FINAL REPORT

EFFECT OF OCEANOGRAPHIC PARAMETERS ON THE DISTRIBUTION AND ABUNDANCE OF SWORDFISH IN THE FLORIDA STRAITS

Project Numbers: R/LR-B-15-PD (125720026 and 125720497)

Project Dates: 2/84 - 5/86

by

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Submitted to the Florida Sea Grant College
September 19, 1986

Check one:

Interim ____

Final X

Annual Synopsis
Florida Sea Grant College

Instructions: Items not self-explanatory are described below.

Date: September 19, 1986

1. Investigators: Principal: Mitchell Roffer

Associate: Peter L. Lutz and Steven A. Berkeley

2. Project Number: R/LR-B-15-PD 3. Institution: Univ. Miami-RSMAS 4. Dates Covered: 2/84 - 5/86

5. Project Title: Effect of Oceanographic parameters on the distribution and abundance of swordfish in the Florida Straits.

6. Student Training & Research Information: Indicate whether undergraduate (U) or graduate (G), and with key words or short phrases describe their role (e.g., U--field interviewer, G--in charge of lab, analyses). Also, give the title of theses and dissertations and year completed. Finally, if a student has graduated, please give current activity (e.g., Biologist II, Cal. Fish & Game; doctoral student, Woods Hole).

Name	Dept.	Status & Activity or Contribution
1) Edward Gaw (G)	Biology and Living Resources.	Graduate Research Assistant-worked on data collection. Still at RSMAS.
2) Mitchell A. Roffer (G)	Biol. and Living Res.	Principal Investigator. Graduation 12/86.

Gaw's Master's Thesis title: Selected size group dynamics of swordfish (*Xiphias gladius*) off the Florida coast. (estimated completion, 1987).

Roffer's Ph.D. dissertation: (graduation 12/86) Influence of the environment on the distribution and relative apparent abundance of juvenile Atlantic bluefin tuna along the United States east coast.

7. Are any patents awarded or in progress due to this project? If yes, briefly describe:

NO

8. Publications: List in standard academic format the citations of literature produced during the reporting period. (Remember Sea Grant's requirement for, and financial assistance with, reprints.) Include journal articles, book chapters, advisory bulletins, etc., both printed and accepted manuscripts

Roffer, M.A., 1986. High-Tech Fishing Via Satellite. pp. 37-48 In: R. Crawford (ed.). 1986 World Record Game Fishes. The International Game Fish Association. Ft. Lauderdale, Florida. 320p.

Roffer, M.A. 1986. Rossby Radius of Deformation and Fish Distribution. Eos, Trans. Amer. Geophys. Soc. (in press).

9. Other Documentation:

A. Are project data stored/to be stored in a depository external to the investigator's department or campus? If yes, identify data, depository, and access:

Data is stored on the Univ. Miami-RSMAS VAX computer and Macintosh Plus compatable 3.5 diskettes. Access is through Principal Investigator.

B. List information that may tell about the project in some way other than in a formal publication. For example, legislative testimony, a feature magazine article, or a letter from someone who has instituted project findings and realized a benefit. Simply identify the item and describe very briefly.

Feature magazine article (see publications). Fishermen are routinely requesting fisheries-oceanographic advisory charts to locate concentrations of swordfish, tuna, marlin and other pelagic fish. I have provided testimony at Fishery Management Council meetings and plan to continue. Article in National Fisherman likely.

10. List sources of outside matching funds or other assistance.

University of Miami ($24596.00)
Charles Trees (private citizen) ($6,000.00)
American Cyanamid Corp. ($600.00)
James Adams (private citizen) ($7,500.00)

11, 12, 13. See instructions

SEE ADDITIONAL SHEETS

Instructions for Narrative Sections to be Attached

Depending on the age and scope of a project, these items may take from one to three double-spaced typed pages: #11 may be a half-page, #12 a page or two, and #13 perhaps a page. Generally, interim reports will be briefer, with the final synopsis addressing the entire life of the project and more resembling an executive summary. Word quality, not quantity, should be the rule.

11. **Background.** Write a concise summary of the motivation to do this project. (Although Florida faculty, scientists, and Sea Grant personnel will be familiar with project rationale and scope of the problem addressed, the intent is to make the synopsis self-contained for outside readers.) In other words, briefly, but as quantitatively as possible, summarize the importance of the issue and the need that exists in Florida that successful completion of the project will alleviate. Speak in terms of potential enhancement of marine productivity, industry, management, education, etc. Name major user interests or co-sponsors.

12. **Technical Progress.** Review major project results to date by giving a status report on each objective listed in the original proposal. To do this, discuss individual objectives in successive paragraphs, by addressing in each paragraph (1) statement of the particular objective, (2) a qualitative indication of the degree to which the objective is achieved (e.g., completed, largely achieved, partially achieved, etc.), (3) a statement of the methodology used, and (4) statements of findings and conclusions to date. Each paragraph will be an abstract in itself.

A sample beginning (abridged) might read, "1. To develop more effective live-boxes for holding pre-molt blue crabs in soft-shell production facilities. (50% achieved.) Four designs from other states have been tested. . . four remaining. . . Design A increases survival by 25%. . ."

13. **Benefits.** This section is geared more to user groups, industry, and the Federal oversight process, and tells how the technical results are actually contributing to solving the need or issue that was described in item #11 as being the motivation for the project.

Hopefully, there will be a quantitative measure of project benefit, such as in the establishment of a new industry. Secondly, though, economic measures will not apply to certain projects that instead deal, for example, with resource management or public education. Therefore, also note changes in behavior or operations of groups, etc. In either situation, document your narrative with names of organizations, sizes of audiences, sources of matching funds, etc.

A sample line in this section might read "The marina design prepared by this project has enabled boatyards to accommodate 15% more boats, thereby expanding profits for the 50 firms that have so far adopted it by approximately X dollars in 1981."

ITEM 11 BACKGROUND

The swordfish (*Xiphias gladius*) longline fishery along the east coast of Florida has become one of Florida's most valuable fisheries, since its development in 1975. In 1985, approximately 1542 metric tons (whole weight) of swordfish were reported landed from Marathon to Jacksonville, Florida. Since the approximate mean ex-vessel price was $6.89/kg ($3.13/lb), the dockside value was about $7.7 million to the fishermen. While the swordfish fishery has developed into one of Florida's high technology fisheries in terms of sophisticated electronic navigation, radar and computerized acoustic fish finders, the most common method for determining the areas and times to fish remains largely a primitive, near-random process of trial and error. Fishing this way is an inefficient and expensive process, because a typical night longline set costs about $1,200 in bait, fuel, artificial light devices and labor. Hence, a major problem in this fishery is the lack of economic efficiency. Despite the high value of the fish and intensive fishing effort, the specific factors which influence the distribution and catch success of swordfish are mostly unknown. Knowledge of the environmental factors associated with the occurrence and absence of swordfish should enable the fishermen to select areas and times which are likely to produce good catches. Conversely, it should provide the fishermen with a method for determining that poor conditions exist and help them decide not to go fishing on a unprofitable venture. Thus, one important aspect of this research is a determination of the major oceanographic factors which influence the temporal and spatial distribution and catch success of swordfish in the Florida Current. This research should benefit the fishermen by enhancing their economic efficiency.

The ultimate goal of this two-year project is to develop fisheries forecasting models related to the time and area patterns of swordfish availability and vulnerability in the Straits of Florida and throughout its geographic range. It is anticipated that the results of this research will provide the basis for a swordfish fisheries-oceanographic advisory service which will educate and disseminate information to fishermen on swordfish catchability on a routine basis. In 1981, the New Jersey Sea Grant Extension Service provided swordfishermen in the Middle Atlantic States and New England States with experimental sea surface temperature and ocean feature charts and saved the swordfishermen approximately $2.25 million in fuel cost during 1980-1981.

Another goal of this research is to enhance fisheries resource management. Information learned from this study should assist resource managers in distinguishing between natural and man-made fluctuations in the abundance and catch success in the fishery. Negative trends in catch success, total area landings and reductions in the average size of captured fish are usually associated with overfishing. However, observed changes in a fishery may be due to natural fluctuations in the population abundance (e.g. recruitment variability) or variations in the ocean environmental conditions which affect the vulnerability and availability of fish. Aspects related to observed changes in fishing success are particularly important at this time because proposed management plans (1984-1986) state that the swordfish stock in the United States Fishery Conservation Zone (FCZ) is being overfished. Information gained from this research should provide resource managers with additional insight for developing optimum management regimes, which should enhance the productivity of the swordfish stocks.

12 TECHNICAL PROGRESS

Statement of Objective 1

In the original proposal Objective 1 was stated as: *To determine the temporal and spatial distribution of swordfish in the Straits of Florida.*

Qualitative Indication of the Degree of Achievement for Objective 1

Objective 1 was completed.

Methodology Used For Objective 1

In the original project proposal the methods for OBJECTIVE 1 were stated as: *Data on catch and effort will be derived from logs provided by cooperating fishermen. Personal fishing logs kept routinely by commercial fishermen will generally include all the necessary data (i.e. LORAN coordinates and times of set and haul back, length of gangions, length of buoy drops, number of hooks set, and number and size of fish caught). The nature of the fishery, its participants, and sources of data are well know to us. We have developed a rapport with many of the fishermen and processors and have been assured by one of major swordfish wholesalers (Merritt Seafood) of their cooperation. From our experience with this fishery we do not anticipate serious difficulties in obtaining the data from a sample of at least* $10-15$ *cooperating fishermen. Emphasis will be given to obtaining catch data from boats operating out of Pompano Beach and Fort Pierce since their fishing areas are in close proximity to the areas in which the environmental data are being collected (*$27°$ *N. latitude). Because there will be a lag from the time when the environmental data is collected until it is available to this project, we* *will collect the fishery data beginning in September 1983. This will allow for the timely completion of all analyses.*

Information about the spatial and temporal distribution of swordfish in the Straits of Florida was derived from catch and effort data recorded primarily in commercial fishing logbooks and secondarily from data derived from the limited recreational fishery. Telephone and personal interview surveys of the potential landing sites and fish processing locations from Daytona Beach to Key West, were used to determine the principal port locations of the captains of swordfish vessels. University of Miami (RSMAS) personnel conducted interviews with captains, crew, vessel owners, fish processors and other people related to the swordfish fishery. Direct interviews with the captains and crews was the principal method used to gain the confidence of the fishermen and thus, facilitate the receipt of the fishing logbooks. Examples of current satellite imagery and other oceanographic data where provided as incentives for cooperation. Personal meetings and interviews were conducted without a fixed schedule, but the time involvement to obtain data ranged from one day to three days per week for 18 months. Logbooks from both commercial and recreational fishermen were collected if they contained data from February, 1984 through January, 1986. Guarantees were made by University of Miami project personnel that logbook data would be confidential and that Federal, State or other management or enforcement personnel would not be given access. In addition to these guarantees, most fishermen specified that statistics on the average catch for individual sets, trips, months and years for both number and weight of swordfish caught could not be released. It was also agreed that information related to individual fishing techniques, such as hook depth, gangion placement, bait color, and the color of artificial lights used during different phases of the moon were not to become publicized. Logbooks data were computer coded if they contained most of the following: a) long range navigation (LORAN) or latitude-longitude coordinates of the start and end of each longline set and haulback, including times; b) length of the gangions; c) length of the buoy drops; d) leader length; e) bait type; and f) number and size of the swordfish caught. Additional information related to SST, moon phase, wind velocity, sea state and depth of the acoustic scattering layers were coded when available. Logbook data were combined and analyzed by season, month, week and day.

Findings and Conclusions for Objective 1

It was determined that swordfish occur in the Straits of Florida during every month of the year. There are at least two populations of swordfish in the Straits. One group of swordfish appears to be composed of resident fish which remain off the east coast of Florida year-round. The other group appears to be composed of swordfish which migrate into the Florida fishery on a seasonal basis. The origin of the migratory fish are unknown, but swordfish of this group are thought to migrate from the Straits of Florida to northern fishery areas in the South Atlantic Bight, Middle Atlantic Bight and Gulf of Maine. It is possible that the migratory group is also composed of swordfish originating from the Gulf of Mexico, Caribbean Sea or other areas of the North Atlantic Ocean. The logbook data suggest a seasonal pattern in the spatial and temporal distribution of swordfish, if the patterns of effort and catch reflect the true distribution and relative abundance of the fish. Peak occurrence is from February through the middle of June in the Straits of Florida. During this period, most of the fishing effort is distributed in the general area bounded by 79 – 82° W. and 24 – 27° N.(Cay Sal Bank-Jupiter). During late June and July, the migratory component leaves the Straits of Florida and are believed to move to other geographic areas including offshore areas from South Carolina to Maine. Factors affecting the timing of this migration are unknown, but appear related to spawning. The migratory component begin their return to the Straits of Florida in September. A relatively unknown swordfish stock component exists in the eastern Gulf of Mexico and Caribbean Sea from November through March. Since 1984, there appears to be an increase in the number of swordfish in an area from the Dominican Republic to Antigua based on the increased catches from March through June. It is not known if the increase in catch indicates a change in the distribution and abundance of the fish in that area or simply reflects a change in the level of fishing effort.

Swordfish appear to be distributed in certain geographic areas in different years. Prior to 1984, most of the effort and catch the Straits of Florida fishery occurred between Delray Beach (26.5° N.) and Fort Pierce (27.5° N.). However, logbook data for the 1984-1986 period indicate that the fishery was centered between the Cay Sal Bank (24° N.) and Jupiter (27°). Although the logbook data are representative of the catch and effort in the Florida Straits during 1984-1986, again it is not known whether the apparent change in the geographic center of the fishery indicates a change in the distribution of the swordfish or reflects an independent change in fishing effort. The location of the swordfish fishery between northern Cuba and the Dry Tortugas did not change during this period. Analyses suggest that the spatial and temporal distribution of swordfish is highly variable on a daily basis. Since the catch of swordfish is contagious, it appears that swordfish are distributed or are concentrated in groups of individual fish. There is no indication that swordfish form schools.

Statement of Objective 2

It was stated in the original proposal that the purpose of Objective 2 was: *To determine oceanographic parameters and their temporal and spatial variability in the Straits of Florida.*

Qualitative Indication of the Degree of Achievement of Objective 2

Objective 2 was completed.

Methodology for Objective 2

The methods for Objective 2 were stated in the original proposal as: *Computer tapes of the relevant ocean environmental data and analyses will be acquired primarily from the STACS program. Parameters that may affect the fish directly or can be used to understand the dynamic interactions between swordfish catch and the ocean environment will be selected. Some of these parameters include: current speed and velocity, depth of the surface mixed layer, slope of the thermocline, Florida Current fronts, meteorological events, and chlorophyll distribution and concentration. These data will be manipulated into the same time and space domains as the fisheries data for later multiple regression, correlation or spectral analysis. Additional information will be obtained by employing manual bathythermographs and expendable bathythermographs (XBT's) aboard R/V ORCA and commercial swordfish vessels to obtain temperature profiles in the specific fishing area. Synoptic surface data will be derived from satellite remote sensing from the GOES, NOAA, and NIMBUS satellites. These satellites will provide data for surface temperature and color fronts, primary productivity and circulation patterns. The satellite imagery will be processed by the State of Florida Department of Natural*

Resources (St. Petersburg), National Earth Satellite Service (Miami), and the University of Miami-Rosenstiel School of Marine and Atmospheric Science. Although we will consider all of the STACS data in our analysis, emphasis will be given to those data from September 1983 to September 1985.

The principal source of hydrographic data analyzed during this research was the Subtropical Atlantic Climate Studies Program (STACS). Additional data were derived from The Florida Atlantic Coast Transport Study (FACTS) and several other hydrographic and circulation studies on the Florida Current, South Atlantic Bight (SAB) and Blake Plateau. Additional hydrographic data were collected by University of Miami project personnel and commercial and recreational swordfishermen. Additional data on water temperature, acoustic scattering layer, satellite derived SST and satellite derived dissolved chlorophyll data from a variety of sources were analyzed. Satellite data analyses for SST and dissolved chlorophyll concentration were conducted at the University of Miami (Virginia Key-RSMAS), National Weather Service (Coral Gables), Texas A & M University (College Station, Texas - see matching funds) and University of California (Visibility Laboratory, San Diego, California - see matching funds). The significance of these comprehensive physical oceanographic studies to our research efforts with the Straits of Florida swordfish fishery is that the integrated data set provides a coherent picture of the dynamics and variability of the Florida Current as it relates to the oceanography of the southeast U.S. continental shelf and the adjacent Gulf Stream system.

Findings and Conclusions for Objective 2

The information gained from the STACS and other hydrographic survey data has given us considerable insight into the fisheries-oceanographic process influencing the distribution and catch success of swordfish in the Straits of Florida swordfish fishery. In the Straits of Florida under mean conditions, there is a positive temperature and density gradient across the Florida Current from the Florida slope toward the Bahamas. The isotherms have a downward slope going from west to east and it is warmer at the eastern side of the Florida Current than on the western side at any particular depth. Water density is primarily controlled by water temperature and secondarily by salinity in the Straits of Florida. Current velocity and the distribution of temperature and density at depth in the Straits of Florida are highly variable. The Florida Current has a maximum northward velocity core approximately eight kilometers east of it's western boundary. Since the Florida Current meanders in an east and west direction, the high velocity core is not always the same distance from the Florida coast and thus, the distribution of temperature and density in the water column varies in time and space. The highest mean current velocity (northward) is approximately 180 cm/sec (3.6 knots) and has a mean location about 5 km from the Florida coast at Jupiter. The standard deviation in the location of the high velocity core is approximately ± 5 km, but the axis has been known to shift offshore about 50 km. The greatest standard deviations in mean water temperature at depth are located at western side of the Florida Current on the continental slope. The overall seasonal circulation pattern in the Straits of Florida during this project was similar to the known climatological pattern in that the highest volume transport (north) occurs in the late spring and early summer months and the lowest transports occur in the late spring and fall.

East-west meandering is common in the Florida Current and other segments of the Gulf Stream system. These wavelike disturbances propagate northward at speeds of 20 – 60 *cm/sec* with a mean speed of about 50 cm/sec. East-west meanders in the Florida Current at 24°, 26° and 27° N. occur at periods of four, five and 10 days. Ten day fluctuations in current speed and temperature are more pronounced in the summer and the shorter period fluctuations are more common in the winter. There is some evidence that the four to ten day period motions are influenced by local wind events originating from the passage of atmospheric fronts, but the evidence is not conclusive. Longer period fluctuations are related to the circulation dynamics of the Caribbean Sea and subtropical Atlantic Ocean. Episodic southward flow at depth in the Florida Current occurs on the Miami Terrace during all seasons, but has not been observed further north.

Statement of Objective 3

It was stated in the original project proposal that the purpose of Objective 3 was *To determine the relationship between oceanographic parameters and swordfish behavior, distribution and availability.*

Qualitative Indication of the Degree of Achievement of Objective 3

Objective 3 was largely achieved.

Methodology for Objective 3

The methods for this objective were stated in our original proposal: *Multiple correlation, multiple regression and spectral analysis of time series data will be used to integrate fisheries data with environmental data to derive fisheries-environmental relationships. Statistically significant relationships will be evaluated* *with known or learned causal relationships to develop hindcasting and forecasting models on the distribution, catchability, and apparent abundance of swordfish.*

Raw data, data reports, final project reports and scientific papers were reviewed for pertinent hydrographic data. Emphasis was made to identify the hydrographic and swordfish data sets which were collected synoptically. Specifically, data sets related to cross stream and downstream current velocity profiles, temperature and density profiles, frontal motion, meander and eddy formation, and upwelling were assembled and analyzed.

Findings and Conclusions for Objective 3

It was determined that oceanographic parameters affect the distribution, apparent abundance, availability and vulnerability of swordfish in the Straits of Florida on three different time scales. On the 1-24 hour time scale oceanographic variability effects changes in the depth distribution of temperature and density, changes in ambient light level and changes in the distribution and relative abundance of forage and swordfish. On the 1-10 day scale, the horizontal and vertical distribution of hydrographic conditions, forage and swordfish are affected by the formation, presence and passage of Florida Current meanders and eddies. Continental shelf circulation is important on this time scale. The 3-12 month and longer period scale of environmental variability effects the distribution of swordfish over its entire range. On this scale changes in the the distribution and relative abundance of swordfish in the Straits of Florida are linked to differences in the timing of large scale migrations for spawning and post-spawning feeding.

From analyzing the temporal and spatial variability in the Florida Current relative to the variability in swordfish catch, it appears that changes in swordfish distribution are due principally to east-west meanders and eddy circulation dynamics in the Florida Current. Upwelling produced by Florida Current meanders and eddies increases the abundance of the organisms in the ASL and attracts and concentrates squid and swordfish. Since most fishermen do not change the depth of their hooks during a fishing trip, the greatest component of catch variability stem directly from changes in the depth distribution and concentration of swordfish relative to the fixed depth of the longline gear. Horizontal and vertical movements of swordfish are linked to the distribution and concentration of squid and other prey. Data from this study and others suggest that swordfish feed in areas of high prey abundance which are usually associated with the acoustic scattering layer (i.e., deep scattering layer) and water density interfaces (thermoclines). The primary forage for swordfish in the Straits of Florida is squid, genus *Illex.* Although our two University of Miami research cruises (scheduled for two-ten day hydro-acoustic and hydrographic surveys) were cancelled, other hydro-acoustic and hydrographic survey data collected from several private sportfishing yachts (Ocean Yachts Sales, Inc.- see matching funds), commercial longline boats, NOAA ships and fishing logbook data confirm this foraging behavior. The distribution and concentration of squid are linked to the changes in the depth and concentration of the acoustic scattering layer (ASL) which is linked to changes in the temperature structure of the Florida Current.

Statement of Objective 4

It was stated in the original proposal that Objective 4 was *To provide participants in the fishery with information or appropriate techniques to obtain the necessary information to allow tactical fishing decisions to be made.*

Qualitative Indication of the Degree of Achievement of Objective 4

Objective 4 was largely achieved.

Methods for Objective 4

The methods for Objective 4 were stated in the original proposal as: *Attempts will be made to derive forecasting models which include parameters that are easily accessible to the fishermen from available environmental products that can be delivered in real time or through their own measurements at sea. Attempts will be made to relate easily measured surface conditions to the subsurface dynamics that are important to the fishery. Such satellite derived parameters as sea surface temperature patterns and location of the Florida Current are presently available from the Satellite Field Services Station (NOAA-NESS) in Miami. These data are routinely available to the public via NOAA's daily marine radio messages and telephone facsimile. It is anticipated that fishermen will be able to use this type of data for tactical decision making as swordfishermen do in the northwest Atlantic. Due to the ephemeral nature of the surface and subsurface current dynamics and the problems of satellite remote sensing in subtropical areas from clouds, it is likely that simple direct ship measurements of the depth and slope of the thermocline will be important. If so, models derived from these two latter parameters will be developed.*

Findings and Conclusions for Objective 4

Numerical models which relate ocean surface conditions to the subsurface dynamics of the Florida Current have not been developed. However, conceptual descriptive models were developed which are useful for locating the geographic location and depth distribution of the swordfish. These conceptual models were refined into diagnostic forecasting models. The diagnostic models were developed using both satellite and *in situ* oceanographic data. The input parameters were data derived from infrared and color imagery from the NOAA-series (*e.g.,* NOAA-9), NIMBUS and GOES satellites, surface and sub-surface water temperature, dissolved chlorophyll concentration and hydro-acoustic data. The output of the model were charts which outlined the Florida Current boundaries, current meanders, eddies, and other surface fronts. Specific geographic areas were highlighted to indicate areas where certain oceanographic conditions suggested an occurrence of swordfish concentrations. Output parameters related to optimum hook depth included, depth of the surface mixed layer, bottom of the thermocline, acoustic scattering layer and slope of the temperature gradient in the thermocline.

An experimental forecasting service was initiated in the latter stages of the project to determine the interest in receiving fisheries-oceanographic forecasts. Out-of-state fishermen were most interested in receiving the forecasts followed by the Florida fishermen who regularly fished in areas outside of the Straits of Florida. Year-round resident Florida fishermen were the least interested in the data products. Attempts were also made to educate and motivate the swordfishermen into collecting various hydrographic data themselves. Florida resident fishermen were not inclined to collect SST or other data while fishing. The out-of-state fishermen were more interested in SST, while the other Florida fishermen were interested in both surface and subsurface measurements. Although curious interest was generated in sub-surface measurements, captains did not purchase commercially available equipment to measure sub-surface water temperatures. However, captains which were loaned manual bathythermographs did express interest in receiving subsurface temperature information on a regular basis. Many fishermen requested the fisheries-oceanographic forecasts during the summer months while fishing from South Carolina to Georges Bank. Requests for the forecasts were received from both commercial and recreational fishermen who were interested in applying the information for finding tuna, marlin and bluefish. It was determined that fishermen were willing to pay from $10-$100 per forecast.

13 BENEFITS

Enhancement of Economic Efficiency

The technical results from this study should benefit fishermen, fisheries scientists, resource managers and other people interested in educating themselves about the effects of the ocean environment on the distribution, movement and catchability of fish. Fishermen have begun using available satellite and other water temperature data products on a regular basis to formulate fishing strategies. Fuel savings from using the experimental environmental data products were estimated between 0-1000 gallons for a typical eight day longline trip in the Straits of Florida.

Benefits to fisheries scientists and resource managers include an increased understanding about the effects of oceanographic parameters on the distribution, availability and vulnerability of swordfish on different time and space scales. Results of this study are presently being used by fisheries scientists and managers at the South Atlantic Fisheries Management Council, National Marine Fisheries Service and the International Commission for the Conservation of Atlantic Tunas to interpret observed changes in catch and for deriving management plans. With the insight derived this project, managers should be able to develop management plans which consider that the relationship between nominal effort and catch is variable and that the distribution, availability and vulnerability are strongly influenced by hydrographic conditions. Thus, a significant contribution of this study is an increased ability to distinguish between environmentally mediated changes in catch success and fishing pressure. Another benefit of this study relates to motivating fishermen to cooperate with fisheries scientists. As a result of this study and other similar projects, more fishermen are willing to cooperate with fisheries research. Reduction in user group confrontations may result from this research. Due to the poor margin of profit resulting from fishing for swordfish alone, swordfish fishermen have increased their fishing effort toward other large pelagic fish, such as tuna and other billfish, to earn money. However, it is likely that increased profits derived from an increase in operational efficiency will keep the level of fishing for other fish either at present or lower levels.

New Business, Audiences, Users and Matching

It appears that the feasibility of a new business, the private fisheries forecasting consulting service, should be evaluated as a result of this and other similar studies. This new business and other research projects using satellites to connect oceanographic data buoys to other data bases would be part of President Reagan's joint program with the National Aeronautics and Space Administration (NASA) for the commercialization of space. Matching funds for determining the feasibility of private fisheries forecasting services and enhancing the capabilities of combining hydrographic and fisheries data via satellite link include the Governor of Florida's Energy Office, NASA, the U.S. Small Business Administration, the World Bank Organization, and the Food and Agricultural Organization of the United Nations. Audiences of interest for the results of the present study and future studies on fisheries oceanographic forecasting include small fishing clubs, commodities investors, different fishing industries (*e.g.*, swordfish, tuna, mackerel, herring, anchovy, sardine) and governmental organizations.

EFFECT OF OCEANOGRAPHIC PARAMETERS ON THE DISTRIBUTION AND ABUNDANCE OF SWORDFISH IN THE FLORIDA STRAITS

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Rosenstiel School of Marine and Atmospheric Science

Division of Biology and Living Resources

Sea Grant Project No. R/LR-B-15-PD

Florida Sea Grant College

September, 1986

BACKGROUND

The swordfish (*Xiphias gladius*) longline fishery along the east coast of Florida has become one of Florida's most valuable fisheries, since its development in 1975. In 1985, approximately 1542 metric tons (whole weight) of swordfish were reported landed from Marathon to Jacksonville, Florida (J. Hoey-National Marine Fisheries Service, Miami Laboratory, Miami, Fl, personal communication, 1986) and since the approximate mean ex-vessel price was $3.13/lb (S. Berkeley-South Atlantic Fishery Management Council, Charleston, N.C., personal communication, 1986) the dockside value was about $7.7 million to the fishermen. While the swordfish fishery has developed into one of Florida's high technology fisheries in terms of sophisticated electronic navigation, radar and computerized acoustic fish finders, the most common method for determining the areas and times to fish remains largely a primitive, near-random process of trial and error. Fishing this way is an inefficient and expensive process, because a typical night longline set costs about $1,200 in bait, fuel, artificial light devices and labor. Hence, a major problem in this fishery is the lack of economic efficiency. Despite the high value of the fish and intensive fishing effort, the specific factors which influence the distribution and catch success of swordfish are mostly unknown. Knowledge of the environmental factors associated with the occurrence and absence of swordfish should enable the fishermen to select areas and times which are likely to produce good catches. Conversely, it should provide the fishermen with a method for determining that poor conditions exist and help them decide not to go fishing on a unprofitable venture. Thus, one important aspect of this research is a determination of the major oceanographic factors which influence the temporal and spatial distribution and catch success of swordfish in the Florida Current. This research should benefit the fishermen by enhancing their economic efficiency.

The ultimate goal of this two-year project is to develop fisheries forecasting models related to the time and area patterns of swordfish availability and vulnerability in the Straits of Florida (Figure 1) and throughout its geographic range. It is anticipated that the results of this research will be the basis for a swordfish fisheries-oceanographic advisory service which will educate and disseminate information to fishermen on swordfish catchability on a routine basis. In 1981, the New Jersey Sea Grant Extension Service provided swordfishermen in the Middle Atlantic States and New England States with experimental sea surface temperature and ocean feature charts and saved the swordfishermen approximately $2.25 million in fuel cost during 1980-1981 (Flimlin, 1981).

Another goal of this research is to enhance fisheries resource management. Information learned from this study should assist resource managers in distinguishing between natural and man-made fluctuations in the abundance and catch success in the fishery. Negative trends in catch success, total area landings and reductions in the average size of captured fish are usually associated with overfishing. However, observed changes in a fishery may be due to natural fluctuations in the population abundance (e.g. recruitment variability) or variations in the ocean environmental conditions which affect the vulnerability and availability of fish. Aspects related to observed changes in fishing success are particularly important at this time because proposed management plans (1984-1986) state that the swordfish stock in the United States Fishery Conservation Zone (FCZ) is being overfished (Angelovic, 1985). Information gained from this research should provide resource managers with additional insight for developing optimum management regimes, which will enhance the productivity of the swordfish stocks.

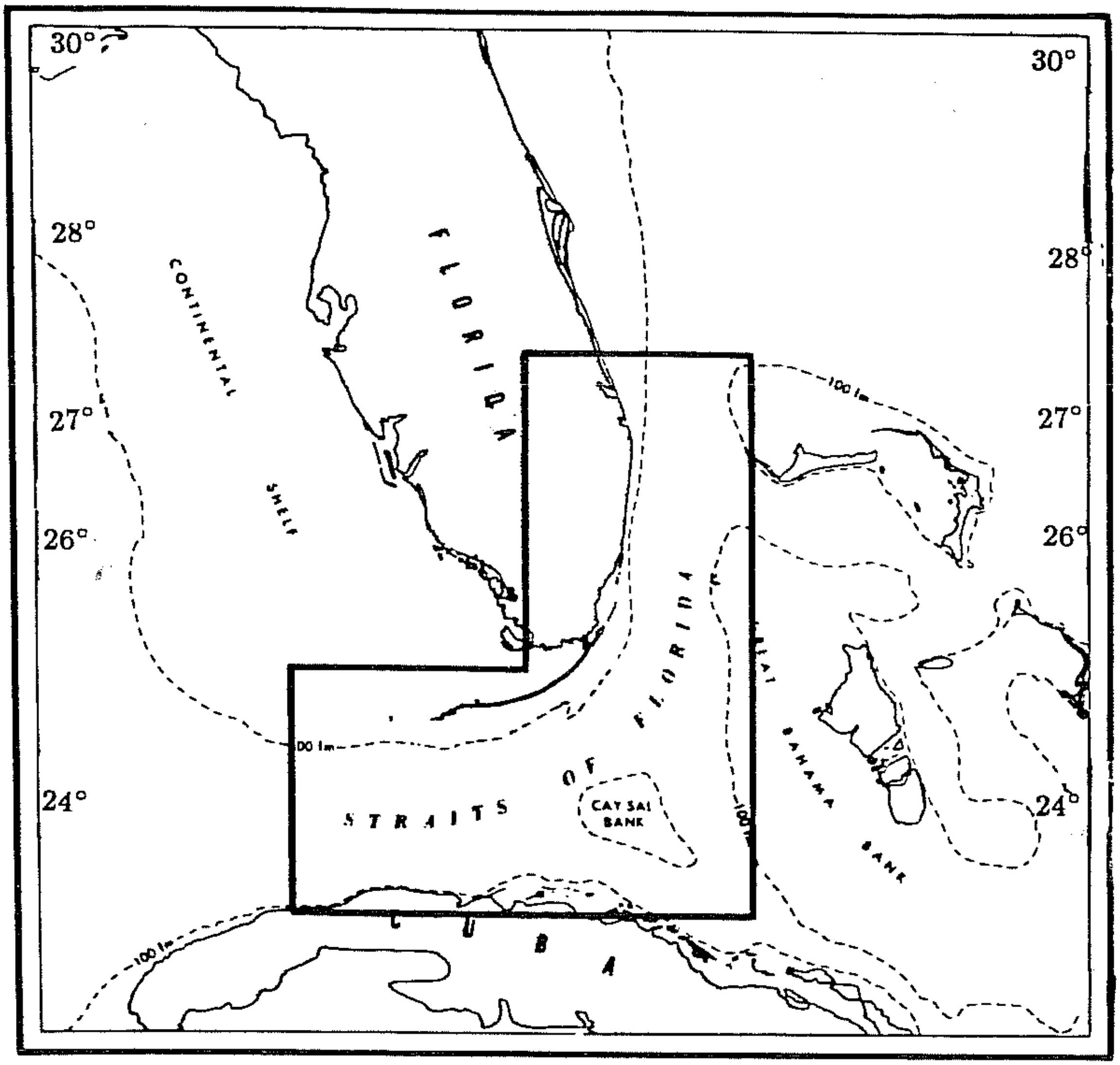

Figure 1. Overview map of the Straits of Florida study area.

OBJECTIVES AND METHODOLOGY

Statement of Objectives

In the original Berkeley and Roffer Proposal (1983) it was stated that : *the overall goal of this project is to test the hypothesis that oceanographic parameters affect the distribution and relative abundance of swordfish in the Florida Straits* and that *the following specific objectives we believe can be met in a project of two-three year's duration: 1. To determine the temporal and spatial distribution of swordfish in the Straits of Florida. 2. To determine oceanographic parameters and their temporal and spatial variability in the Straits of Florida. 3. To determine the relationship between oceanographic parameters and swordfish behavior, distribution and availability. 4. To provide participants in the fishery with information or appropriate techniques to obtain the necessary information to allow tactical fishing decisions to be made.*

Methodology Used For Objective 1

In Berkeley and Roffer (1983) the methods for OBJECTIVE 1 were stated as: *Data on catch and effort will be derived from logs provided by cooperating fishermen. Personal fishing logs kept routinely by commercial fishermen will generally include all the necessary data (i.e. LORAN coordinates and times of set and haul back, length of gangions, length of buoy drops, number of hooks set, and number and size of fish caught). The nature of the fishery, its participants, and sources of data are well know to us. We have developed a rapport with many of the fishermen and processors and have been assured by one of major swordfish wholesalers (Merritt Seafood) of their cooperation. From our experience with this* *fishery we do not anticipate serious difficulties in obtaining the data from a sample of at least* 10 − 15 *cooperating fishermen. Emphasis will be given to obtaining catch data from boats operating out of Pompano Beach and Fort Pierce since their fishing areas are in close proximity to the areas in which the environmental data are being collected (27° N. latitude). Because there will be a lag from the time when the environmental data is collected until it is available to this project, we will collect the fishery data beginning in September 1983. This will allow for the timely completion of all analyses.* In this Sea Grant project, information about the spatial and temporal distribution of swordfish in the Straits of Florida are derived from catch and effort data recorded primarily in commercial fishing logbooks and secondarily from data derived from the limited recreational fishery. Telephone and personal interview surveys of the potential landing sites and fish processing locations from Daytona Beach to Key West, were used to determine the principal port locations of the captains of swordfish vessels. University of Miami (RSMAS) personnel conducted interviews with captains, crew, vessel owners, fish processors and other people related to the swordfish fishery. Direct interviews with the captains and crews was the principal method used to gain the confidence of the fishermen and thus, facilitate the receipt of the fishing logbooks. Examples of current satellite imagery and other oceanographic data where provided as incentives for cooperation. Personal meetings and interviews were conducted without a fixed schedule, but the time involvement to obtain data ranged from one day to three days per week for 18 months. Logbooks from both commercial and recreational fishermen were collected if they contained data from February, 1984 through through January, 1986. Guarantees were made by University of Miami project personnel that the logbook data would be confidential and that the

National Marine Fisheries Service, other management or enforcement personnel would not be allowed access to it. In addition to these guarantees, many fishermen specified that statistics on the average catch for individual sets, trips, months and years for both number and weight of swordfish caught could not be released. It was also agreed that information related to individual fishing techniques, such as hook depth, gangion placement, bait color, and the color of artificial lights used during different phases of the moon were not to become publicized. Logbooks data were computer coded if they contained most of the following: a) long range navigation (LORAN) or latitude-longitude coordinates of the start and end of each longline set and haulback, including times; b) length of the gangions; c) length of the buoy drops; d) leader length; e) bait type; and f) number and size of the swordfish caught. Additional information related to SST, moon phase, wind velocity, sea state and depth of the acoustic scattering layers were coded when available. Logbook data were combined and analyzed on a seasonal, monthly, weekly and daily basis. Maps of the distribution of effort and catch were derived with analyses directed to those data sets which were sufficiently large to allow area and time comparisons of catch.

Objective 2: Oceanographic Parameters and Their Variability

The methods for OBJECTIVE 2 were stated in the original proposal as: *Computer tapes of the relevant ocean environmental data and analyses will be acquired primarily from the STACS program. Parameters that may affect the fish directly or can be used to understand the dynamic interactions between swordfish catch and the ocean environment will be selected. Some of these parameters include: current speed and velocity, depth of the surface mixed layer, slope of the* *thermocline, Florida Current fronts, meteorological events, and chlorophyll distribution and concentration. These data will be manipulated into the same time and space domains as the fisheries data for later multiple regression, correlation or spectral analysis. Additional information will be obtained by employing manual bathythermographs and expendable bathythermographs (XBT's) aboard R/V ORCA and commercial swordfish vessels to obtain temperature profiles in the specific fishing area. Synoptic surface data will be derived from satellite remote sensing from the GOES, NOAA, and NIMBUS satellites. These satellites will provide data for surface temperature and color fronts, primary productivity and circulation patterns. The satellite imagery will be processed by the State of Florida Department of Natural Resources (St. Petersburg), National Earth Satellite Service (Miami), and the University of Miami-Rosenstiel School of Marine and Atmospheric Science. Although we will consider all of the STACS data in our analysis, emphasis will be given to those data from September 1983 to September 1985.*

The main source of hydrographic data analyzed during this research was the Subtropical Atlantic Climate Studies Program (STACS). Additional data were derived from The Florida Atlantic Coast Transport Study (FACTS) and several other hydrographic and circulation studies related to the Florida Current and South Atlantic Bight (SAB). Descriptions of the respective research programs can be found in Molinari (1983) for STACS, Maul (1985) for FACTS, Atkinson *et al.* (1985) and Lee (1983) for SAB. Figure 2 shows the distribution of sampling strategies for the STACS Program. Areas where additional hydrographic data were collected for this Sea Grant research by RSMAS personnel, commercial and recreational swordfishermen are indicated. Additional data on water temperature, the acoustic scattering layer, satellite derived SST and derived dissolved chlorophyll

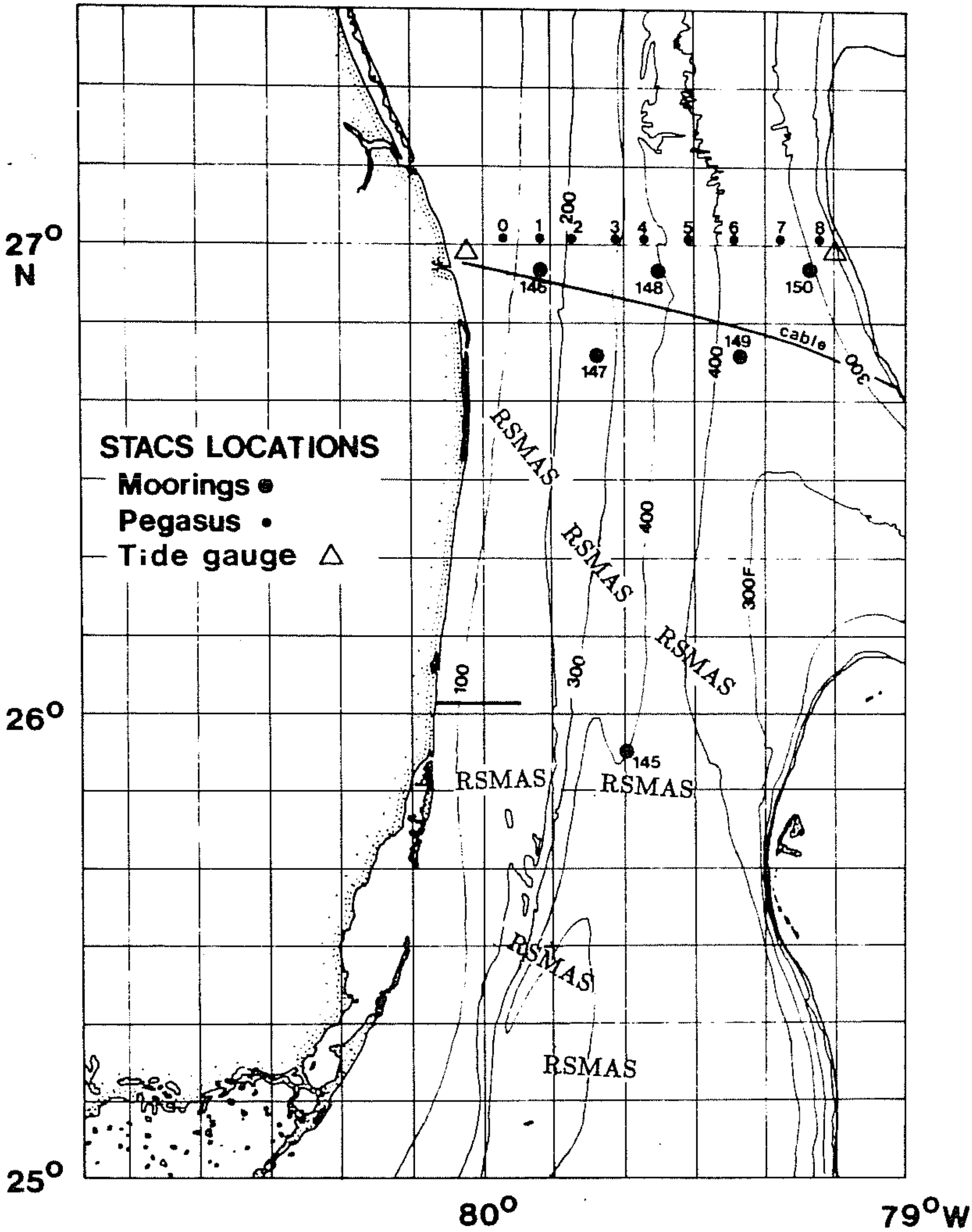

Figure 2. The STACS sampling regime (dots, triangles) and the Miami - RSMAS sampling stations (RSMAS) in the Straits of Florida, 1982 - 1986 (adapted from Molinari, 1983).

from a variety of sources were analyzed. The significance of these comprehensive physical oceanographic studies to our research efforts with the Straits of Florida swordfish fishery is that the integrated data set provides a coherent picture of the dynamics and variability of the Florida Current as it relates to the oceanography of the southeast U.S. continental shelf and the adjacent Gulf Stream system.

Raw data, data reports, final project reports and scientific papers were reviewed for pertinent seasonal, monthly, weekly and daily hydrographic data. These data sets were studied for information which could be used in the fisheries oceanographic analyses to derive relationships between the the observed variations in catch and measured environmental conditions in the Straits of Florida. Emphasis was made to identify the hydrographic data and swordfish data sets which were collected synoptically. Specifically, data sets related to cross stream and downstream current velocity profiles, temperature and density profiles, frontal motion, meander and eddy formation, and upwelling were assembled and analyzed.

Objective 3: Swordfish and Their Environment

The methods for OBJECTIVE 3 were stated in our original Proposal: *Multiple correlation, multiple regression and spectral analysis of time series data will be used to integrate fisheries data with environmental data to derive fisheries-environmental relationships. Statistically significant relationships will be evaluated with known or learned causal relationships to develop hindcasting and forecasting models on the distribution, catchability, and apparent abundance of swordfish.* Environmental and fisheries data sets were integrated and analyzed for evaluating the effects of oceanographic parameters on the distribution, apparent abundance, availability and vulnerability of swordfish in the Straits of Florida and elsewhere.

Relationships were evaluated on three different time scales: 1) month-year; 2) day-week; and 3) minute-hour.

Objective 4:Fisheries-Oceanographic Data Products

The methods for Objective 4 were stated as: *Attempts will be made to derive forecasting models which include parameters that are easily accessible to the fishermen from available environmental products that can be delivered in real time or through their own measurements at sea. Attempts will be made to relate easily measured surface conditions to the subsurface dynamics that are important to the fishery. Such satellite derived parameters as sea surface temperature patterns and location of the Florida Current are presently available from the Satellite Field Services Station (NOAA-NESS) in Miami. These data are routinely available to the public via NOAA's daily marine radio messages and telephone facsimile. It is anticipated that fishermen will be able to use this type of data for tactical decision making as swordfishermen do in the northwest Atlantic. Due to the ephemeral nature of the surface and subsurface current dynamics and the problems of satellite remote sensing in subtropical areas from clouds, it is likely that simple direct ship measurements of the depth and slope of the thermocline will be important. If so, models derived from these two latter parameters will be developed..* Forecasting models were refined and integrated into an experimental fisheries-oceanographic advisory service to determine if the forecasting models would be used by the fishermen. In addition, the experimental advisory service was used to determine the feasibility of a routine swordfish fisheries-oceanographic advisory service.

FINDINGS

RESULTS AND INTERPRETATIONS

Telephone surveys and personal interviews with swordfishermen were conducted from Key West to Daytona Beach, Florida to collect general information about the swordfish fishery and collect logbook data. The surveys and interviews were conducted at marinas, boat yards, fish processing plants and public hearings. Fishermen were approached in a similar manner, but cooperation was highly variable. Response to our survey ranged from complete cooperation, to polite interest, to polite disinterest, to mild annoyance, to anger and to threats of physical violence. There was no geographic pattern to the different levels of cooperation. However, when various aspects of the Proposed Fishery Management Plans for Swordfish were being reviewed by the South Atlantic Fishery Management Council, there was a general lack of cooperation. This was particularly acute when several respected swordfishermen openly campaigned against providing "non-fishermen" with any information related to catch and effort. Unfortunately, public review of the most controversial aspects of the Proposed Fishery Management Plan coincided with our research efforts. Despite this adversity, a considerable amount of information and logbook data were collected during this project.

It was determined that fishing for swordfish occurs during every month of the year in the Straits of Florida and most of the fishing effort originates from the major inlets near Pompano Beach, Fort Pierce, Key West, Stuart and Cape Canaveral. Swordfish fishermen who fish in the Straits of Florida can be separated into three groups on the basis of state residency and whether they move their operations away from their home ports. One group is composed of *resident* Florida fishermen, who fish in the Straits year-round. These fishermen represent approximately 50 – 70% of the effort in the Straits of Florida fishery. The *migratory* fishermen are Florida residents who fish in the Straits of Florida but travel to other areas away from Florida to fish. The third group is composed of non-Florida residents (New England, Middle Atlantic and Southeastern States) who fish throughout the western North Atlantic Ocean during the year. These *out-of-state* fishermen fish the Straits of Florida, Gulf of Mexico and Caribbean Sea during the winter months. The two latter groups of swordfishermen represent the remainder of the commercial fishing effort in the Florida Straits. From our survey of these three groups of fishermen and other personnel related to Florida swordfish fishery, it appears that about 30 to 150 boats participate in the Straits of Florida commercial swordfish fishery during any one seasonal period. The actual number of boats fishing from Key West to Cape Canaveral on any given night usually ranges from about 10 to 50 boats.

Principal effort was directed to obtaining logbook data from Florida *resident* and *migratory* fishermen based in Pompano Beach and Ft. Pierce (Merritt Seafood and Triple-M Seafood) because the greatest number of swordfish boats operate from these port areas and because these two areas are near the STACS research area (27° N.). In addition, logbooks from *out-of-state* fishermen were collected. Logbook data suggest a seasonal pattern in the spatial and temporal distribution of swordfish, if the patterns of effort and catch reflect the true distribution and relative abundance of the fish. Peak occurrence (peak catch and effort) is apparent from February through the middle of June in the Straits of Florida. During this period, the apparent center of gravity of the available swordfish population and fishing effort are located in the area bounded by $79 - 82°$ W. and $24 - 27°$ N.(Cay Sal Bank to Jupiter). During late June and July, a migratory component of the swordfish stock migrates north and during the same period the *out-of-state* and the *Florida migratory* fishermen move to more northern fishing areas from South Carolina to Maine. The factors influencing the timing of the swordfish migration are not know, but some factors appear related to a post-spawning feeding migration to the more productive areas in the western North Atlantic Ocean. The timing of the northward migration by the fishermen and eventual return south is influenced by the relative fishing success and ex-vessel prices in Florida and in other areas. There is an apparent increase in the catch of swordfish in the Straits of Florida beginning in September and continuing through December and the *Florida migratory* and the *out-of-state* fleet return to fish in the Florida Current. An unknown component of the swordfish migratory population exist in the eastern Gulf of Mexico and Caribbean Sea from November through March. Since 1984, there has been an increase in the number of swordfish landed from the Dominican Republic to Antigua, particularly during February through June. In 1984, most of the effort in the Caribbean Sea occurred between the Virgin Islands and Puerto Rico. However, high catch rates in this area resulted in an rapid expansion of the fishery to more northern and southern areas during the 1985 and 1986 winter fishing seasons. It is not known whether this sudden increase reflects a change in the distribution or abundance of the swordfish stock or that the high recorded landing result from the increase in fishing effort. Puerto Rico remains in the approximate geographic center of this expanded Caribbean fishery due to its deep water port and airport facilities, which are used to ship the catch to the U.S. mainland. As a consequence of the recent development of the Caribbean fishery, many boats no longer return to the Straits of Florida during March, April, May and June to fish. Instead, they move directly from the Caribbean region to the South Atlantic Bight, the Middle Atlantic Bight and New England regions.

Throughout the year in the Straits of Florida fishery, effort is clumped to specific geographic areas where groups of 10-15 cooperating fishermen exchange information on catch and fishing techniques (buoy and gangion length, hook depth, etc.). Fishing trips range from three to ten days in duration with a mean of about eight days. The general pattern of fishing for swordfish is same for all boats. Usually at dusk, approximately 5 to 15 longline boats organize themselves and begin setting their longline gear from west to east allowing about 2-5 km distance between mainlines. Most year-round fishermen set approximately 32 km of gear. After drifting all night, the swordfishermen begin hauling their longlines at dawn. Depending primarily on the orientation of the mainline and current velocity, the longline gear drifts about 10-30 km by the time the haulback is completed. At this time the boats return to previous night's starting location and start the fishing cycle of setting and hauling again. The volume of fuel which is used for a 24 hour period ranges from 50 gal for small (*e.g.*, 36 ft) single engine boat to 120 gal for large (*e.g.*, 60 ft) twin engine boat. The catch is cleaned and stored on ice below deck during the return trip from the end of the haulback to the starting location of the next night of fishing. Most of the fishermen in this fishery do not change the length of their gangions during a fishing trip, although many set both shallow and deep lines ranging from about 20-100 m depth. Generally, fishermen drift along with their longline gear, but do not remove fish or change bait during the night, which means that they do not know the location or time that fish are hooked. The distribution of fishing effort is related to the moon phase in this fishery. Most eight day swordfish trips are designed to begin $4 - 5$ days before a full moon. However, the actual effective trip length and the number of trips per month is highly variable due to bad weather, poor catch rates, low ex-vessel price, equipment failure, repairs and holidays. During 1984-1986 the preferred area for swordfishermen operating from Pompano Beach was an area between Cay Sal Bank and the Little Bahama Bank ($24 - 27.5°$ N.). Approximately 80% of the total longline sets which we were able to sample were made in that area. Infrequently, boats originating from the Pompano Beach area fish off Fort Pierce and Cape Canaveral. Fishermen originating from the Fort Pierce area usually fish between Jupiter to Daytona Beach (27° and 29.5° N.), with infrequent trips to the Cay Sal Bank area. Swordfish boats originating from Key West usually fish between 86° W. in the eastern Gulf of Mexico and Cay Sal Bank with the Dry Tortugas (83° W.) as the favored area.

In this study, catch success was defined as catch-per-set because data on the exact number of hooks for each set were not always recorded in the logbooks. Results of our analyses indicate that catch rates are highly variable with a range of 0-20 swordfish/set. Although the frequency distribution of catch/set is a negative binomial distribution, the zero catch frequency was not the highest. Analyses suggest that the catch of swordfish is contagious in that high and low catch rates typically occur for two to four consecutive nights on an eight day trip for a single boat. On a daily basis, catch success was highly variable for boats fishing in the same area. For example, in a group of 10 boats fishing in a particular area, usually less than 50% will have similar catch rates the same night. This appears to be related to the different depths of their hooks as discussed below. Catch-per-longline section was highly variable as well. No single section or group of sections along the longline had a consistent pattern of catch, either in number or weight of swordfish or total fish caught. Approximately 40% of the catch taken in the Straits of Florida fishery weigh between 0-22 kg (0-49 lb), 30% between 23-45 kg (50-9 lb) and 15% between 46-68 kg (100-149 lb). Size composition data for 1985 have not been derived at the writing of this report.

Attempts were made to make statistical inferences on the observed differences in catch rate between different areas during one time period and for differences in catch within areas, but at different times. These analyses were not successful due to statistical nature of the logbook data. The distribution of fishing effort over time in this fishery is clumped which is a common problem in fisheries analyses. Attempts to resolve this problem resulted in reducing the sample size to where statistically significant results were impossible to derive because the variance in catch rate was much larger than the mean and the sample sizes (N) were too small. Attempts to derive any statistically significant differences between areas for the same time period suffered for similar reasons. Most of the logbook data were collected from the relatively inexperienced captains. Most of these fishermen would fish together in the same area with little or no effort in adjacent areas. Hence, the sample size which was needed to provide sufficient degrees of freedom to derive statistically significant relationships was lacking. Data analyses identified a few captains which were better at catching swordfish compared to other captains. Attempts were made to reduce the variance in catch success by standardizing the fishing power between boats. However, the sample size for the time-area strata matrices were too small to be successful with this normalization technique. Hence, remaining data analyses focused on evaluating individual trips in particular areas for patterns in catch success related to hydrographic conditions.

Before this research project began in 1984, it was anticipated that the majority of fishing effort and catch in the Straits of Florida fishery would occur between Delray Beach (26.5° N.) and Fort Pierce (27.5° N.), as it had in previous years, so that the environmental data derived from the STACS program would overlap the swordfish fishery in time and space. However, the data derived from the fishing logbooks indicate that in 1984-1986 the fishery was centered between the Cay Sal Bank (24° N.) and Jupiter (27°). The logbook data which were received appears to be representative for the fishery during 1984-1986. But, it is not known whether this apparent movement south indicates that a change in the distribution of the swordfish has occurred because there was little or no effort in the other more northern area. Although the apparent center of the swordfish fishery in the Straits of Florida was not located in the same area as the STACS study, the information gained from the STACS and other hydrographic survey data has given us considerable insight into the fisheries-oceanographic process influencing the distribution and catch success of swordfish in the Straits of Florida swordfish fishery.

Data analyses suggest that the greatest component of swordfish catch variation stems from changes in the depth distribution of the swordfish relative to the fixed depth of longline hooks. Previous studies (Carey and Robinson, 1981; Carey, unpublished data, 1986; Roffer, unpublished data from this study) suggest that swordfish feed in areas of high prey abundance which are usually associated with the acoustic scattering layer (i.e., deep scattering layer) and water density interfaces (thermoclines). In the Straits of Florida, the primary forage for swordfish is squid, genus *Illex* (Toll and Hess, 1981; Roffer, unpublished results from this Sea Grant project). Although the two University of Miami research cruises (scheduled for two-ten day hydro-acoustic and hydrographic surveys) were cancelled, other hydro-acoustic and hydrographic survey data collected from several private sportfishing yachts (Ocean Yachts Sales, Inc.- source of matching funds), commercial longline boats, NOAA ships and fishing logbook data confirm this foraging behavior. Thus, the distribution and catch of swordfish are linked to the horizontal and vertical location of squid and other prey, which are linked to the changes in the depth and concentration of the acoustic scattering layer (ASL).

Information on the circulation of the Florida Current allows one begin to understand the factors influencing the swordfish-squid-ASL interactions which affect changes in swordfish catch success. In the Straits of Florida under mean conditions, there is a positive temperature and density gradient across the Florida Current from the Florida slope toward the Bahamas. Thus, the isotherms have a downward slope going from west to east and it is warmer at the eastern side of the Florida Current than on the western side at any particular depth. In geostrophic terms, under mean conditions there is more water on the Bahamas side of the Florida Current which means that the sea level is higher on the eastern side. Thus, a pressure gradient exists in the eastward direction which is balanced by a westward current that is turned northward due to the Coriolis force. The Florida Current has a maximum northward velocity core approximately eight kilometers east of it's western boundary. Since the Florida Current meanders in an east and west direction, the high velocity core is not always the same distance from the Florida coast. Mean current velocity and mean temperature data at 27° N., derived by by Leaman and Vertes (1982) and Vertes and Leaman (1983), are shown in Figure 3, which includes the standard deviations. Under mean conditions on the eastern side of the Florida Current, the east-west component (see a) of the current

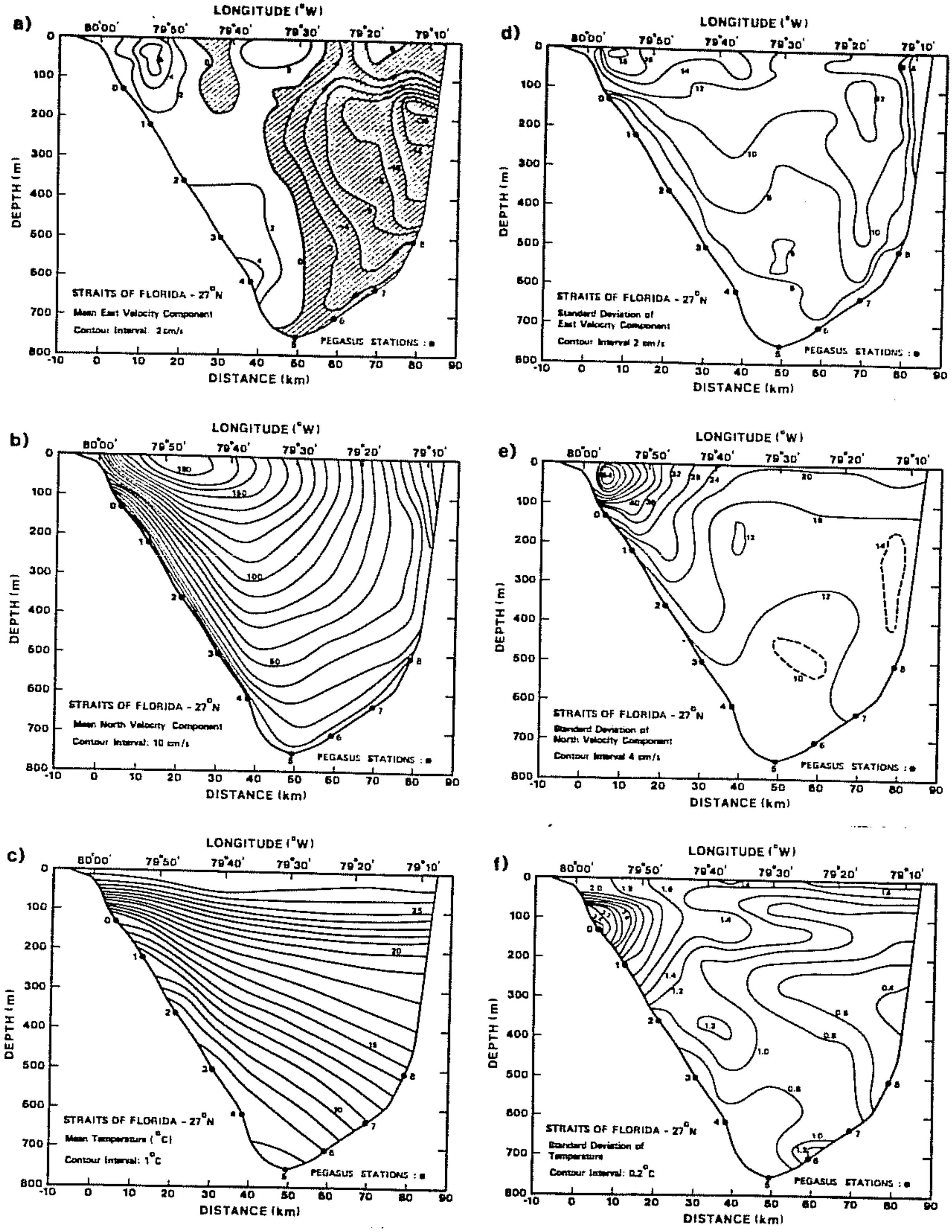

Figure 3. Mean current meter data derived from PEGASUS current meter stations at 27° North: a) mean east velocity component; b) mean north velocity component; c) mean temperature; d) standard deviation of mean east component; e) standard deviation of mean north component; and f) standard deviation of mean temperature. (adapted from Leaman and Vertes, 1982 and Vertes and Leaman, 1983).

velocity is negative, meaning that for this component of the current is directed toward the west. Although there is a very small eastward component associated with the Bahama's side of the current, it should be noted that the standard deviation (see d) is larger than the mean. This suggests that this component is highly variable. At 27° N., the highest mean northward component of velocity (see b) is approximately 180 cm/sec (3.6 knots) and has a mean location about 5 km from the coast. Substantial deviations (see e) in the location of the high velocity core occur on both sides of the mean location by about 5 km, but the axis has been known to shift offshore about 50 km. The mean temperature conditions (see c) illustrate that the eastern side of the current is warmer throughout the water column. The largest standard deviations in mean temperature (see f) are clumped on the continental slope at western side of the Florida Current. Lee *et al.* (1985) observed that the highest fluctuations in current speed were located in the vicinity of the western continental slope and that these fluctuations were principally due to east-west meanderings of the Florida Current. This variability is important to the swordfish fishery because most of the fishing effort occurs in the western side of the Florida Current and changes in the vertical and horizontal distribution of squid are linked to changes in the temperature structure of the Florida Current. The water density in the Florida Current is principally controlled by water temperature and secondarily controlled by salinity.

Although information on the mean conditions is important, the greatest problem in the Straits of Florida swordfish fishery is the inability of swordfishermen to locate concentrations of swordfish consistently on a daily basis. From analyzing the temporal and spatial variability in the Florida Current relative to the variability in swordfish catch it appears that the principal changes in swordfish distribution and catch are a consequence of east-west meandering motions and eddy circulation in the Florida Current. It is well documented that changes in the temperature result from meanders and eddys in the Florida Current. A time series of the Florida Current transport derived from current meter data along 27° N. (Lee *et al.*, 1985) illustrates the variability on a daily, monthly and seasonly basis and is presented in Figure 4. During an eastward meander the velocity to the right of the Florida Current axis increases and the velocity to the left of the axis decreases because the high velocity core moves away from the continental slope. Conversely, when a current westward meander occurs, the velocity to the left of the axis (west) increases, but the velocity on the right side (east) decreases. This westward movement brings warmer water with it and temperatures are observed to increase in relation to fixed positions. A long-term continuous time series of water temperature and current velocity data for the upper 50 m in the water column does not exist in the Straits of Florida, but data from depth suggest that current fluctuations result in substantial changes in the temperature and density structure of the water column. For example, velocity changes of 50 cm/sec related to east-west meanders are common at 300 m water depth and these fluctuations result in $6°C$ fluctuations (14° - 8° C) in water temperature at that depth. East-west meandering is common in the Florida Current and other segments of the Gulf Stream system. These wavelike disturbances propagate northward at speeds of $20 - 60$ cm/sec with a mean speed of about 50 cm/sec. East-west meanders at 27° N. in the Florida Current occur at periods of 10 days and at periods of four to five days. Ten day fluctuations in current speed and temperature are more pronounced in the summer and the shorter period fluctuations in the winter. There is some evidence that the four to ten day period motions are influenced by local wind

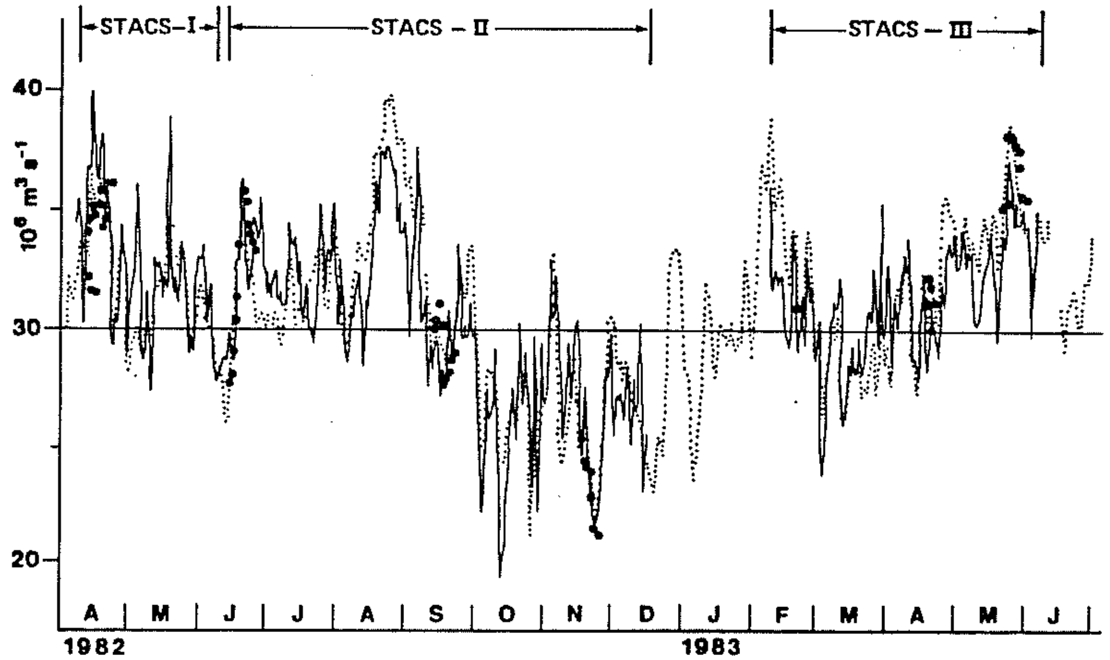

Figure 4. Time series of the Florida Current volume transport from April, 1982 through June, 1983 determined from five moored current meters (solid lines), from cable voltages (small-dot lines) calibrated by PEGASUS current meters (large-dot lines). (adapted from Lee *et al.*, 1985).

events originating from the passage of atmospheric fronts, but the evidence is not conclusive. Longer period fluctuations are related to the circulation dynamics of the Caribbean Sea and subtropical Atlantic Ocean (Schott and Zantopp, 1985). Variability in catch success is linked to these meanders.

The mean conditions of the Florida Current offshore of Miami (25.75° N.) are approximately the same as off 27° N. East-west fluctuations in the Florida Current off Miami have periods of about 4-6 days and 10-13 days. Observations of deep southward flow in the entire lower half (200 − 840 m) have been made by Duing (1975), Lee *et al.* (1977) during westward meanders. This reversal phenomena appears to be restricted to the western side of the Straits and reversals in the direction of the Florida Current deeper than 200 m have not been observed in the STACS data set off Jupiter (27° N.). The deep southward flows occur at the same frequencies as the east-west meanders of the current. Duing (1975) believed that the southward flow resulted when atmospherically generated continental shelf waves moved southward on the Miami Terrace causing westward meanders in the Florida Current. When westward meanders occur, the total flow through the Straits off Miami is low. Since the typical integrated northward flow in water deeper than 200 m off Miami is near zero under mean conditions, these continental shelf waves force the deep water to flow southward for three days. Observations show that episodes of southward flow occur during all seasons. Although it is now known that additional factors influence the production of meanders in the Gulf Stream, there are no known reasons why southward flow has only been observed off Miami (T. Lee-University of Miami-RSMAS, personal communication, 1986). There were no current meter data available which were derived from the Cay Sal Bank area to to analyze any relationships which may exist between swordfish catch and flow reversals. However, since catch rates were observed to change during episodes of westward meandering, it is likely that flow reversals do influence the distribution and vulnerability of swordfish in the Straits of Florida. Figures 5a and 5b shows the circulation related to east-west meanders and eddys in the Straits of Florida. Figure 5a (top) shows a segment of the Gulf Stream with several frontal eddys. Hydrographic data suggest that these eddys pass a given geographic location on approximately the same frequency that meanders occur and the same frequency observed for changes in swordfish catch. Figure 5b (bottom) indicates that downwelling occurs when the leading edge of a frontal eddy passes through a particular area. However, when the center of the eddy passes, upwelling is observed. Upwelling and downwelling circulations have different effects on catch success depending on the depth where the hook is set. If the hook is deeper than the strata where swordfish are foraging, then a downwelling circulation pattern will often result in higher catches because the downward motion tends to push the ASL-squid-swordfish complex downward into the depth strata where the hooks are located. Conversely, if the longline hooks are above the strata where swordfish are foraging, upwelling motion will usually produce good catch rates because the ASL-squid-swordfish complex will be pushed in the direction where the hooks are located. In the Straits of Florida fishery, upwelling circulation usually results in good catch rates, whereas catch success related to downwelling is mixed. Figure 6 shows a time series of water temperature data and the different water temperature regimes that longline hooks would experience during the passage of frontal eddys. Hooks are shown at 50 m. Although the hooks remain at the same depth, the temperatures surrounding the hooks can change substantially over a few days, *e.g.*, from 18° C on 3 July to 11° C on 8 June. Thus, if the acoustic scattering layer-

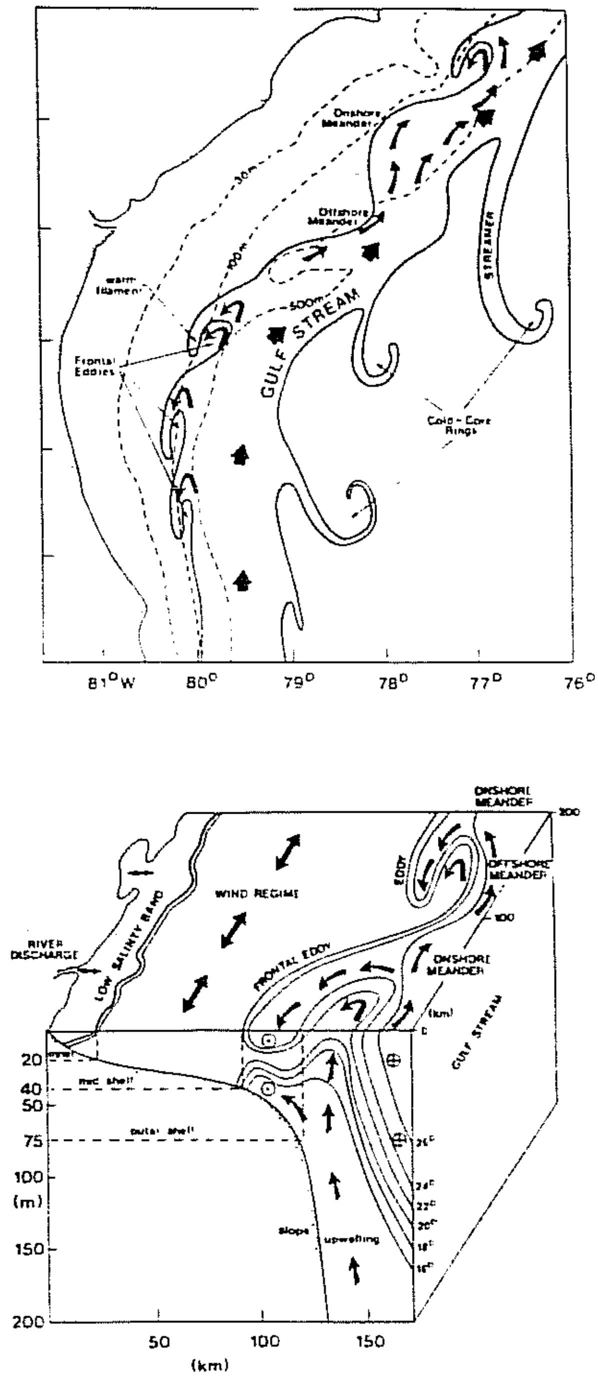

Figure 5. Meaders and eddys in the Florida Current: a) a segment of the Gulf Stream showing a series of eddys and meanders (top); and b) circulation related to the movement of an eddy showing both upwelling and downwelling (bottom).

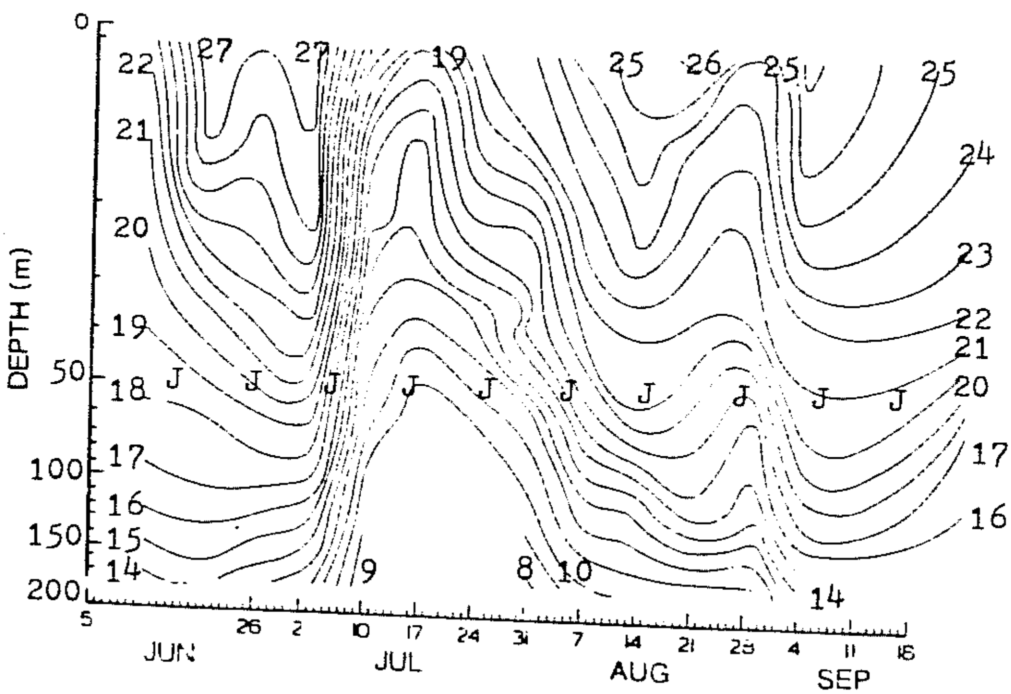

Figure 6. Time series of water temperature data shown with longline hooks (J) in relation to the different thermal regimes that the hooks would experience in time at constant depth (adapted from Smith, 1983).

squid-swordfish complex were associated with 16°C - 18° C water temperatures and the longline hooks were set at 50 m, high catch rates would occur on 3 - 5 July. Without the influence of eddys and meanders in this fishery, subtle changes in the temperature structure of the Florida Current result in substantial changes in catch success. Figure 7 shows three water temperature sections derived from transects from Jupiter to the Little Bahamas Bank. Recall that most fishermen place their hooks between 20 m and 100 m depth. The top temperature contour plot is typical of temperature conditions which exist during periods when high catch rates occur. Note that the temperature gradients are located in the upper 100 m of the water column and the distinct slope of the isotherms. The best catch rates usually occur on the western side of the Straits of Florida under this type of regime. The middle contour plot is typical of below average catch rates. Note that the largest temperature gradients are located between 100 m and 200 m. In the middle contour plot, note that the Florida Current is isothermal above 100 m, except for the western side. The bottom temperature contour plot is typical of conditions which exist when catch rates are poor. Note that there is no distinct slope to the isotherms in the upper 150 m of the water column. This bottom contour plot was derived from data collected after the first University of Miami cruise was postponed due to the lack of fishing effort in the study area. Lack of fishing effort resulted when catch rates were so low that it was not economically feasible to fish.

Model Development and Forecasting Advisory Service

Numerical models which relate ocean surface conditions to the subsurface dynamics of the Florida Current have not been developed. However, conceptual

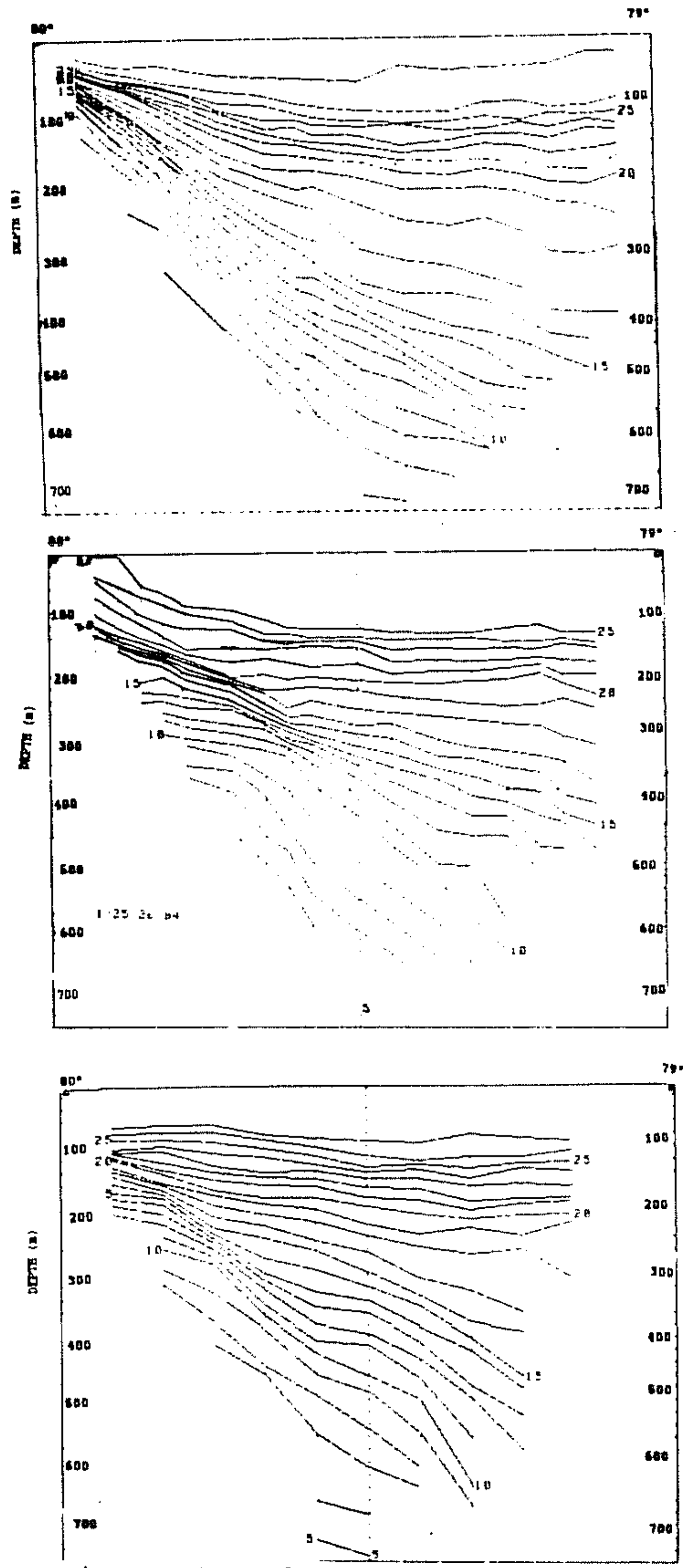

Figure 7. Three temperature contour plots of a hydrographic section between Jupiter and Little Bahama Bank. The three contour plots, top, middle and bottom are typical temperature conditions which exist in the Straits of Florida during high, below average and poor catch rates, respectively.

descriptive models were developed during this study which are useful for inferring the horizontal and vertical distribution of the swordfish. These conceptual models were refined into diagnostic forecasting models during the latter stages of this project. The diagnostic models were developed using both satellite and *in situ* oceanographic data. The input parameters were data derived from infrared and color imagery from the NOAA-series (*e.g.,* NOAA-9), NIMBUS and GOES satellites, surface and sub-surface water temperature, dissolved chlorophyll concentration and hydro-acoustic data. The output of the model is integrated into advisory charts which indicate the Florida Current boundaries, current meanders, eddies, and other surface fronts. In these advisory charts, specific hydrographic features are enhanced and notes are included where conditions suggest the likelihood of concentrations of swordfish. In the diagnostic models, parameters related to optimum hook depth include, depth of the surface mixed layer, bottom of the thermocline, acoustic scattering layer and slope of the temperature gradient in the thermocline. An example of a Swordfish Advisory chart is shown in Figure 8 which includes a map showing Florida, northern Cuba, Grand Bahama, eastern Gulf of Mexico and the northern Caribbean Sea. This chart was produced by tracing the land masses and SST boundary of the Loop Current (eastern Gulf of Mexico) and Florida Current (Straits of Florida). The location of the SST boundary was derived from NOAA and GOES satellite imagery on 28 March 1984. Since the location of swordfish is related to the presence of meanders and eddys, the diagnostic model evaluates the circulation features in the Florida Current and identifies regions of upwelling and downwelling. In Figure 8, an eddy feature south of Key West is outlined and an enlargement is shown in separate box at the side of the chart. The enlarged area indicates the probable location

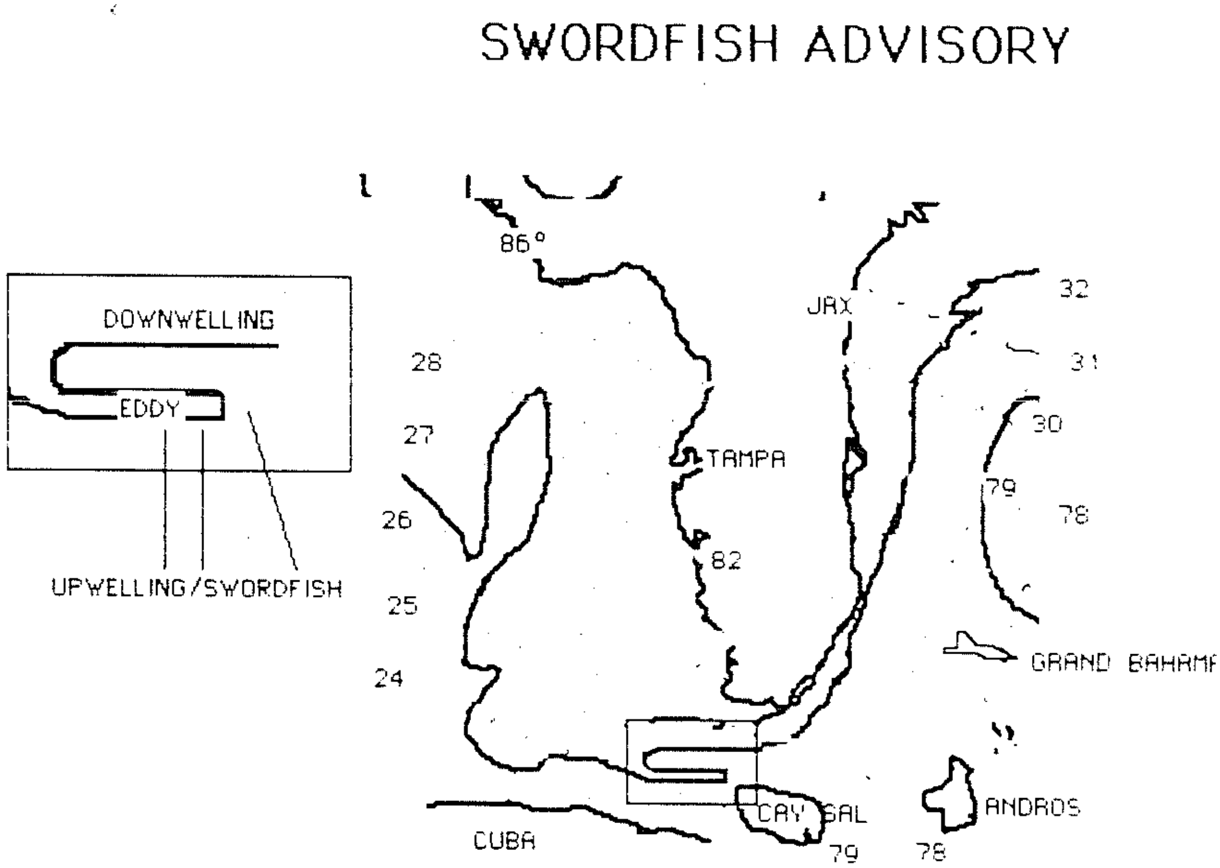

Figure 8. An example of a Swordfish Advisory chart for Florida.

of swordfish concentrations near the center of the eddy. Downwelling is indicated on the northern section of the meander feature and upwelling is indicated at the center of the eddy. The advisory charts were made using a Macintosh Plus (Apple Computers, Inc.) system with a variety of hardware (including two digitizers) and standard computer software packages. A system was developed where computer generated advisory charts could be directly sent to fishing boats at sea through portable telephone systems. The easy operation of the Macintosh Plus was easily accepted by the fishermen. The apparent complexity of other personal computer systems appeared to inhibit the fishermen.

Swordfish fishermen who had previously cooperated with project personnel by providing logbook data were provided different types of oceanographic data including satellite imagery and water temperature data. During the last few months of research, advisory charts were provided to those cooperating fishermen who requested them. *Out-of-state* fishermen were most interested in receiving the forecasts followed by *Florida migratory* fishermen. Year-round *resident* Florida fishermen were the least interested in the data products. Attempts were also made to educate and motivate the swordfishermen into collecting various hydrographic data themselves. Florida resident fishermen were not inclined to collect SST or other data while fishing. The out-of-state fishermen were more interested in SST, while the other Florida fishermen were interested in both surface and subsurface measurements. Although curious interest was generated in sub-surface measurements, captains did not purchase commercially available equipment to measure sub-surface water temperature. However, captains which were loaned manual bathythermographs did express interest in receiving subsurface temperature information on a regular basis. Many fishermen requested the Swordfish

Advisory charts during the summer months while fishing from South Carolina to Georges Bank.

To determine if the Swordfish Advisory charts could be the basis of a dedicated fisheries-oceanographic advisory service, fishermen were asked to pay for the forecasting charts. Although a price scale was discussed when requests for subscriptions to the advisory service were made, no money was collected since it was not the purpose of the experiment. However, fishermen were not told that the service would be gratis until after they indicated they were willing to pay. By the end of the research, requests for the forecasting charts came from both commercial and recreational fishermen who were interested in applying the fisheries-oceanographic information for finding swordfish, tuna, marlin and other fish from Maine to Puerto Rico. Fishermen were willing to pay from $10 to $100 per forecast. The $10 rate was the suggested price for one advisory chart per week which was send via surface mail. The $100 per advisory rate was for specially prepared charts for real-time analyses. These advisories were usually prepared immediately after receipt of the early morning NOAA satellite pass between 0400 and 0600 hrs. The special charts were sent via telecopier, radio-telephone, single-side band radio, special parcel service or from personal computer to personal computer.

BENEFITS

Enhancement of Economic Efficiency

The technical results from this study should benefit fishermen, fisheries scientists, resource managers and other people interested in educating themselves about the effects of the ocean environment on the distribution, movement and catchability of fish. Fishermen have begun using available satellite and other water temperature data products on a regular basis to formulate fishing strategies. Fuel savings from using the experimental environmental data products were estimated between $0 - 1000$ gallons for a typical eight day longline trip in the Straits of Florida.

Benefits to fisheries scientists and resource managers include an increased understanding about the effects of oceanographic parameters on the distribution, availability and vulnerability of swordfish on different time and space scales. Results of this study are presently being studied by fisheries scientists and managers at the South Atlantic Fisheries Management Council, National Marine Fisheries Service and the International Commission for the Conservation of Atlantic Tunas. In this study, it was determined that nominal fishing effort is not equivalent to effective fishing effort in the Straits of Florida fishery, which means that fixed levels of nominal fishing effort will produce variable catches. This occurs because the distribution, availability and vulnerability of swordfish are strongly influenced by hydrographic conditions. One implication is that management plans which aim to regulate the total mortality of swordfish would be more effective if they considered limits on total landings, rather than limits on effort. Another implication of this study to fisheries managers is that catch-per-unit effort statistics do not provide good indices of swordfish abundance, but rather indices of availability and vulnerability. Results suggest that changes in CPUE result principally from changes in catchability and secondarily from changes in abundance. This implies that population assessment techniques which use CPUE indices as the basis to derive population abundance estimates need to be re-evaluated. Thus, one benefit of the research presented in this report should be an increased ability to distinguish between environmentally mediated changes in catch success and fishing pressure. Another benefit of this study relates to motivating fishermen to cooperate with fisheries scientists. Fishermen usually distrust fisheries scientists. Until about 1978, the Straits of Florida swordfish fishery was a clandestine fishery. As a result of this study and other similar projects, more fishermen are willing to communicate and cooperate with fisheries researchers. Another potential benefit of this research is the reduction of user group confrontations between commercial and recreational fishermen. Due to the poor profit margin resulting from fishing only for swordfish which is highly inefficient, swordfish fishermen have increased their fishing effort to other large pelagic fish, such as tuna and other billfish, over the last four years to earn money. However, it is likely that increased profits will result from the increase in operational efficiency derived from this study. This may keep the level of fishing effort for other large pelagic fish either at their present levels or help lower them.

New Business, Audiences, Users, and Sources of Matching

It appears that the feasibility of a new business, the private fisheries forecasting consulting service, should be evaluated as a result of this and other similar studies. This new business and other research projects using satellites to connect oceanographic data buoys to other data bases would be part of President Reagan's joint program with the National Aeronautics and Space Administration (NASA) for the commercialization of space. Matching funds for determining the feasibility of private fisheries forecasting services and enhancing the capabilities of combining hydrographic and fisheries data via satellite link include the Governor of Florida's Energy Office, NASA, the U.S. Small Business Administration, the World Bank Organization, and the Food and Agricultural Organization of the United Nations. Audiences of interest for the results of the present study and future studies on fisheries oceanographic forecasting include small fishing clubs, commodities investors, different fishing industries (*e.g.*, swordfish, tuna, mackerel, herring, anchovy, sardine, snapper, grouper) and governmental organizations.

New Research Development

The results of the present study suggest that the use of fisheries-oceanographic data analyses provide useful information for fishermen, resource managers, educators, and businessmen. New research, development and demonstration projects are likely consequences of this swordfish research project. While the present study evaluated the distribution and apparent abundance of swordfish through indirect, fishery dependent methods (*i.e.*, catch and effort data), the objectives of a follow-on study should be to determine the factors influencing the short-term swimming behavior using such fishery independent techniques as acoustic telemetry. A direct follow-on study to the present swordfish study should focus on short-term (*i.e.*, minute-hour scale) movements of swordfish during foraging and should encompass swimming behavior in relation to the spatial and temporal dynamics of forage organisms and other organisms which compose the acoustic scattering layer. These aspects have not been comprehensively evaluated by the research reported in this document, by Carey and Robinson (1981) or other researchers. Results would have applications to many different fish which search the ocean environment for for needed concentrations of food. Full-time expertise in ocean hydro-acoustics and part-time assistance with aspects related to squid behavior are needed for this type of research.

Other research projects which would be a logical follow-up to the present study involves the use of fishery dependent and fishery independent methods to access the dynamics other fisheries in which the fisheries resources are behaviorly linked to known physical conditions. A good area to conduct this type of research is off the Florida coast near Cape Canaveral. The Florida Current is easily monitored from tethered current meters. By using satellite communication capabilities, one can monitor the oceanographic conditions in a near real-time manner and direct sampling strategies based on current meter and satellite infrared data. Sonobuoys which are passive acoustic listening devices, can be used to independently monitor the biological activity related to the passage of Florida Current meanders and eddys. In this way, the use of boats for sampling will be optimized by responding only when an episode or an event occurs. In addition, the use of sonobouys reduces the bias which stems from fishery dependent sampling systems which depend on catch and effort data. Snapper, grouper and other important fish occurring off Cape Canaveral would be good subjects for this type of research. Potential audiences include fishermen, physical and biological oceanographers, the satellite communication industry and fisheries scientists. These users would be the potential source of matching funds.

Another follow-on project to the present study would be to conduct an extensive feasibility study of developing routine fisheries-oceanographic advisory services for the State of Florida. The purpose of such services would be to develop the capability to forecast the spatial and temporal distribution and catchability (*i.e.*, availability and vulnerability) of fish. This capability is necessary for longer-term economic and social planning at the State and local municipal levels. This type of study would involve organizing various data bases to comprehensively evaluate the known biology of important fish in relation to the environment factors effecting their abundance, timing of long range and local migrations and daily changes in concentration and catchability. This type of information is needed by fishermen, resource developers and managers, and fisheries scientists. Benefits include increased economic efficiency, improved management regimes, new fisheries development, and optimal utilization of both the fish resources and leisure time activities.

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