/frequency composition of two species with taxonomic, morphological, and ecological similarities; D. comparison of two similar-sized reef species in which one is found on reefs at all sizes while the other recruits only as a young adult (from Bohnsack and Bannerot, 1986).

as scientifically designed structures. There are many unanswered scientific and management questions surrounding artificial structures which are being addressed by the SEFC (Bohnsack and Sutherland, 1985). Wire fish-trap fisheries operate in some areas and have been widely criticized by recreational interests. We have actively studied the south Florida fishery in cooperation with that state (Sutherland and Harper, 1983), and research efforts are continuing. The question of recruitment of reef fishes is very complex, as described by Richards and Lindeman (1987) (Table 1), and projects are underway to answer some of the critical questions concerning early life history aspects.

Sea Turtles

SEFC research on sea turtles includes: 1) Assessing population sizes, 2) developing gear to reduce mortalities from commercial trawling operations, 3) rearing Kemp's ridley turtles, *Lepidochelys kempi*, 4) determing basic life history information, and 5) developing methodology to identify sea turtle flesh and other products for enforcement purposes. Since 1980, three major data collection programs have been initiated to assess populations. The Sea Turtle Stranding and Salvage Network (STSSN) maintains data provided by state network coordinators on dead and dying turtles. These data were used to support regulations requiring shrimpers in southeast waters to utilize the Trawling Efficiency Device also called the Turtle Excluder Device (TED). The Cooperative Marine Turtle Tagging Program distributes flipper tags and maintains recapture data to provide information on distribution and movements. A third major sampling effort has been directed at obtaining data that lead to the estimation of turtle abundance and include both nesting beach and pelagic surveys. These surveys employ airplanes and have provided the first estimates of abundance for turtles in southeastern U.S. waters (Shoop et al., 1985).

Since 1978, the SEFC has conducted an extensive gear research and development program to reduce the incidental capture and mortality of sea turtles in shrimp trawls. The technical option of developing a trawling efficiency device (TED) was seen as an effective alternative to closing shrimp grounds. Essentially, all TED development was conducted on cooperating commercial shrimp vessels (Henwood and Stuntz, 1987). Continued development resulted in a TED (Fig. 22) that is collapsible, relatively lightweight, and provided some benefits to the operation of a shrimp trawl (Watson, 1985).

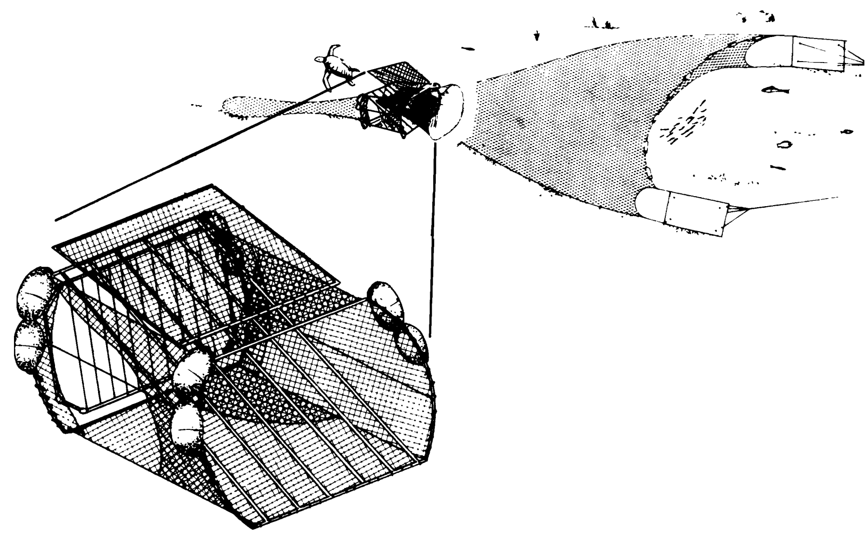

Figure 22.—The Turtle Excluder Device or Trawling Efficiency Device (TED). (From Watson, 1985).

Since 1978, the SEFC has participated in an international program to prevent extinction of the most endangered of the sea turtles, Kemp's ridley. Cooperators are the Instituto Nacional de la Pesca of Mexico, the U.S. Fish and Wildlife Service, National Park Service, NMFS, and the Texas Parks and Wildlife Department. Our role has been that of head starting Kemp's ridleys by rearing them in captivity during their critical first year of life, then tagging and releasing survivors into the Gulf of Mexico with the hope that some will survive to nest on beaches to which they were exposed ("imprinted") as eggs and hatchlings (Klima and McVey, 1982). The goal of the Kemp's ridley sea turtle head start research project is to establish a new nesting colony on Padre Island National Seashore, near Corpus Christi, Tex., within the historical nesting range of the species. Currently, nesting aggregations are confined to the only known primary nesting beach near the village of Rancho Nuevo in the state of Tamaulipas, Mex. The results of the first 9 years of head starting Kemp's ridleys have been summarized in a series of scientific papers and reports dealing with survival, growth, mark-recapture, and pathology (Caillouet et al., 1986). Among the biological studies was the discovery of overwintering loggerhead turtles, *Caretta caretta*, taking refuge in the mud of the Port Canaveral, Fla., ship channel during the extremely cold winter of 1977-78 (Ogren and McVea, 1982). This was the first time apparent hibernation was observed in sea turtles.

On the international scene, the SEFC coordinated and supported the Western Atlantic Turtle Symposium (WATS) which was held in San Jose, Costa Rica in 1983 (Bacon et al., 1984). This meeting collated information on the status of sea turtles in this area and brought about a multinational recognition of the need for conservation of these species. A second symposium was held in Mayaguez, P.R., in October 1988. SEFC chemical research facilitated NMFS law enforcement personnel in controlling the illegal harvest of sea turtles by identifying sea turtle flesh from its chemical constituents (Bradden et al., 1982).

Marine Mammals

Marine mammal research at the SEFC focuses on the bottlenose dolphin, *Tursiops truncatus*, and large whales. The bottlenose dolphin research monitors population levels of this species along the coast (Muccio et al., 1987). Relative distribution maps have been prepared and show evidence of seasonal aggregations (Fig. 23). This research (Burns et al., 1987) was presented at the December 1987 meeting of the Society of Marine Mammalogy organized in part by the SEFC. Additional research is directed at an investigation to determine the cause and impact of a die-off of nearly 400 bottlenose dolphins along the Atlantic coast.

Large whale research includes SEFC and the Northwest and Alaska Fisheries Center with Right Whale Consortium, a group of several private research institutions. The SEFC is currently developing a computerized image analysis system for identifying individual whales.

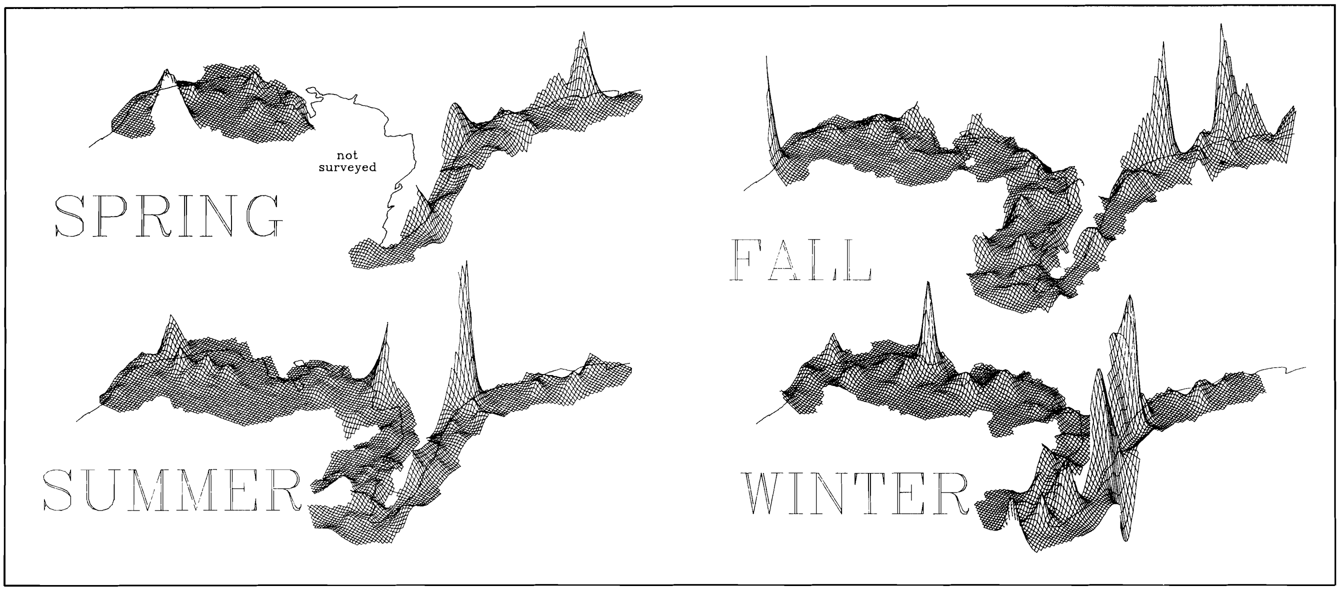

Figure 23.—Encounter rates of an index of bottlenose dolphin abundance along the southeastern coast of the United States (from Burns et al., 1987).

This research is being done cooperatively with the NOAA-University of Miami Cooperative Institute for Marine and Atmospheric Studies. The SEFC also participates in aerial surveys for right whales, *Eubalaena glacialis*, and has funded two reports on the historical status of right whale populations off the U.S. east coast (Reeves and Mitchell, 1987, 1988).

Utilization, Product Quality, and Safety

Utilization research within the SEFC addresses such research questions as: 1) How to measure deteriorative changes in fish composition, 2) what are the natural and man induced contaminant levels, 3) the physiological interaction of minerals and chemical contaminants that affect assimilation, 4) determining the safety of fish oil for human consumption, 5) how to detect and eliminate microbial, viral, and contaminants from molluscan shellfish, and 6) alternative uses of fish and fishery products, e.g., surimi.

In June 1986 a petition was submitted to the Food and Drug Administration seeking affirmation of menhaden oil (MO) and partially hydrogenated menhaden oil (PHMO) as being Generally Recognized as Safe (GRAS). The petition culminated 9 years of research and presented findings on: The description of the composition of MO, showing it to be generally similar to other fish oils and edible vegetable and seed oils used in foods; the history of the safe use of fish and fish oils, including MO; an account of the safe use of cod liver oil (CLO), the fatty acid components of CLO being broadly similar to those of MO; an account of the safe use of PHMO in the United States and Europe; a review of the literature on epidemiological and community observations on the consumption of fish and fish oils, and studies of MO consumption by humans and experimental animals, in which trained observation revealed no adverse effects; an account of protocols and results of a progam of commissioned toxicology studies on dogs and rats that showed no significant adverse effects from consumption of PHMO compared to partially hydrogenated soybean oil and low erucic acid rapeseed oil by the accepted indices of safety evaluation.

In 1985 a new fish oil program was begun to help the biomedical community ascertain the effects of the omega-3 fatty acid subcomponents of fish oil in ameliorating, modulating, or preventing certain human disease associated with faulty lipid metabolism. Preliminary laboratory and epidemiological studies have indicated a significant role of two of the omega-3 fatty acids in cardiovascular disorders, inflammatory responses, growth and human neurological development and function, and possibly cancer. Years of research remain to ascertain the role of these fatty acids, their chemical mechanism and clinical trials. Key to successful conduct of this research is the availability of highly purified, quality assured test materials. Facilities and staff have been dedicated to research and manufacture a range of test materials that will be supplied to the medical research community through a joint NIH, ADAMHA, FDA, DOC biomedical test materials program.

Safe and wise use of fishery products requires the knowledge of products chemical composition, the stability of the product throughout the handling, processing and marketing system, the chemical and microbiology contaminants level, and how to deal with these substances and organisms in a business and regulatory environment. Significant data and literature bases exist at the SEFC's Charleston Laboratory that are useful in dealing with the constant stream of questions associated with seafood consumption. Research is underway to determine: Chemical contaminant levels, how to depurate molluscan shellfish, microbial, chemical, and viral methodology that will allow research to continue, nutrient composition and the effect of different handling technology, and biotoxins in fish.

Major publications in this field include studies on the chemical and nutritional composition of marine animals and their products (Sidwell 1981); processing menhaden for conventional food (Hale and Ernst 1986; Hale et al. 1987); mercury in swordfish (Stillings and Legally, 1974); and fish oils (Bauersfeld and Winemuller, 1985).

Conclusion

This overview outlines the broad research operations carried out by the SEFC. As management problems continue to expand in the future, the SEFC research staff is well prepared to meet problems by providing expertise. The accompanying literature cited section clearly demonstrates the output by the SEFC. On the international scene we enjoy an especially close research relationship with Mexico which was begun in 1977 (Richards and Juhl, 1987). Only through international cooperative work can we begin to solve the problems posed by marine animals which move widely along the U.S. waters into neighboring nations waters and beyond for some of the oceanic species and coastal species with extended early life history stages.

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