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APPLICATION OF ERTS-1 DATA TO THE HARVEST MODEL OF THE U.S. MENHADEN FISHERY

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16. Abstract

This investigation represents a joint effort between EarthSat and the National Fish Meal and Oil Association, representing the menhaden industry. The primary objective was to demonstrate the utility of spacecraft remotely sensed data to the harvest technology of an operating commercial fishery. The project was conducted in Mississippi Sound in the north-central Gulf of Mexico. It utilized conventional surface data, obtained from fishing and other vessels, as well as aircraft and spacecraft remote data.

A relationship was established between surface measured water transparency, temperature and salinity, and commercial fish-stock availability. Numerical models of the relationships were derived. A multiple regression was performed relating ERTS-1 MSS Band 5 image density to measured transparency and water depth. It is concluded that remotely acquired data can play a role in harvest decisions of commerical fisheries.

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APPLICATION OF ERTS-1 DATA TO THE HARVEST MODEL OF THE U.S. MENHADEN FISHERY

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PREFACE

This investigation was undertaken to demonstrate the utility of spacecraft remotely sensed data to the harvest technology of an operating commercial fishery. In order to accomplish this principle objective, it was first necessary to establish a relationship between key environmental variables and the fishery and then to develop relationships between satellite acquired data and those environmental variables shown to be correlated with fish behavior or with the fishery.

The results reported herein are derived from data taken during the course of the 1972 menhaden fishery season in Mississippi Sound, a coastal estuarine system located adjacent to Louisiana, Mississippi, and Alabama in the north-central Gulf of Mexico. The experiment design called for the acquisition of data from commercial fishing vessels, other surface vessels, several aircraft platforms, and the ERTS-1 spacecraft. The experiment was conducted in cooperation with the National Fish Meal and Oil Association and several government laboratories so that the total data available far exceeded that called for in this component of the overall program. This report will deal only with analysis performed as required by this program, which coexisted as a separate contract entity.

The results obtained demonstrate conclusively that satellite sensed environmental data can be of benefit to commercial fishing interests. Specifically, a qualitative relationship was established between ERTS-1 imaged turbid features and location of fishing activity. Statistically significant relationships were derived relating the environmental parameters salinity, temperature and water transparency to the fishing effort. For modeling purposes, polynomial expressions were developed which conform more closely to the natural condition than the statistically derived linear relationships. A methodology was also formulated and statistically validated to predict water transparency from ERTS-1 Band 5 image density.

It was concluded that the ERTS-1 sensor system can provide data of considerable utility in the definition of the fishing environment and potentially useful in management decisions. The potential for development of a NASA constituency in the marine resources is discussed and recommendations are made concerning refinement of derived predictive models, an improved ERTS system, and a dedicated ocean/estuarine monitoring system. Considering the constraints on ERTS-1 as on oceanographic sensor system, considerable promise exists now for refining ERTS-type data utility and for designing more fundamentally valuable satellite systems for the ocean data user community.

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INTRODUCTION

Purpose of the Study

This report represents the results of an eighteen-month study under NASA Contract NAS-5-21743 to demonstrate the feasibility of the ERTS-1 system as a data source for use in management decisions pertinent to the harvest operations of the domestic menhaden fishery. The specific objectives of this investigation were:

- to define the subjective decision process whereby environmental information is translated into specific fisheries decisions,
- to quantify environmental relationships which are pertinent to fisheries operations, and
- to quantify relationships between ERTS-1 information and other earth resources information affecting decision processes in the commercial fishery.

The study concept grew from a previous working relationship between the professional staff of Earth Satellite Corporation (EarthSat) and members of the National Fish Meal and Oil Association (NFMOA), who represent the majority of the commercial menhaden interests in the United States. This relationship had developed over a period of years as a result of our interest in commercial fishing and previous contract work for NASA and the U.S. Navy (Spacecraft Oceanography Project) relating to the utility of remote data as a management tool in commerical fishing. The impetus for initiating this program was a mutual desire on the part of the user group (NFMOA) and EarthSat to cast an experiment in an operational framework, so that data acquired from actual fishing operations could be coordinated with synoptic satellite data and quasi-synoptic surface environmental data in such a fashion as to determine the feasibility of satellite-acquired information as a management tool in the fisheries operations. The desire was to build an empirical earth resources information relationship which could be used not only in the menhaden fishery but also serve as a basis for developing the remote sensing user constituency potentially available in commercial fisheries.

Within EarthSat, the specific goal was to determine relationships which would translate earth resources information into useful management actions through the application of a relevant decision model. Our goal was not an academic description of fisheries/environment relationships, but rather the development of a methodology which provides new information of management significance to an operational industry already subjectively processing environmental information. Thus, the focus was on a quantitative and qualitative model building process, which serves to define unique occurrences not readily observable to the fishery through the current operating procedures. The success of this approach is dealt with in the text to follow.

During the initial planning activities for this program, EarthSat and NFMOA became aware of a complementary ERTS-1 investigation being planned jointly by the National Marine Fisheries Service's Fisheries Engineering Laboratory (FEL) and NASA's Earth Resources Laboratory (ERL). Their experiment was to be executed near the Mississippi Test Facility and overlapped geographically and conceptually with ours. EarthSat/NFMOA then joined cooperatively with the FEL and ERL laboratories in a joint ERTS-1 experiment.

The cooperative ERTS-1 experiment was designed in four parts with overlapping responsibility of the participants. These parts included the "Space Experiment," "Oceanic Experiment," "Living Marine Resources Experiment," and the "Utilization Experiment." EarthSat and NFMOA had principal responsibility for the Utilization Experiment and provided input data for use in the remaining three experiments. Similarly, the other participants provided data under each of their experimental programs which was also made available to the EarthSat/NFMOA team.

A complete description of the cooperative experiment may be found in Project Plan, ERTS-A Experiment (Stevenson et al, 1972). The EarthSat/NFMOA portion (SR258), funded as a separate entity by NASA, is all that will be considered in detail herein, with reference to the other experiments as required for continuity and clarity.

The User

The focus of EarthSat's involvement was with the ultimate user group, NFMOA, an informal association which then represented four of the six principal companies which dominate the commerical fishery for menhaden. These four companies were:

- Haynie Products, Inc.
  with processing plants in Mundy Point, Cape Charles, and Reedville, Virginia; Moss Point, Mississippi; Wildwood, New Jersey; and Morehead City, North Carolina. Its headquarters and a research laboratory are located in Baltimore, Maryland.

- Standard Products Company, Inc.
  with processing plants in Amagansett, New York; Lewes, Port Monmouth, Crab Island, and Tuckerton, New Jersey; Kilmarnock and Reedville, Virginia; Beaufort, Southport, and Morehead City, North Carolina; Lewes, Delaware; Morgan City and Cameron, Louisiana; Moss Point, Mississippi; and Sabine Pass, Texas. Its headquarters are located in Kilmarnock, Virginia.

- J. Howard Smith, Inc.
  with processing plants in Tuckerton, Crab Island, and Port Monmouth, New Jersey and Lewes, Delaware. Its headquarters and a research laboratory are located in Port Monmouth, New Jersey.

- Wallace Menhaden Products, Inc.
  with processing plants in Empire and Cameron, Louisiana. Its headquarters are located in New Orleans, Louisiana.

During the course of this investigation, Haynie Products merged with the fifth major interest in the menhaden fishery, Zapata Corporation, with processing plants in Cameron and Dulac, Louisiana; Zapata-Haynie subsequently joined NFMOA.

The organizational structure and receptivity to technological innovation of the menhaden industry, and the habitat and life style of the fish, made this fishery ideal for an ERTS-A investigation. The relatively uncomplicated organizational structure greatly simplified communication and coordination, and made possible an understanding of the decision structure. Of greatest scientific importance was the fact that adult menhaden are pelagic residents of shallow coastal waters, thus presumably affected by surficial conditions which can be remotely sensed.

Although the menhaden industry is the leading domestic fishery in volume of landings and eighth domestic fishing in ex-vessel value, the industry is ultimately composed of only five independent corporations. There are several companies subordinate to those corporations, but industry and corporate policy is determined by five sets of managers. In addition, all capital equipment used in producing and processing the resource is company owned, the only exception being spotter aircraft, which some companies contract separately. This structure is in direct contrast to that of other fisheries in which producers and processors each may be independent and unrelated to other levels, and not necessarily bound to do business with any one entity. Formal communication among menhaden industry leaders is through its trade organization, the NFMOA, which is headquartered in Washington, D. C.

The menhaden industry has a continuing history of technological advance with a company at Reedville, Virginia using a radio-equipped sea plane to find and report menhaden schools as early as 1917. This first application of remote school detection can be considered among the earliest applications of remote sensing techniques. By 1922, at least one vessel fishing in Chesapeake Bay had a refrigerated fish hold, standard equipment in the current Gulf of Mexico fishery. The period following World War II saw the fishery become totally dependent upon aerial fish spotters in radio contact with the fishing vessels. Also, numerous new techniques and technology have been tried, resulting in several major advances in operational efficiency. The history of technological development of this industry is reviewed in _The Impact of Remote Sensing Data on the U.S. Menhaden and Shrimp Fisheries_ (Maughan, et. al. 1972).

Currently, the industry is looking not only to improve the means for capturing fish schools, but also for improved fish location and prediction capabilities.

Fishing Operations

Menhaden are a surface schooling pelagic species which are fished in shallow coastal waters. The harvest process is initiated from large (on the order of 60 meters in length) vessels (called steamers) designed to carry smaller capture boats (called net boats) and to store the catch. Fishing activities are conducted from the two net boats (approximately 15 meters in length) which carry between them a very large net called a purse seine.

The fish are located by a pilot in a fixed wing aircraft (operating at an altitude of approximately 250 to 300 meters) who is in direct radio communication with both the steamer and the net boats. Upon sighting a school to be captured, the pilot directs the steamer captain to release the net boats and then, circling the school, guides the net boats to the school and directs their enclosure of the fish. Thus, for a period during the fishing activity, the majority of the crew has left the steamer and under normal circumstances, the steamer stands-to in the immediate vicinity of the school to be captured. When the purse seine has been successfully closed, it is drawn up into the net boats, concentrating the captured fish, at which point the steamer comes alongside the net boats and the fish are pumped aboard the steamer. The net boats are then either recovered or towed behind the steamer until a spotter pilot has sighted another school and the process is repeated.

Test Site

The commercial fishery for menhaden presently exists in two geographically separated coastal areas, one extending from the southern Chesapeake Bay to northern North Carolina, the other lying in the coastal waters of the Gulf of Mexico east and west of the Mississippi Delta. Both fisheries are seasonal, with activity extending from approximately May to November. The eastern fishery has been in a state of erratic decline for more than a decade, whereas the Gulf has been an expanding fishery since its inception in the late forties. The more viable Gulf of Mexico fishery extends from Galveston Bay, Texas to Mobile Bay, Alabama. Approximately 30% of the landings are taken in Mississippi Sound, a narrow east-west feature bounded on the north by Louisiana, Mississippi, and Alabama, and on the south by a series of barrier islands 10-15km offshore (Figure 1). The Sound is fished by three menhaden companies whose reduction plants are co-located on the Escatawpa River at Moss Point, Mississippi. Menhaden found in the Sound are almost entirely of the species Brevoortia patronus; some development stage of menhaden are found in the Sound every month. Adults usually occur in sufficient

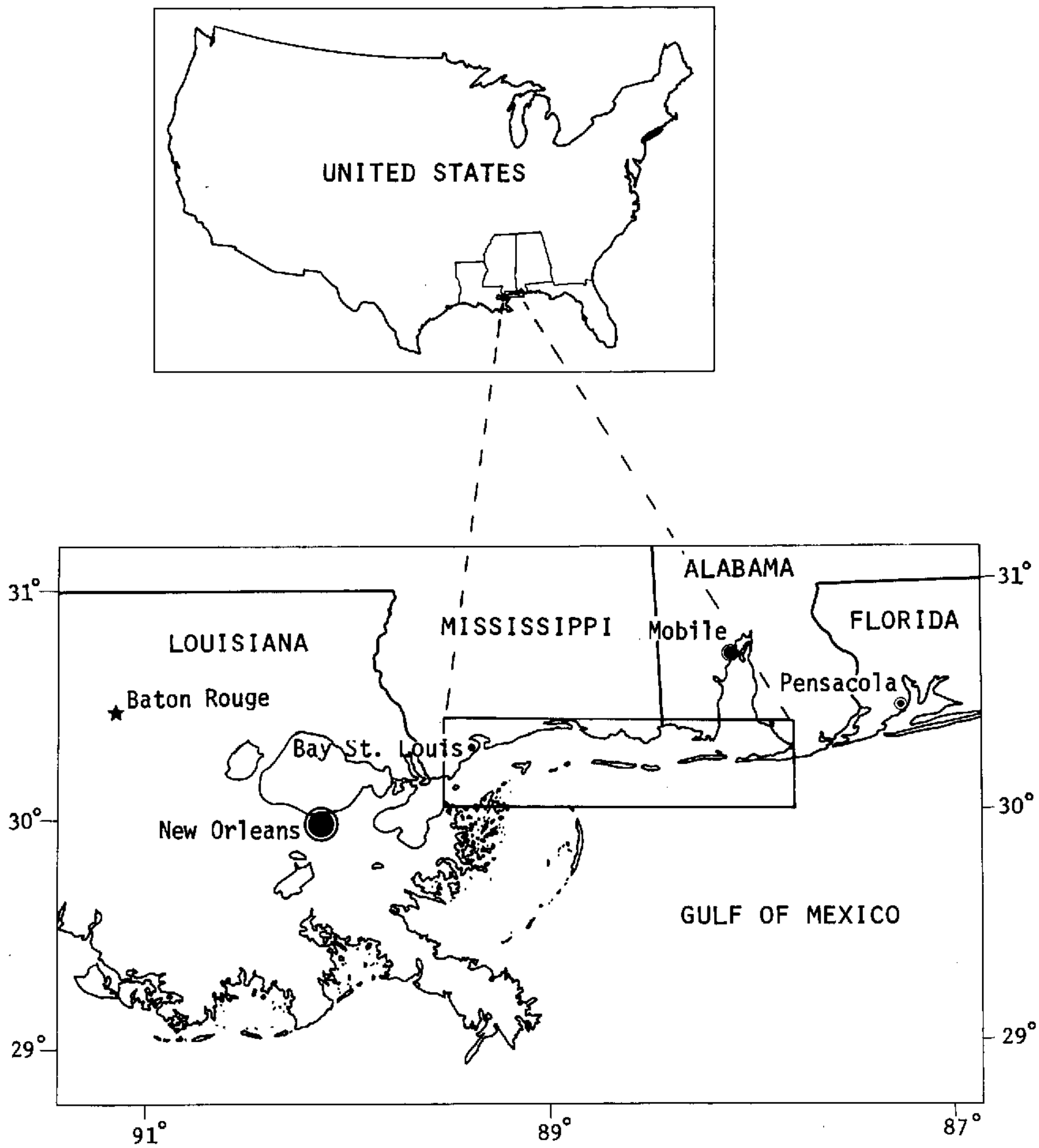

FIGURE 1: ERTS-1 Test Site

quantity to support a fishery from April through October.

The Mississippi Sound was chosen as the test site because it was an easily-defined geographic and fishing entity and because it was already contained within a designated NASA test site. As previously mentioned, it was also within the larger area chosen for the investigation being undertaken by FEL and ERL. The test site is approximately 170km by 50km, and extends from Lake Borgne eastward to the eastern shore of Mobile Bay and from the coast offshore about 50km. Primary emphasis was given Mississippi Sound proper. Maximum depth of the Mississippi Sound is about 10m, although about half the Sound is less than four meters in depth.

DATA ACQUISITION

Based on an understanding of fishing procedures employed in the menhaden fishery, it was determined that basic fishery-environmental data would be obtained from selected fishing vessels during their normal activities. The number of fishing vessels (steamers) operating in the test area varied during the field operations period, but three were usually available as sampling platforms. EarthSat personnel were placed on each of the steamers and instructed to obtain data (to be described below) during the interval when the net boats were deployed and the steamer was idle. Thus, the data so obtained was designed to sample the mesoscale environment, rather than the microscale conditions extant at any instant within a fish school. Such data was deemed more nearly representative of conditions viewed by the remote platforms to be utilized.

A field operations center was established in Moss Point, Mississippi, in the vicinity of the processing plants from which the fishing vessels operated. This center occupied a converted instrumentation trailer provided by FEL. The primary responsibilities of the operations center staff were to coordinate day-to-day activities of the personnel aboard the steamers, coordinate the intermittent use of the industry spotter aircraft, and provide an operational interface between EarthSat field activities and those of the other participants.

The menhaden fishery operates on a weekly basis, although depending on success, individual steamers may return daily to the processing plants. No fishing occurs on Sunday; however, spotter aircraft fly patrols on Sunday to locate concentrations of fish. This information is used in deploying the fleet for the fishing which begins Monday. Fishing proceeds until Friday, unless weather intervenes, and if fishing is good, may continue until early afternoon Saturday. Operations are strictly during daylight hours. Generally, fishing is best early in the week and tapers off towards the end of the week, possibly due to school disruption by fishing activity. To obtain data most representative of optimum fishing, EarthSat confined its "sea truth" program to the first three days of each fishing week, with the exception of those weeks when satellite overflight or a major field exercise involving all cooperants was scheduled to occur later in the week.

Two days were required for ERTS-1 to image the entire test area, but only selected overpass sequences were utilized for major field exercises. On ERTS-1 overflight days occurring during the week but not scheduled as an exercise period, EarthSat field activities were continued to include those days. Due to the uncertainty of Saturday data and lack of Sunday data, no major field events were scheduled on weekends.

The data obtained from the fishing vessels is shown in Table 1. Four categories of data were obtained. Meteorological data was obtained at the request of ERL and was ancillary to this experiment. All other data was of direct importance to the objectives of this program.

Although EarthSat sea truth data was acquired throughout the season, data acquisition by FEL and ERL occurred at specified intervals designated "Main" and "Secondary" days. With the exception of the first Main Day, which was used as a system test, Main Days were scheduled coincidental with, or as close as possible to, days of ERTS-1 overflight of the test area. On Main Days, ERL/FEL-chartered surface vessels occupied discrete stations in the test area and aircraft overflights were accomplished utilizing light aircraft from ERL and the NASA NP3A from Houston. During Main Days, the number of fishing vessels utilized as sampling platforms was increased to as many as six, depending on availability.

Secondary Days were scheduled for each Tuesday from mid-July until mid-October, except for weeks when Main Days were scheduled. On Secondary Days one charter vessel was utilized, but primary sea truth was obtained from fishing vessels. Only a portion of Main Day flight lines were utilized and these were selected to coincide as nearly as possible with fishing vessel activity. The aircraft deployment decisions were made jointly by ERL personnel and EarthSat/NFMOA personnel.

The weekly patrols flown on Sunday by industry spotter pilots were utilized as a further inventory of surface schooling species, in that the pilot reported both menhaden and non-menhaden schools and an estimation of school size. Data were retrieved from these flights either by placing an EarthSat observer aboard or, when that was not possible, by monitoring the pilot's observations which were radioed to the operations center. Thus, school positioning could be accomplished on the occasion of a Sunday ERTS-1 overflight, such as occurred on August 6, but ancillary environmental data was lacking.

Field activities for this experiment extended from June through September and spanned the most active portion of the fishing season. Table 2 lists the dates during which field data was acquired, as well as dates of Main and Secondary Days and dates of ERTS-1 overflights. This table shows the actual acquisition dates of EarthSat/NFMOA field data. In some cases, such as September 12, the field program was in effect but no data was collected due to a lack of fishing success.

Fishing by industry vessels was reduced to two vessels in early October and terminated entirely in early November.

CATEGORY

Logistical	Parameter	Accuracy
	Date	Day
	Time	Minute**
	Location	0.1°Lat., Long.
Environmental	Water Temperature	0.1°C
	Water Salinity	0.1 parts per thousand (0/00)
	Water Transparency (Secchi Depth)	0.5 feet*
	Water Color (Forel-Ule)	(to scale)
Fishery	Fish Catch	1000 fish
Meteorological	Wind Speed	5 knots*
	Wind Direction	5 compass degrees
	Air Temperature	0.1°C
	Wave Height	1 foot*

* Data were collected using common usage units, but later converted to metric units by the conversion routine of the computerized data management system.

**American Rolex Watch Corporation kindly provided three wrist chronometers for use by the EarthSat Field crew. The precision performance of these chronometers easily allowed field accuracy within this standard.

TABLE 1. EarthSat/NFMOA Sea Truth Data

EarthSat/NFMOA Sea Truth	Main Day	Secondary Day	ERTS-1 Overpass
7 June			
9-12 June			
15 June			
18 June			
21-29 June			
2-8 July	6 July		
10-13 July		11 July	
16-19 July			
		20 July	
21 July			
23-26 July		25 July	
31 July			
1-2 August		1 August	
6-9 August	7 August		6-7 August
13-16 August		15 August	
20-25 August	25 August		24-25 August
28-30 August			
3 September			
5-6 September		6 September	
			11-12 September
13-14 September		13 September	
18-19 September		19 September	
26-29 September	28 September		29-30 September

TABLE 2. Summary of Data Acquisition Dates for the period June through September, 1972

DATA ANALYSIS

Analysis of the total data body proceeded in four phases. Each occurred independently, but each provided input to the others, as follows:

- Subjective Analysis of Qualitative Data Obtained from Fishery Personnel
  This phase emphasized consideration of the impressions and experiences of the spotter pilots and officers of the fishing vessels.

- Visual Analysis of Remote Data
  This phase concentrated on the information available by standard photo-interpretive techniques from the ERTS-1 and other imagery. These analyses also included density slicing and color additive enhancement of relevant imagery and were limited to analysis of ERTS-1 and aircraft data obtained during two ERTS-1 overflights of the test area.

- Quantitative Data Analysis
  This phase involved the numerical analyses and interrelation of the fishery/environmental data obtained from the sea truth program. These analyses utilized the entire data body acquired from the fishing vessels throughout the period of the 1972 fishing season.

- Computer Enhanced Analysis of ERTS-1 Data
  This phase concentrated on the generation of enhanced qualitative and quantitative data from the ERTS-1 spacecraft by utilizing NASA supplied Computer Compatible Tapes (CCT's) as the data source.

An example of the sea truth data acquired during the 1972 menhaden season in Mississippi Sound is presented in Figure 2. The data appears in the computer format developed for FEL as one of its ERTS-1 tasks. The following presentation discusses the subjective impressions gained from the fishermen and spotter pilot concerning the interactions between the menhaden, the fishery, and the environment. It then focuses on the results obtained from the analyses undertaken in the other three phases discussed. For clarity, the reader should bear in mind that all results pertaining to remote data were derived from analyses performed on data acquired during the two days which represented the best juxtaposition of representative fishing activity, acceptable weather, and ERTS-1 overflight.

```
ID                                                                                      DATE:111372                     PAGE 27
PRINT:
(DATE,TIME,LAT,LONG,SET #,NO. FISH/SET,FISH. COND.,AC SCH. SZ.,CLASS,HOH TEMP.)
(SAL,SECCHI VISD.,F-U COLOR #,AIR TEMP.,WIND SPEED,WIND DIR.,SEA STATE,CLOUD COV
ER)LOG RMK 1,LOG RMK 2,(VES RMK 1,VES RMK 2)(VES RMK 3,VES RMK 4)(AC RMK 1,AC RM
K 2)(AC RMK 3,AC RMK 4)LOG RMK 3,SOURCE
FOR ITEMS WITH DATA SOURCE,NFMOA *

NO. OF ITEMS IN QUERY RESPONSE =  603
NO. OF ITEMS IN THE DATA BANK = 4766
PERCENTAGE OF RESPONSE/TOTAL DATA BANK = 12.65

 60772  654 30.30 DEG.N.  88.60 DEG.W. 201  25 K FISH UNLIMITED FISHING ---       MENHADEN                 25.0 DEG C
     ---          1.4 METERS  17 ---           51 CM/SEC NW   .2 METERS  10 PCT
           ---
                ---
                     SALINITY OR AIR TEMPERATURE VALUE DELETED     ---
                          ---                                  ---
                               ---                                      ---
                                    ---                         ---
                                          THERMOMETER # 74448
                                               GRAFTON
 60772  820 30.32 DEG.N.  88.74 DEG.W. 202  40 K FISH UNLIMITED FISHING ---       MENHADEN                 26.0 DEG C
     ---          1.2 METERS  16 ---          206 CM/SEC NW   .5 METERS  10 PCT
           ---
                SECCHI DEPTH NOT IDENTICAL; VALUE GIVEN FOR SECCHI DOWN; SECCHI UP SUBTRACT 0.2 METERS
                     SALINITY OR AIR TEMPERATURE VALUE DELETED     ---
                          ---                                  ---
                               ---                                      ---
                                    ---                         ---
                                          THERMOMETER # 74448
                                               GRAFTON
 60772 1400 30.30 DEG.N.  88.48 DEG.W. 203  50 K FISH UNLIMITED FISHING ---       MENHADEN                 35.2 DEG C
     ---           .9 METERS  14 ---          206 CM/SEC SW   .3 METERS  35 PCT
           ---
                SECCHI DEPTH NOT IDENTICAL; VALUE GIVEN FOR SECCHI DOWN; SECCHI UP SUBTRACT 0.2 METERS
                     SALINITY OR AIR TEMPERATURE VALUE DELETED     ---
                          ---                                  ---
                               ---                                      ---
                                    ---                         ---
                                          THERMOMETER # 74448
                                               GRAFTON
 60772 1450 30.32 DEG.N.  88.46 DEG.W. 204  45 K FISH UNLIMITED FISHING ---       MENHADEN                 34.5 DEG C
     ---           .6 METERS  14 ---          206 CM/SEC SW   .3 METERS  45 PCT
           ---
                ---
                     SALINITY OR AIR TEMPERATURE VALUE DELETED     ---
                          ---                                  ---
                               ---                                      ---
                                    ---                         ---
                                          THERMOMETER # 74448
                                               GRAFTON
```

FIGURE 2: An Example of Sea Truth Data in Computer Format

Thus, all references to relationships developed between remote and sea truth data are confined to information obtained on either August 7, 1972 or September 29, 1972. Conversely, relationships developed between the fishery and sea truth environmental data utilize the data body resulting from the discontinuous sampling over the entire fishing season.

Subjective Analysis

Many hours were spent throughout the early portions of the field investigation interrogating the senior spotter pilots and ships' officers to garner their impressions of the interactions of the environment and the fishery. The pilots and officers proved to be keen observers of relationships, as indeed they must be to remain economically successful, and many of their impressions were borne out by the results of this investigation. The principal result of these discussions was to translate into the experimental design the important interactions between the environment in Mississippi Sound and the menhaden fishery operating there; for example, the inclusion of water color and transparency in the measurement scheme. The decision that sampling from the steamers was sufficient to define the mesoscale environment was also due in large part to the information obtained from the pilots.

The primary contribution made by the spotter pilots was the observation that general water turbidity (here used interchangeably with transparency) has a strong influence on fish presence. The pilots (and ship reported a general tendency for fishing to be more successful in the more turbid regions, except for exceptionally turbid water, where even if fish were present, they were extremely difficult to capture. Further, areas in the Sound identified as traditionally supporting good fishing proved to be the same areas, with some exceptions, that provided most of the fishing action during this experiment.

Visual Analysis

The strong correlation between fish occurrence and water transparency reported by the fishermen provided the impetus for careful examination of ERTS-1 and other imagery of Mississippi Sound for indices of transparency differences. Almost from the first scene analyzed, it was clear that the ERTS-1 MSS system exceeded the expectations of the project team in regard to detail and resolution of differences in color and turbidity of coastal waters. Visual inspection of the four bands as supplied by the NDPF at GSFC indicated that Band 5 (600-700nm) contained the most detail with respect to differences in water turbidity. This relationship can be clearly seen in Figure 3, wherein all four bands of scene 1015-16013 (August 7, 1972) are reproduced. Notice that the highly sediment-charged waters of the Sound overdrive the system in Band 4 (500-600 nm), resulting in a washed-out appearance and no

FIGURE 3a: ERTS-1 MSS Image 1015-16013 Band 4, August 7, 1972

FIGURE 3b: ERTS-1 MSS Image 1015-16013 Band 5, August 7, 1972

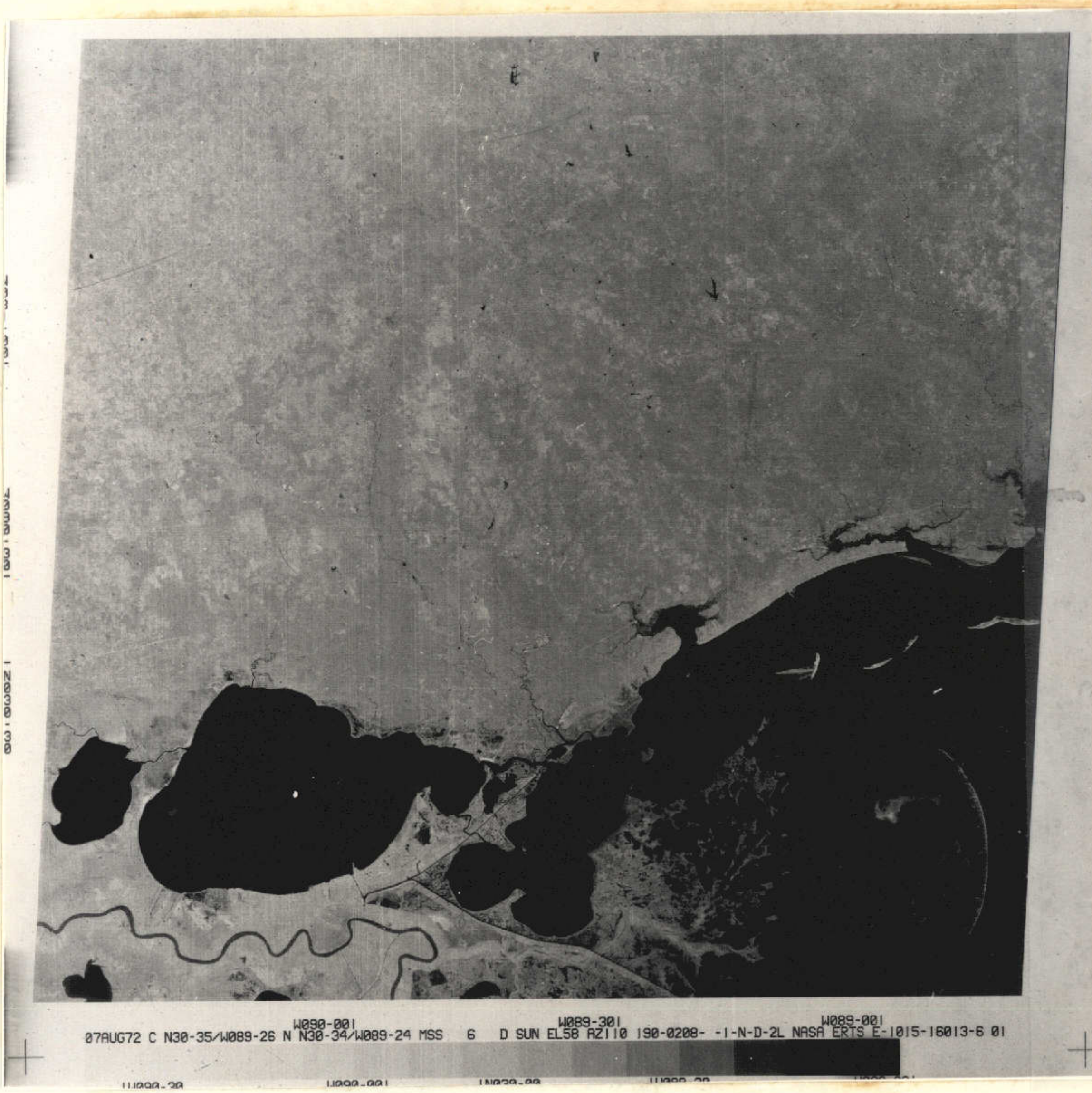

FIGURE 3c: ERTS-1 MSS Image 1015-16013 Band 6, August 7, 1972

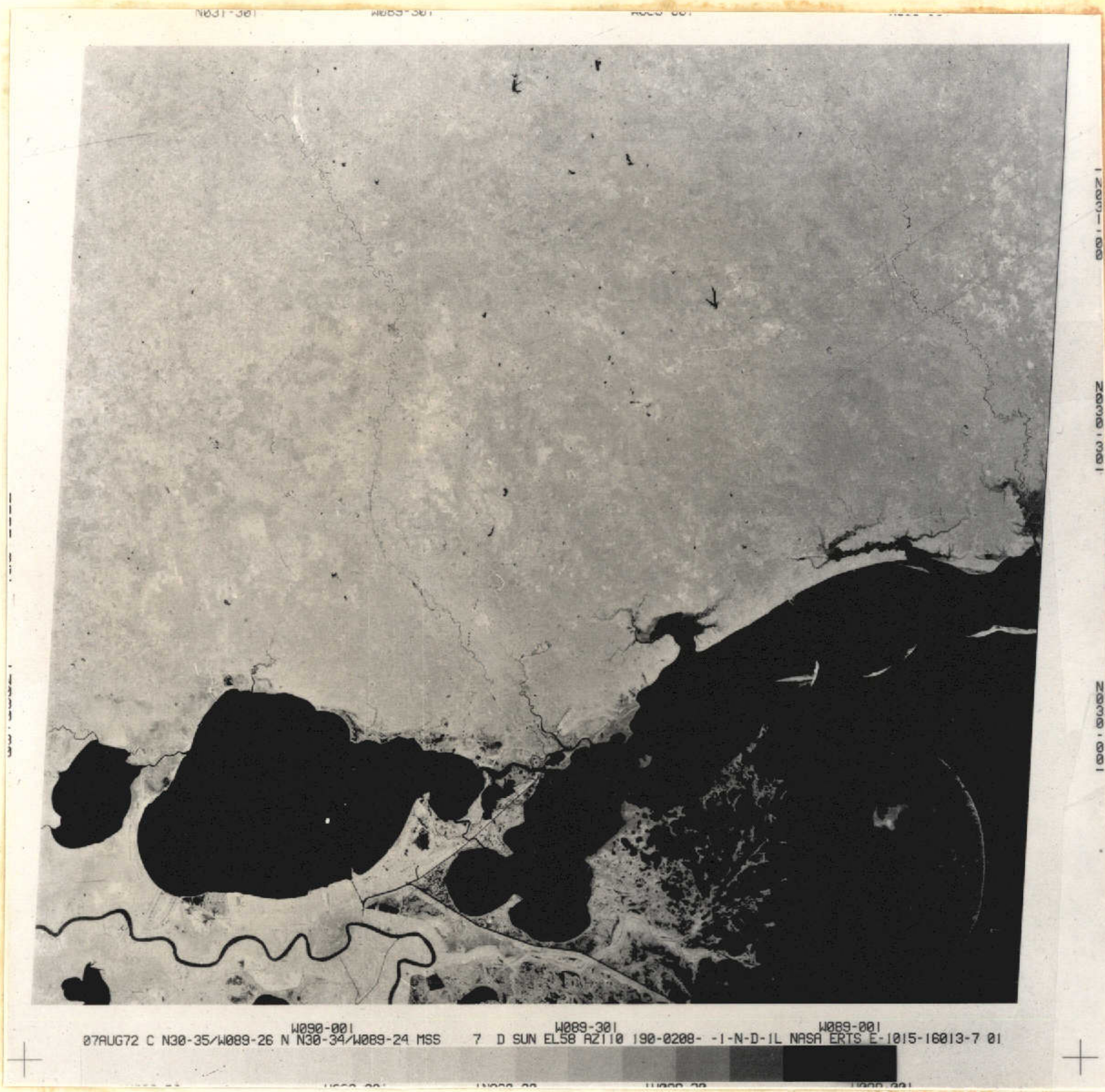

FIGURE 3d: ERTS-1 MSS Image 1015-16013 Band 7, August 7, 1972

detail. The infrared sensitivity of Band 6 (700-800nm) and Band 7 (800-1100nm) result in very little detail, with signal return only in areas of high turbidity, assumably in the surface waters.

On August 7th, fish were caught in four locations within the area imaged, as shown in Figure 4. This figure is a black-and-white reproduction of an electronically produced, color-enhanced, density-sliced presentation of the relevant portion of Band 5. This enhancement was produced on an I^2S Digicol and serves to highlight the boundary between the two water areas of contrasting turbidity. The shorelines and islands have been outlined and the positions of the four catches circled. The positions of these captures correspond in all cases to or near the edges of the more turbid (higher image density in this rendition) areas of the images, always to the turbid side of the boundary.

To test qualitatively for persistence, the following day's data were similarly annotated. Figure 5 is a photographic reproduction of Band 5. Note that it is more difficult to discriminate boundaries of turbid features. (Use of color additive procedures, of great benefit in terrestrial applications, did not materially increase the ability to discriminate turbid boundaries, although the resultant display was more aesthetically pleasing.) The catches discussed in the previous figure (annotated as 09860-09863) are shown here for comparison. Those of August 8 (09930-09934) occur several miles to the east but are also associated with regions of somewhat higher turbidity (lower image density in this rendition) than the surrounding areas.

On one other occasion, the coincidence of an ERTS-1 overpass (on September 29), relatively clear skies and good fishing allowed a qualitative analysis of the relationship between fishing effort and ERTS-1 imaged environmental features. Immediately behind Dauphin Island (Figures 6 and 7), an area was observed to contain numerous fish schools centered in a transient turbid feature. This represented a highly atypical situation in that, generally, catches in the eastern Sound were made slightly to the north in association with a large marshy island known to the fishermen as Coffee Island. On this date, no fish were observed in the vicinity of Coffee Island, which was extremely unusual, and all catches were made in the turbid feature in an area where few catches had been made over the previous three months of the fishing season. On the 29th of September, two million fish were taken by three vessels from this area. Examination of catch records prior to this overpass demonstrates that an increasing association of fish with this area occurred from the 26th to the 29th of September. Figure 8 is an enlargement of the relevant portions of this scene. Locations of the fishing effort for the period September 26 to 29 are shown. Positions 15130-15136 represent fishing on September 29. Note that all of these positions are within the plume. Positions 15030, 15033, and 15034 are for September 28 and are also entirely within the plume, indicating that the feature may have been present at least one day prior to the

FIGURE 4: Enhanced Portion of ERTS-1 Image 1015-16013 Band 5, Showing Association of Menhaden Capture Sites with a Turbidity Feature.

FIGURE 5: Photographic Reproduction of Image 1015-16013 Band 5 with Fishing Locations for August 7th and 8th.

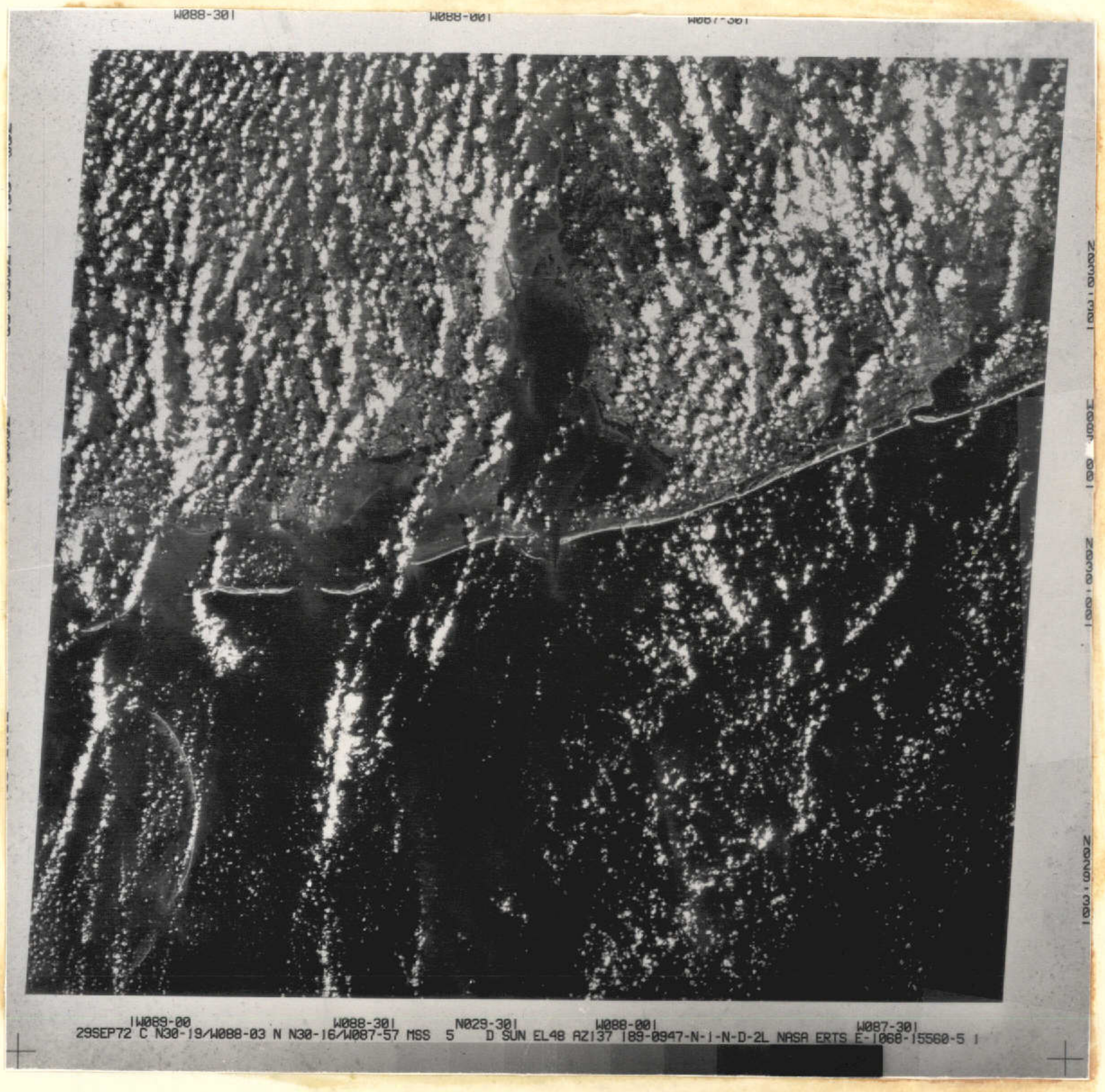

FIGURE 6: ERTS-1 MSS Image 1068-15560 Band 5, September 29, 1972.

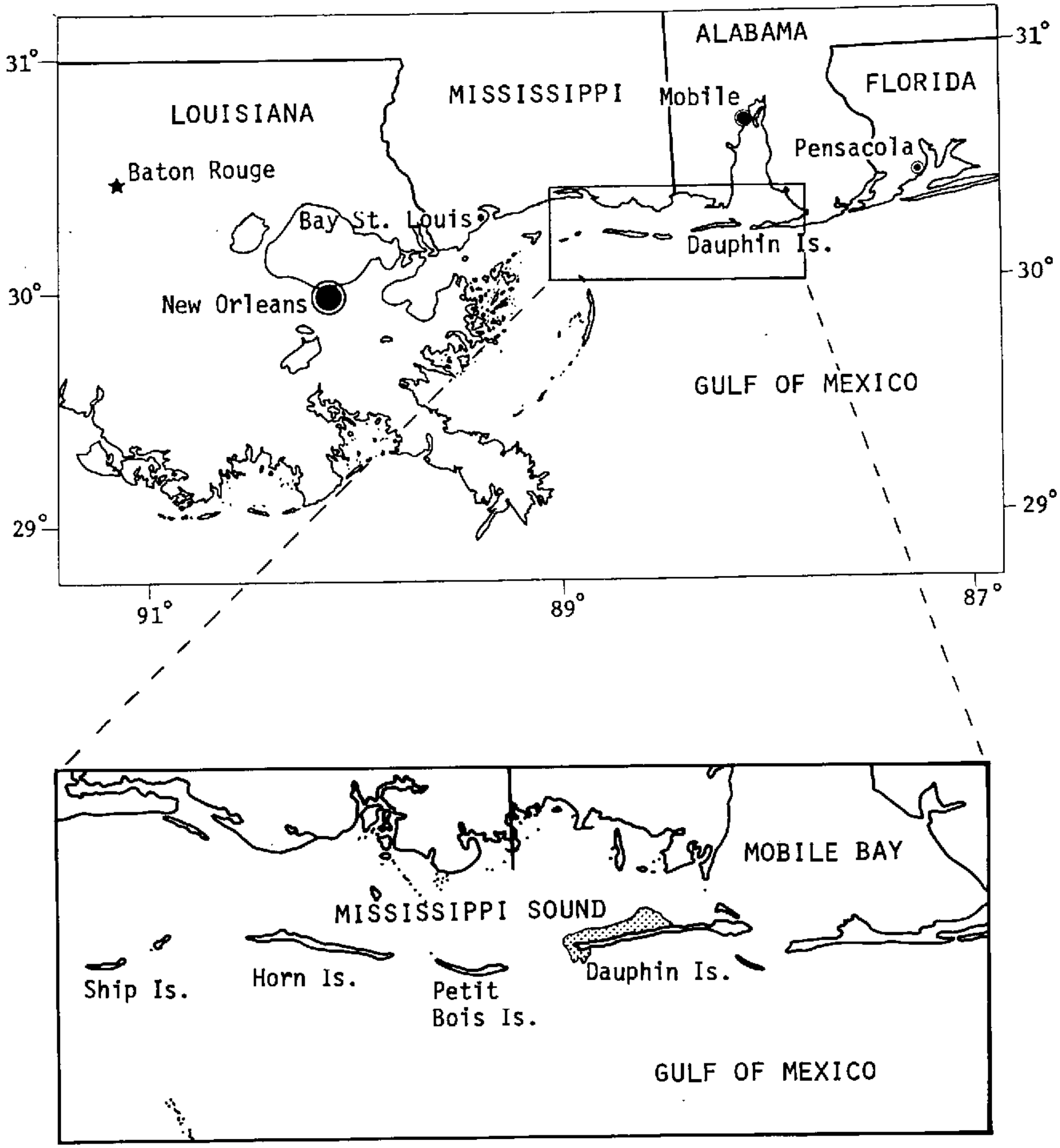

FIGURE 7: Location of Anomalous Plume

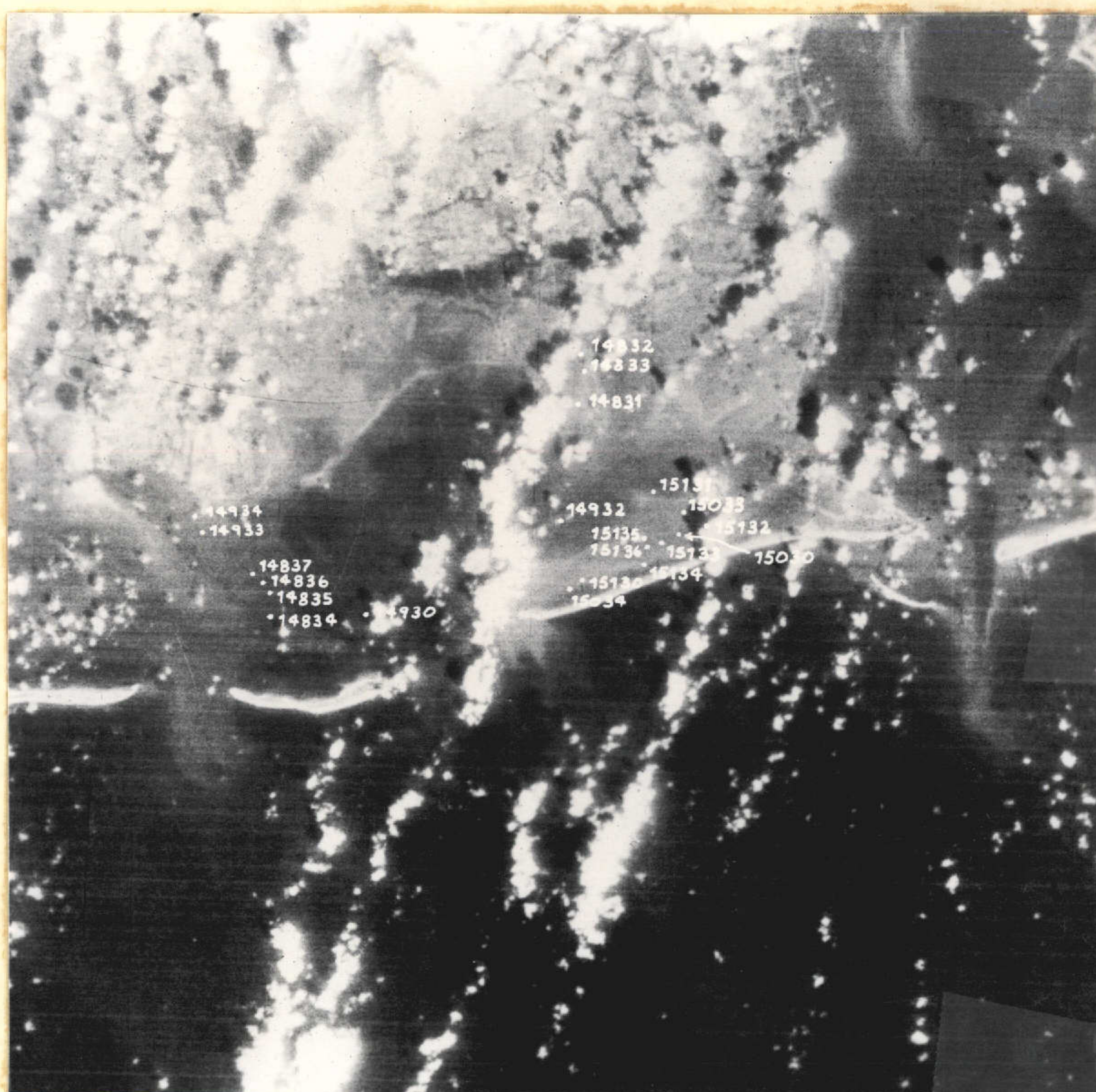

FIGURE 8: Photographic Enlargement of Image 1068-15560 Band 5 (September 29, 1972) with Fishing Locations for September 27th through 29th.

day of overflight. This inference is supported by the positions of catches from the previous two days, September 26 (14831-14837) and September 27 (14930, 14932-14934), which represent the usual situation of fish being caught near the Pascagoula Channel (14834-14837 and 14933-14934) and near Coffee Island (14831-14833). Only one fishing attempt occurred in the vicinity of the plume on the two days prior to September 28, and this one (14932) may have been coincidental.

Events after the 29th, a Friday, were not defined due to the cessation of fishing. The complexity of these associations notwithstanding, it is interesting to note that the association of fishing with turbid features is present during both periods discussed, and may be useful in assessing persistence of such features.

Quantitative Analysis

The primary variables considered in developing relationships between the fishery and the environment were surface water temperature, salinity, and secchi depth (a relative measure of water transparency). A comparative measure of water color (Forel-Ule Scale) was taken, but problems with achieving a reliable match between the standards provided and the prevailing colors of Mississippi Sound resulted in a decision to reject this data.

Although it was recognized that no inherent relationship would necessarily prevail between the size of a fish school and these variables, initial analysis consisted of an attempt to relate, through linear regression, each variable in turn to the number of fish caught at the time the variable was measured. No significant relationships were found.

A second approach proceeded on the assumption that the presence of fish schools, rather than their size, should be related to the environmental variables measured. In order to undertake this analysis, the raw data had to be reordered as follows. In the case of secchi depth, each measurement resulted in a discrete data set showing number of fish caught, secchi depth, and the other parameters. For this approach, each catch record was regarded as an entity, and the total number of catches at a discrete secchi depth were summed, ignoring the other variables. Each variable in turn was treated accordingly. Then, the number of catches at any variable value was linearly regressed against that value for each of the variables, according to the manner in which the data was ordered. In the case of temperature and salinity, values were summed over discrete intervals, as the precision of measurement resulted in little data overlap. In both cases, observations were accumulated over half-unit ranges, so that for temperature, 28.25 corresponds to a range of 28.00 to 28.49° C. and for salinity, 28.250 corresponds to a range of 28.000 to 28.499 parts per thousand, and so on. Regressions were performed for each week and month, and for the season. The results of linear regressions for each of these variables over the course of the fishing season were:

Variable	Regression Coefficient	Standard Deviation	Correlation Coefficient	Degrees of Freedom
Temperature	7.40	3.76	+ 0.51 *	11
Salinity	1.01	0.30	+ 0.53 ***	28
Transparency (Secchi Depth)	- 24.52	9.71	- 0.57 **	13

Level of Significance (F-test): * 90%
** 95%
*** 99%

In each case a statistically significant relationship was found.

When each data set was plotted to show distribution of effort for that parameter, a quasi-normal disbribution resulted (Figure 9). This is to be expected when one considers that the data reflects only the presence of fish, which would follow a more or less normal distribution about whatever optimum value represents their preference for each parammeter. In order to achieve a more reliable prediction based on the displayed results, a qualitative relationship was derived for each parameter independent of the others by subjecting each data set to a curve fitting routine.

In developing these qualitative descriptive models, it was recognized that the data originated from a sub-set of the total menhaden fleet fishing within Mississippi Sound. Therefore, in order to make the predictions based on these models applicable to the entire fleet, it was determined that a new dependent variable "Percent Total Effort" should be developed by normalizing the measured dependent variable "Number of Fishing Attempts." This normalization was achieved by totalling the number of fishing attempts in each data set and dividing each entry by the total number of attempts within that set. For example, in developing the qualitative model for water transparency, the total number of fishing attempts during which a secchi depth measurement was taken was 382. Each discrete entry was then divided by that number. Thus, at a secchi depth of 0.6 meters, 26 fishing attempts were made. Dividing 26 by 382, it was seen that 6.8 percent of the total effort was achieved at this

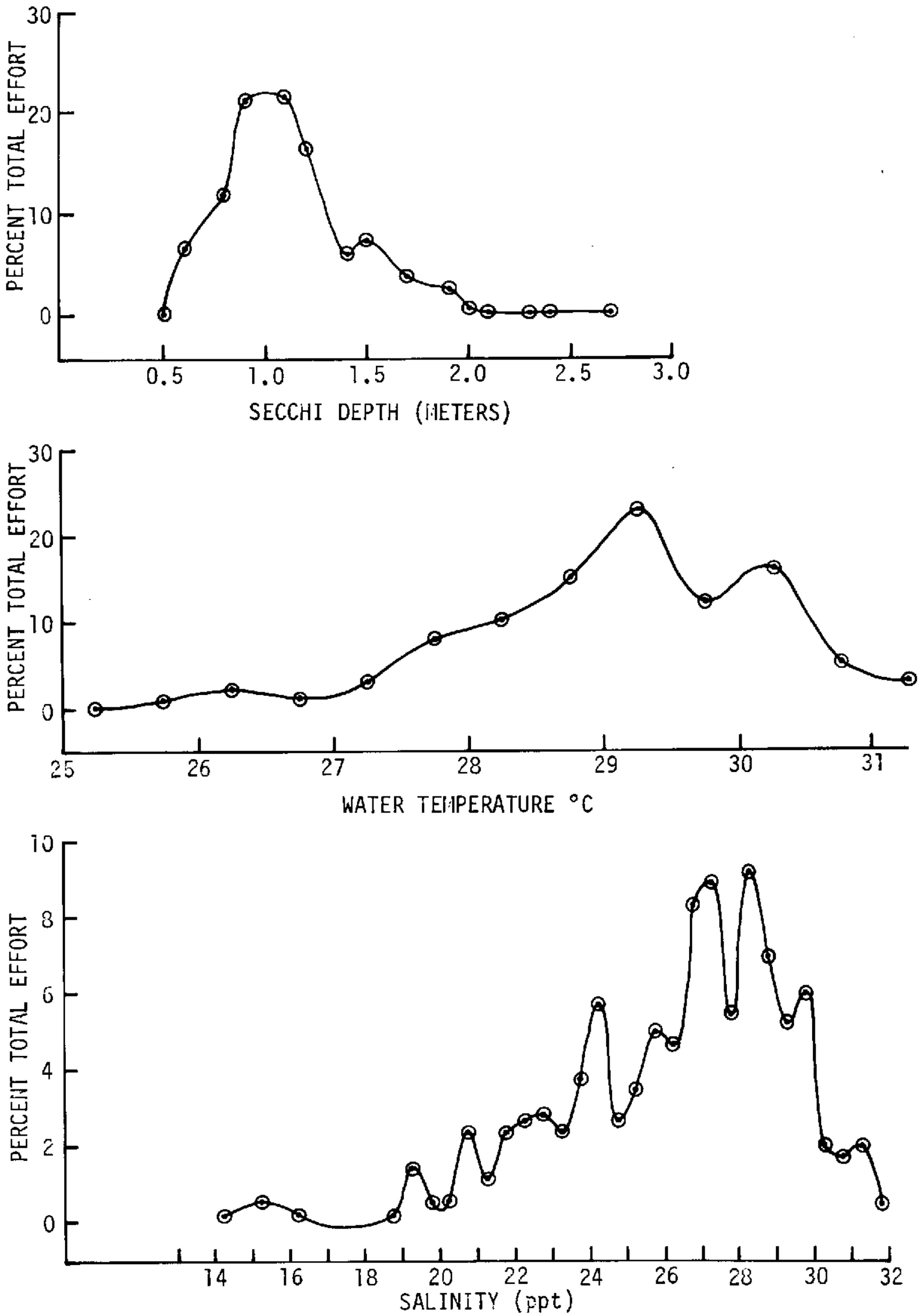

FIGURE 9: Distribution of Fishing Effort as a Function of Secchi Disc Depth, Water Temperature, and Salinty.

secchi depth. This was the "Percent Total Effort" entered for a secchi depth of 0.6 meters. Each of the data sets in turn was treated similarly. Thus, the output of these models became the distribution of effort as it related to an environmental parameter. The routine utilized generated a third order polynomial for each parameter, and in each case the resulting equation accounted for a much larger fraction of the variability, as shown:

Environmental Variable	Equation	Correlation Coefficient	Explained Variance
Water Transparency	$Y=0.445+1.36x-0.940x^2=0.186x^3$	.895	80%
Salinity	$Y=1.27-0.189x+0.00896x^2-0.000134x^3$	.853	73%
Temperature	$Y=4.80+0.097x+0.011x^2-0.0003x^3$	.763	58%

Where Y = distribution of effort in each case.

Computer Enhanced Analysis

Analyses were undertaken to relate ERTS-1 image density to the oceanographic parameters secchi depth and water depth. This direction was pursued following visual analysis of the images, which demonstrated some relationship between Band 5 image density and these parameters. Analysis proceeded through the application of computer processing techniques to the digital image data supplied on CCT's by the NDPF.

The CCT's for image 1015-16013 (August 7, 1972) were reformatted in order to isolate Band 5 information. Figure 10 is a photographic reproduction of a computer-generated display which serves to enhance water quality information by the technique of gray scale adjustment. In this process a histogram of image density is generated and from this gray scale assignments are made so as to concentrate gray scale levels in the density range of interest. All levels above that of interest are assigned white, all those below, black. For this image, gray scale assignments were concentrated in the water portion of the scene, hence the high contrast and decreased information content over land areas. From this image, it is clear that considerable information is contained in Band 5 concerning water quality not routinely visible in the EBR generated images supplied by GSFC.

FIGURE 10: Computer Enhanced Version of ERTS-1 Image 1015-16013 Band 5, August 7, 1972.

In other words, high radiometric resolution in any area (water and land) is sacrificed in the standard products in order to present the greatest range of information in the entire scene.

The realization that more detailed information was available from the reformatted CCT's led to a decision to display the image so as to allow detailed analysis of that information. A routine was utilized to generate shade-prints of appropriate sub-image portions of the Band 5 image. In shade-printing, each unique digital value or range of values is assigned one or more letter characters designed to allow an aesthetic as well as quantitative impression. Each line of pixels (picture elements) is printed by a standard line printer. A shade-printed portion of scene 1015-16013-5 is shown in Figure 11. The routine utilized also produces a histogram of the pixel values from the image being shade-printed, which is useful in adjusting character assignments in order to cover the density range of interest. In a low contrast scene, such as water, all information is contained in a narrow range of density values, thus relatively few characters are assigned allowing their visual density to relate to their value. When viewed from a distance (1-2 meters), the shade print becomes a visually intelligible picture. Since each character represents actual pixel value, the actual image density at any point can be accurately determined. For the scene in question, all water related information fell in the range of values from 19-30 out of the total available range of 0-255 (256 density or gray levels). The utility of this method lies in its ability to converge on available information. Since even high quality photographic reproductions rarely exceed 64 gray levels, resolution is traded against photographic latitude in scenes involving high or widely varying contrast. Routinely available photographic images depict both land and water areas resulting in loss of gray scale resolution in water areas.

For this analysis, the position of 40 ERL sea truth stations in Mississippi Sound were manually annotated onto the shade-print. Twenty-five pixel values were averaged at each station location to arrive at an average density value for that station. The average image value for each station was then related to measured secchi depth and water depth at the station by a multiple regression routine. A third independent variable was generated by considering the interaction (product) of the measured variables. This step considerably improved the regression accuracy.

SUBIMAGE SHADE PRINT:

STARTING AT PIXEL (1400,1950)

250 ROWS WERE PROCESSED
250 COLUMNS WERE PROCESSED

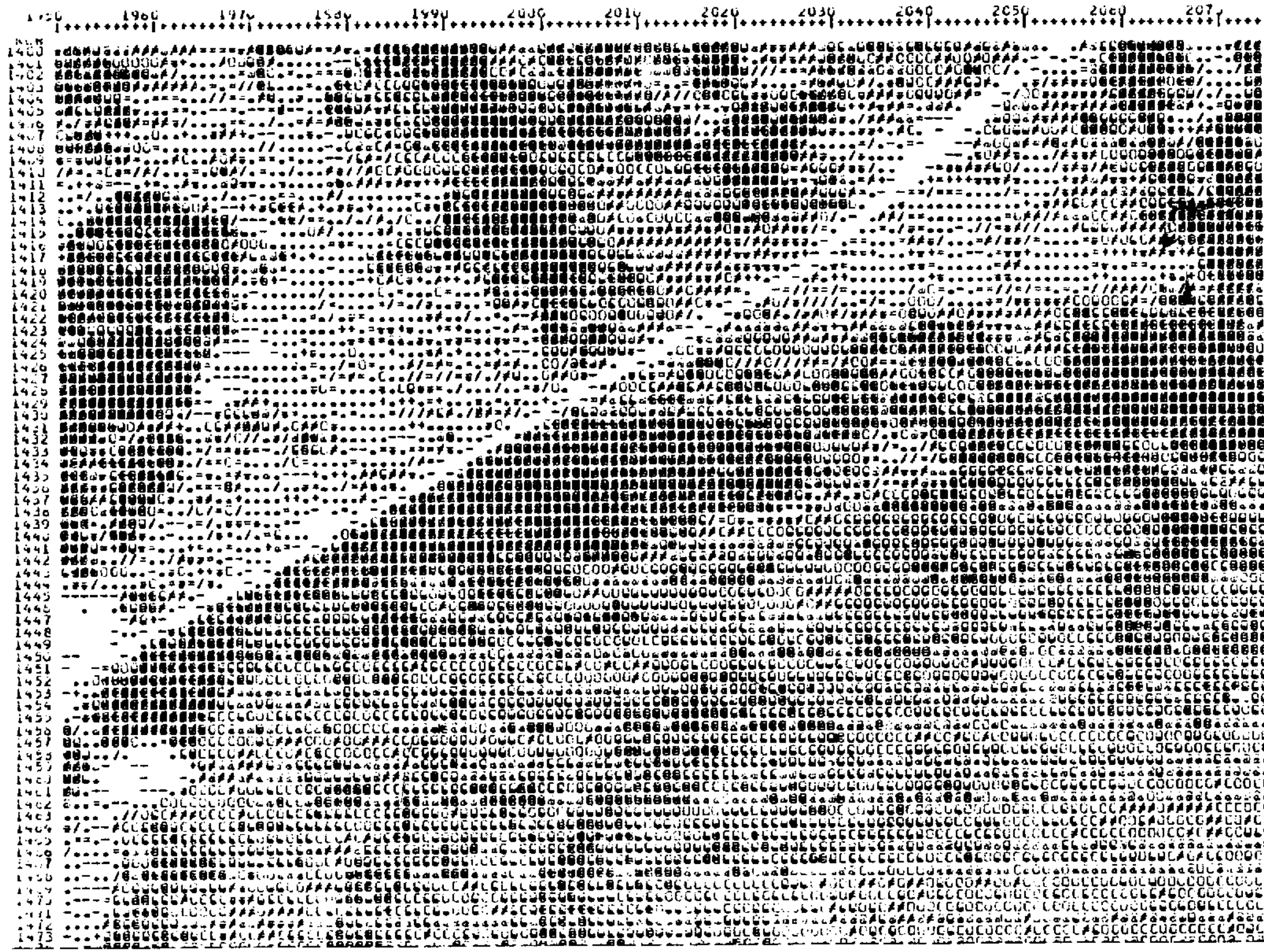

FIGURE 11: Shade-Print of a portion of Scene 1015-16013 showing the Northwest Corner of St. Louis Bay.

Results of this multiple regression were:

Function	Partial Correlation Coefficient	Regression Coefficient	Standard Deviation Regression Coefficient	Level of Significance (T-test) Regression Coefficient
Secchi Depth (S)	-0.37	-0.725	0.213	99%
Water Depth (W)	-0.08	-0.169	0.082	95%
Interaction (SW)	-0.20	0.033	0.012	99%

Intercept = 25.82
Correlation Coefficient = 0.53
Significance Level (F-test) = 99%
Degrees of Freedom = 36

These results generate a predictive equation of image density (I) based on secchi depth (S) water depth (W), and their interaction (SW), of the form:

$$I = 25.82 - 0.725(S) - 0.169(W) + 0.033(SW)$$

which can be rearranged as follows:

$$S = \frac{I - 25.82 + 0.169(W)}{0.033(W) - 0.725}$$

The validity of this equation was qualitatively verified by using it to predict the secchi depth at several data stations not included in the regression, and then comparing to the actual values for these stations. The results of this analysis are:

Station	Water Depth* (Feet)	Image Density	Measured Secchi (Feet)	Computed Secchi (Feet)	Percent Error
A	7	21.52	3.0	5.9	+96.7
B	9	22.20	5.0	4.9	-02.0
C	8	21.40	5.0	6.6	+32.0
D	11	22.40	4.0	4.3	+07.5

*Raw data for the regressions were in units of feet, hence the necessity for maintaining that unit.

DISCUSSION

The relationship developed between water turbidity and fishing effort, as between any environmental parameter and the fishery, is only of value if it provides information not otherwise readily available to the fishermen. Very often a quantitative description of a fishing phenomenon, although of academic interest, only provides the fishing industry with a new perspective for traditional information. For example, areas exhibiting turbidity in shoal water tend to be those areas which were previously well known as centers of fishing activity, such as the area around Coffee Island and the area to the west of Bay St. Louis analyzed on the August 7 image. Generating relationships about this type of activity is a useful exercise, but the results provide nothing of management potential to the fishing industry, in that these areas are traditionally the first to be examined for fish.

However, the one instance demonstrated in the September 29 image, where fishing activity centered in an apparently transient plume in deeper water, represents a unique occurrence, which when supported by repeated evidence, can provide a clear indication of the manner in which satellite acquired synoptic data can be useful as a management tool. In this particular instance, had an operational system been available, it is possible that all three menhaden companies fishing in Mississippi Sound could have participated in this immense concentration of fish, rather than the one company still actively fishing at that late date in the season. Although two million fish were taken from three boats, all indications were that many times that amount of fish remained available and that almost any menhaden vessel operating in the vicinity would have been able to catch its full load within a matter of hours. The ability to predict such anomalous situations has great economic and resource management impact on the fishery.

When taken in this context, the quantitative (linear regressions) and qualitative (polynomial expressions) relationships developed take on added significance. When applied to such anomalous situations as that described on September 29, their importance to the fishery becomes very real. That none of the linear regressions accounted for a major fraction of the variability in the data is not discouraging. Rather, it is interesting that the correlation coefficients for the simple linear regressions between each of these variables and the fishing effort were as high as they were. The Mississippi Sound is an extremely complex estuarine environment in which the natural dynamics are further disturbed by the heavy ship commerce. This factor is particularly important in considering the turbidity measurements within the Sound. The shallow, soft mud-bottom of Mississippi Sound is easily disturbed by larger ship traffic. The maneuvering prior to the release of net boats by the steamers frequently caused disturbances in the bottom sediments and it is felt that one source of error in the data is locally increased water turbidity due to agitation of the bottom sediments by ship traffic. Similarly, the shifting currents and changing tidal structure within the estuary introduced transient and complex patterns to all three parameters - turbidity, temperature, and salinity. This is especially true with temperature. Generally speaking, any introduction of fresh or brackish water from the various rivers entering into Mississippi Sound would result in a decrease in salinity. However, depending on location, time of day, time of season, etc., entering fresh water may have a higher or lower temperature than the ambient temperature in the Sound. Thus, preference of the fish for either entering fresh water or ambient Sound water would result in a coherent association with salinity (lower salinities in fresh water or higher salinities in Sound water). However, a continuing preference for one or the other water type would result in a confused temperature relationship due to a lack of consistency in Sound water/fresh water temperature relationships. This may account for the lower correlation coefficient in the temperature regression.

There is evidence that the same physical phenomena affecting one variable within Mississippi Sound may alter the others. For example, Figure 12 is a reproduction of a radiometrically corrected thermal infrared image of a portion of Mississippi Sound corresponding to that shown in Figures 3-5. It will be recalled that in Figure 4, the image was annotated to show the position of four fishing operations which occurred quasi-simultaneously with the time of ERTS-1 overflight. Figure 12 represents a thermal reproduction of the same area. Examination of these two images demonstrates that a clear visual relationship exists between turbidity patterns and thermal patterns. When positions of catch locations were compared to Figure 12, all fell within the darker (lower temperature) water. Quite likely, both distributions are a function of tidal movements within the estuary. In the case of transparency, relationships are complicated by the influence of waves and ship commerce which stir the soft mud bottom and increase the general level of turbidity. Nontheless, relative levels of turbidity were probably a function of water movements which would also affect the temperature distribution and, hence, force the relationship seen.

The regression equation describing the relationship between Band 5 image density and the parameters of water depth and secchi depth explained 27 percent of the variability in the image density. This low value is not suprising in that a number of errors are implicit in the type of analysis done. Once again, the soft mud bottom of the Mississippi Sound made it extremely difficult to accurately determine water depth and introduced local, often extreme, differences in secchi disc measurements, especially in areas where a great deal of traffic kept the bottom stirred continually. When this is compounded by the problem of accurately locating station positions, the error becomes more severe. This location error is three-fold. First, the ideal location of the stations as plotted on charts was frequently not the point occupied by the vessel in data collection.

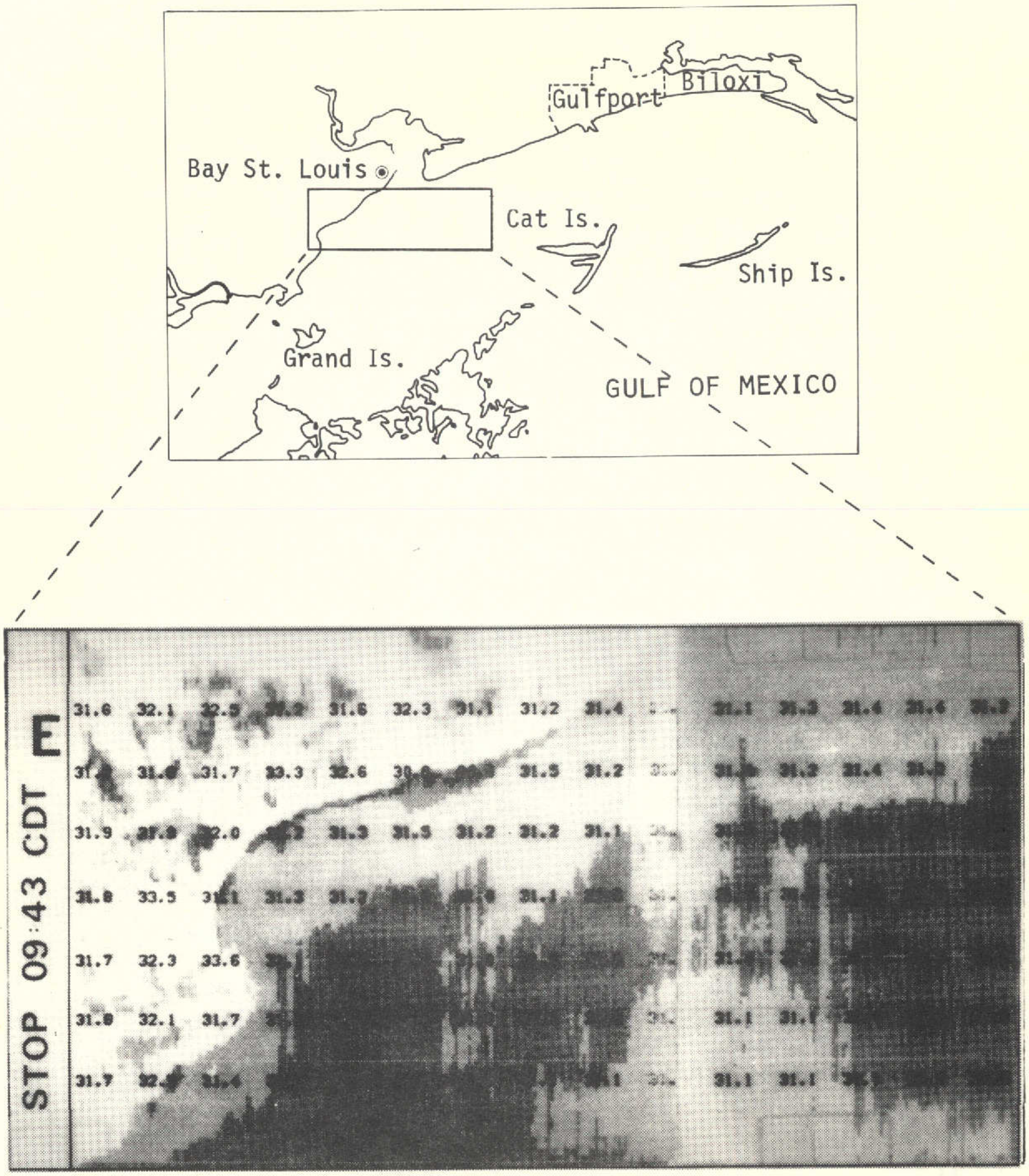

FIGURE 12: Thermal Infrared Image of a Portion of Mississippi Sound.

Second, the positioning of the stations on the ERTS-1 image was also subject to error due to the difficulty of translating the geographic station coordinates onto the uncorrected ERTS-1 image. Finally, several station sites were occupied by any given vessel, so that the data was not acquired in a truly synoptic fashion. Thus, the measurements vary in time about the overflight time of the ERTS-1 satellite, so that the changes due to the dynamic nature of Mississippi Sound, particularly those influencing secchi depth measurements, also added considerable variability and thus error to the regression analysis. Furthermore, the variation in the predicted versus actual values calculated (page 30) is are at least partially due to several hours difference in time between the ERTS-1 overflight and the surface measurements used for comparison, as well as to position errors. All these factors notwithstanding, the regression is a valid expression of our current understanding of the relationship between image density and water turbidity and can thus be used as a first order predictive tool.

Perhaps the most meaningful statistic derived, however, was the value of the correlation coefficient, which when squared is a measure of the variability in the data set accounted for by the regression. Thus, 33% of the variability in the fishing effort is explained by differences in water transparency (secchi depth) considered alone. Similarly, 28% is accounted for by salinity alone, and 26% by surface temperature alone. This does not imply a direct cause/effect relationship for these environmental factors. More likely, the relationships were indirect. Further, all three factors considered together are not likely to account for a very much larger fraction than any one taken alone. The effects of combining environmental factors can be examined in a multiple regression analysis. Unfortunately, the process of summing the number of catches per variable value for each parameter made it impossible to combine all three parameters in a multiple regression.

In view of the types of analysis performed on the various fish/environment data, some caution is required in interpreting the results. As briefly stated in the analysis section, two directions were taken in these analyses. Simple linear regressions were performed relating surface environmental measurements to fishing effort. This was done with the full realization that simple linear relationships were not likely to adequately explain the complexity of the interaction between fishing effort and any given environmental variable. Nonetheless, if some basic relationship did exist, this linear approach would at least quantify the level to which the relationship was valid. The utility of this approach is demonstrated by the fact that significant relationships could be developed between the three prime environmental variables and fishing effort. In each case a defined linear relationship could be derived and supported through the application of the F-Test for the variance in the data.

For predictive purposes addressing the goal of this experiment, it was necessary to define a relationship which more adequately followed that found in the natural condition. In order to do so, a qualitative approach was utilized wherein an equation generating a curvelinear relationship was employed. In this case, the correlation is merely a qualitative descriptor of the degree of agreement between the natural condition and the contrived arithmetic relationship. That is to say, the correlation coefficient in a linear regression combined with the level of significance defines the degree of relationship between fishing effort and the environment in a quantitative fashion, whereas the same statistics applied to the curvelinear approach are simply a measure of the success of curve-fitting rather than the degree of relationship. Thus, having established a defensible quantitative relationship, one can proceed to refine the analysis by fitting a predictive equation to the natural situation. Without the support of quantitative analysis, however, this is a meaningless exercise because one cannot feel confident that the relationships discovered and so described are any more than probabilistic.

A visual impression of the success achieved in the modeling exercise can be gained from Figure 13, in which the actual distribution of effort with respect to water transparency (secchi depth), and the distribution of effort predicted from the linear and polynomial equations based on secchi depth are plotted. Clearly the polynomial expression reasonably simulates the real situation and as a first approximation, is of management information potential to the menhaden industry.

The manner in which the results described in the preceding section are applied to the present harvest technology of the menhaden fishery must be considered in the context of the assumptions under which the data was acquired and the manner in which the experiment was executed. Implicit in the decision to sample the surface environment solely from the fishing vessel was the understanding that this negated any opportunity to coherently sample that environment, or to include data which describe conditions extant when commercially accessible schools of fish were <u>not</u> present. The data and models derived from this experiment pertain only to those circumstances wherein fish were present in a commercially desirable setting. Thus, the results do not address the subject of whether or not fish are present, but rather, given the presence of fish, they describe the manner in which the fishing effort should distribute.

Another central issue addresses the question of whether or not the sampling undertaken reflects the true fishing effort in Mississippi Sound. Since sampling was achieved from a small segment of the total fishing fleet, there is the problem of representativeness of the data. In order to answer this question early in the experiment, previous years' records of fishing success were examined in order to select sampling vessels which were representative of the total effort in the Sound. To the extent possible, sampling continued on the same vessels all through the season, in order to maintain this subjective air of representative sampling. The vessels upon which EarthSat crews were stationed tended to fish within the general areas occupied by

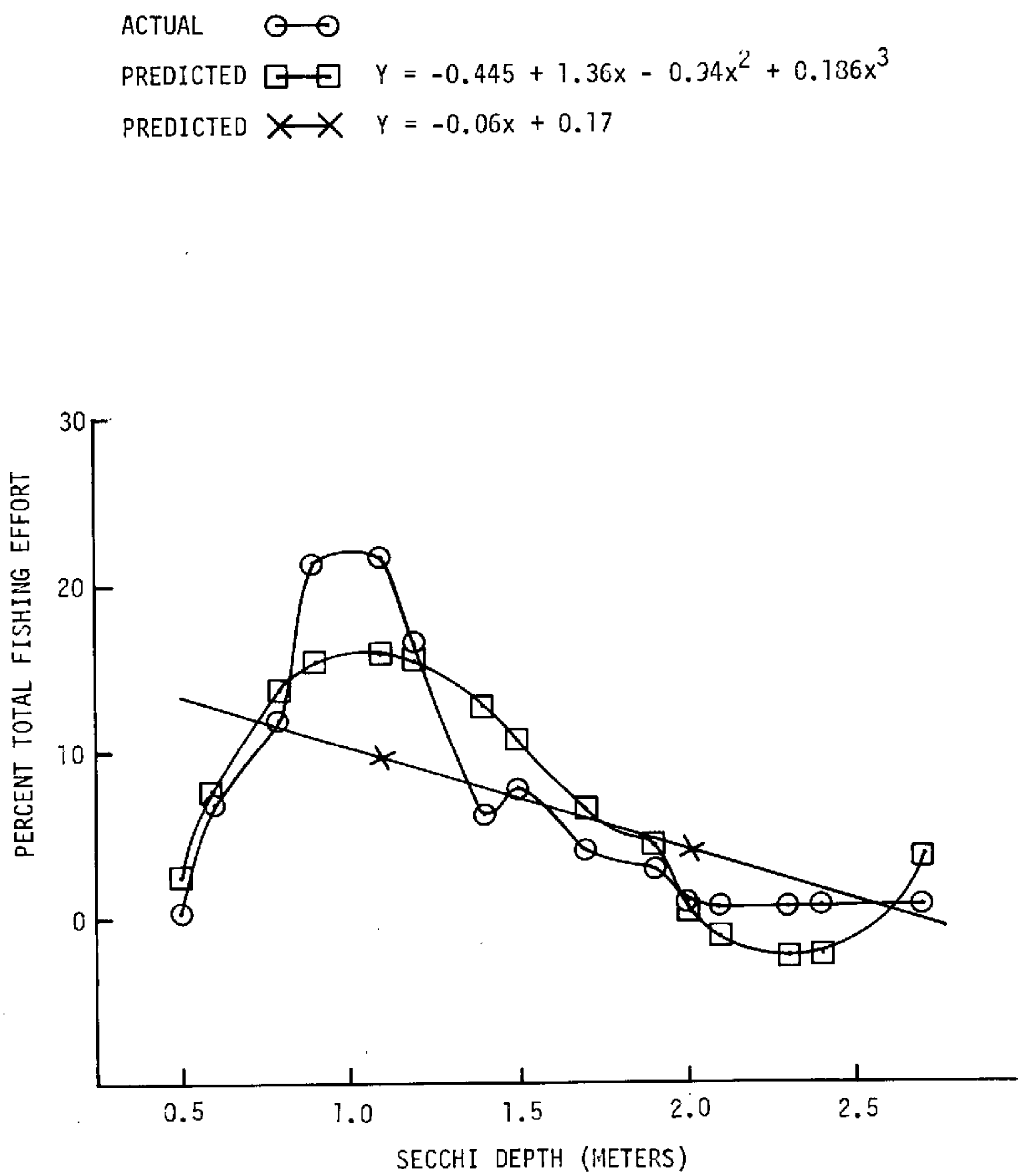

FIGURE 13: Comparison of Actual Versus Predicted Relationship of Water Transparency (Secchi Depth) and Distribution of Effort

the majority of the fleet operating from the Moss Point facilities. On occasion, the sample vessels were isolated from other vessels but this was not inconsistent with activities in the Sound in that frequently one or two boats would be isolated from the rest and on a few occasions, none of the vessels would be fishing in concert with any other vessels. As a results of our monitoring of effort through the 1972 season, we feel that the samples acquired are representative of the total effort in Mississippi Sound. However, since the data reflects a small number of the total vessels involved, it is presented as distribution of effort rather than as the total number of fishing attempts, in order to be applicable to the entire fleet.

The manner in which the models derived can be applied to the menhaden fishery is also a function of the way in which the fishery is presently operated. This was briefly outlined in the introductory material and will be reviewed here. A fishing week begins with a routine surveillance flight by one or more spotter pilots looking either for concentrations of fish or areas where visible environmental indicators show a potential fishing area. This information is transmitted to the individual fishing captains who then make a decision as to where in general within the fishing area they are going to locate. On the morning of the first fishing day of each week, the vessels leave well before dawn and are at their selected areas by sunrise, at which time the spotter aircraft also arrive in the vicinity and begin the daily search operations looking for concentrations of fish. There is unfortunately no rigidly defined structure within which these decisions are made. Rather, a loose knit communications network exists between the chief spotter pilot and his assistants, and between the vessel captains individually and the chief spotter pilot or one or more of his assistants. Further, each company fishing in a given area has its own spotters and fishing vessels. The only degree of cooperation is in the area of weekly (Sunday) surveys done prior to the initiation of the fishing activity. Frequently, one pilot will fly a survey mode and report the results to all companies interested. This assignment then rotates weekly through the various fishing companies.

Corporate level management decisions do not seem to affect the daily progression of fishing activity, except at the point where overall activities are to terminate or are to start up following some period of cessation. Nonetheless, it is envisioned that the output of a model such as those generated in the course of this study would have an impact in the operational progression of the fishery. This impact would come in a lessening of the degree of dependence upon spotter aircraft, specifically when those aircraft are applied in a survey mode. For example, it is envisioned that with refinement of the model based on visibility differences, the industry could forego weekly survey flights and rather subscribe to a weekly or bi-weekly map series which would describe for them areas of greatest fishing potential in terms of the manner in which their effort should be distributed, based on imagery acquired from an

ERTS-type vehicle. Thus, once or twice weekly, one can envision the management officials at the processing plant level receiving a map-like product with contoured display showing the principal areas in which fish are likely to occur and the percent of total effort, in terms of ship-time available, to be distributed within those areas. As the models are refined and become more precise, it is possible that a daily display of this type would be sufficient to initiate each fishing day's effort and that the spotter aircraft could be concomitantly reduced and used only in immediate school location. Since a significant fraction of industry cost in involved in spotter aircraft operations, this would represent a considerable decrease in such expenditures.

CONCLUSIONS

The results achieved during this initial investigation of the application of satellite acquired environmental data to an operational commercial fishery lead to the following conclusions:

Environmentally Driven Models Utilizing Satellite Acquired Data Can Provide An Alternative Source Of Information For Harvest Decisions In Commercial Fishing

The principal difficulty in the application of the present remote sensing techniques to the harvest technology of the menhaden fishery lies in the fact that the models derived are temporally and geographically limited. This is particularly true in that, although the environment in which the fish are harvested is similar throughout the Gulf and East Coast fishery, the levels and variation of the environmental parameters may not necessarily be coincident. For the time being then, these first order relationships of necessity must be limited to application in Mississippi Sound. They form the basis, however, for an extension of techniques to determine if the relationships derived for the brief season in the Mississippi Sound are applicable to the more intense and lengthy season to the west of the Mississippi Delta and, also, whether the quantitative and qualitative relationships can be directly transferred to other geographic areas, or whether the techniques are transferable but the particulars are not. Even this limited application may be presumptuous in that all relationships are derived from one fishing season's data and it is questionable whether that narrow a sampling regime is sufficient to account for long-term variation in the fishery. It is, therefore, best to view these results as initial evidence to support the contention that satellite borne environmental sensing systems can provide the type of timely data necessary for the management of coastal and, perhaps, open-ocean pelagic fisheries. To go beyond this is exceeding the limits designed into the initial analysis. The success achieved, however, should be sufficient impetus to continue investigations, and refinements of, the application of ERTS and other satellite systems to the commercial fishing community as a user constituent for spacecraft oceanography.

Potential benefits to be derived from the application of ERTS or similar satellite-obtained data to a fishery such as that for menhaden can be realized through the costs associated with the present harvest techniques. For example, the average cost to the menhaden industry for the spotter aircraft operations is approximately 75 cents per thousand fish caught. For this past (1973) season, this represented a total expenditure of about $1.5 million. To the extent that dependence on spotter aircraft for routine survey procedures can be reduced, a concomitant dollar savings will be realized by the industry as their aircraft costs diminish. The figure of $1.5 million is roughly 10 percent of the total harvest cost and represents a major expenditure in the harvest operation. As the types of models derived are refined and methods for supplying the environmental data made routine, as for example, with the advent of more diversified satellite platforms, more reliable predictions may be achieved and may decrease not only the costs associated with aircraft operations, but also the considerable time lost in general cruising aboard the steamer.

The advancing technology associated with model building and remote sensing of the environment may result in the ability to forecast the place, time and magnitude of expected catches and thereby reduce completely the non-productive time which currently represents a major portion of the time spent at sea by this and other fisheries. Although such increased efficiency in the menhaden fishery is probably not necessary as the fishery currently operates near its maximum fishing level, the ability to achieve such results with any fishery is encouragement for the application of such techniques and technology to more complex, less defined, but equally important open-water fishing activities. It is almost a certainty that the fisheries for tuna and salmon, as well as those which will probably develop for other, presently underutilized or nonutilized pelagic species, would derive similar benefit from an appropriately structured monitoring system. The importance of these fisheries as NASA constituents can be viewed as a function of the increasing world demand for consumable protein.

An Important Constituency Exists Within The Commercial Fishing Community Which Should Be Considered In Future Ocean Sensing Systems Developed By NASA

The results obtained in this investigation have direct implications to planning activities within NASA itself, in that they occurred in spite of the fact that ERTS-1 was not designed to monitor a dynamic environment whose time constant is as small as that in an estuarine system. The spectral, spatial and temporal resolutions provided by the ERTS-1 spacecraft are such that prior to delivery of data it seemed unlikely that any significant results could be derived for an industry dependent on timely, clear analyses of a dynamic environment. However, both the spatial and spectral resolutions proved adequate. The ability of Band 5 to resolve differences in the water transparency and the persistence of events in Mississippi Sound all converged to produce a readily extractable relationship between the ERTS-1 MSS system and an information need within the fishery. Thus, a direct link could be established between an earth resource information need and a measurement system.

Given the fact that the sensor systems presently operating on ERTS-1 are sufficient to define the environment in a manner which addresses the management needs of the menhaden fishery, it would seem that the simplest expansion of the ERTS program of utility to this fishery would be the insertion of other operational ERTS-type platforms in such a manner as to increase the return-time and decrease the time lag in coverage. A second direction would be a somewhat modified ERTS which would include the thermal channel originally planned for ERTS-B. Such an improvement would allow utilization of the temperature relationship in predicting events in the menhaden fishery. Perhaps the most productive approach would be the development of an Ocean Sensing Satellite System. Such a system would require multiple satellites so that the dynamic ocean environment was viewed several times daily, would require increased spectral resolution, particularly in the wavelenth bands from 400-700 nanometers, would also include a thermal channel in the 8-12 micron region, and, when feasible, a microwave sensing system for salinity. For this particular application, such a system would address all of the variables which to date have been related to the occurrence and availability of the menhaden resource. Applications to other, similar fisheries can be envisioned which would greatly expand the NASA constituency in an area whose national and international focus is continuing to grow.

RECOMMENDATIONS

The conclusions presented in the previous section lead to the following recommendations.

It Is Recommended That Continued Investigations Be Pursued With The Goal Of Refining The Application Of Remote Sensing Data To The Management Models In The Menhaden Fishery

The results achieved during this investigation must be considered preliminary in that they address a very small fraction of the total geographic range of the menhaden fishery and were acquired over only a single season's fishing effort. Due to various constraints, data were not acquired in a fashion commensurate with a complete description of the fishery. A more ideal system would be capable of relating variability in fish availability to all relevant environmental factors acting together, rather than to a few acting singly. Second, it would account for the presence and absence of fish as well as the distribution of fish when present. It is therefore recommended that continued research be pursued to alleviate the above deficiencies. Specifically, the work should be carried on for a sufficient length of time to get an adequate feel for long term temporal variation in the response of the fishery to relevant parameters. Second, sampling should be achieved over a broad geographic area in order to totally describe the fishery, or at a minimum, to determine if separate models are necessary in different geographic ranges at different times of the year. Third, future research should attempt to relate in a multiple fashion all parameters relevant to the presence and distribution of the resource, not only for the benefit of industry management, but as a source of data to resource managers at the State and Federal level.

The Following Considerations For An Operational ERTS System Are Recommended

Perhaps the major deficiency in the present ERTS-1 system, aside from its vulnerability to cloud cover, is the lack of sufficient repeatability to maintain continuity of observations in a dynamic situation such as exists in a commercial fishery. The first improvement that is suggested for an ERTS-type system would simply be either more vehicles, spaced so that under optimum conditions no more than four days transpires between successive imaging of any given area, or alteration of orbital parameters to achieve more frequent coverage. Given the present state of the art, little can be done about the problem of cloud cover.

Addition of a thermal infrared channel would provide another source of information of value to management. However, the results presented herein demonstrate that temperature is probably the least reliable of the variables measured and that rather than thermal data, a more profitable approach might be to refine the spectral resolution of the ERTS-1 sensors to address only those wavelengths pertinent to defining water transparency relationships. It is recognized, however, that alteration of the orbital parameters or sensor specifications is not compatible with applications to other broad disciplines, such as agriculture and geology so that, in essence, redesigning the ERTS-1 system might not be the most ideal approach to management of coastal and ocean resources.

It Is Recommended That An Ocean Dedicated System Be Given Careful Consideration

Perhaps the most relevant need to management of coastal and open ocean fisheries is the creation of a dedicated ocean monitoring system, employing satellites and/or high altitude aircraft. Data derived from such a system would have far reaching implications in all coastal zone management problems, including pollution, shoreline management, recreational activities, and regulation of ship traffic, as well as commercial fisheries. Addressing the coastal zone only, such a system would ideally be designed to cover all domestic coastal zone areas at least twice daily and would acquire data pertinent not only to water color and transparency determination, but to surface temperature and, with some refinement of present microwave systems, salinity as well.

The management models derived in this experiment point the way to an integrated management system, utilizing all possible synoptic data sources. It is clear that such synoptic data is not economically feasible when it is derived from surface operations. The potential benefits to be derived in relation to cost expended for either an operational satellite or operational aircraft program have yet to be determined, but in their determination one should also address the question of appropriateness of the data. That is, any system so analyzed should provide data specific to the needs of coastal zone management. Visible wavelength sensors should have narrower spectral resolution (20-50nm) in the blue and green region, a separate, broader band in the red region, high resolution thermal capability, and as soon as feasible, high resolution salinity capability as well. For the ocean side of the coastal zone, it is doubtful that solar infrared channels are of much value. Their utility on the terrestrial side of the coastal zone, however, is unquestioned, so that the system would have to have considerable flexibility in order to address all of the pertinent problems of the coastal zone. Specifically, for the menhaden fishery and possibly for all other coastal fisheries, data acquired on turbidity, salinity and temperature would likely address the major environmental influences on fishing and fish stock availability. We therefore recommend continued definition and development of an oceandedicated remote sensing system.

REFERENCES

1. W. H. Stevenson, Project Plan, ERTS-A Experiment. National Marine Fisheries Service Southeast Fisheries Center, Fisheries Engineering Laboratory, Bay St. Louis, Mississippi, 1972.

2. P. M. Maughan, et al. The Impact of Remote Sensing Data On the U.S. Menhaden and Shrimp Fisheries. Final Report to Spacecraft Oceanography Project, U.S. Naval Oceanographic Office, Washington, D.C. 1972.

APPENDICES

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Appendix A

Publications

The following is a list of papers resulting from this project which have been presented to date:

September 19, 1972: Project review presented to the Technology Committee of NFMOA at their annual meeting. New Orleans, Louisiana.

October 6, 1972: Application of ERTS-A Data for Fishery Resource Assessments and Harvest. Eighth International Symposium on Remote Sensing of Environment. Ann Arbor, Michigan.

March 7, 1973: Application of ERTS-1 Imagery to the Harvest Model of the U.S. Menhaden Fishery. Symposium on Significant Results Obtained from the Earth Resources Technology Satellite-1. Greenbelt, Maryland.

October 5, 1973: Application of ERTS-1 Imagery to the Harvest Model of the U.S. Menhaden Fishery. Symposium on Remote Sensing in Oceanography, ASP Annual Convention. Orlando, Florida.

Appendix B

Acknowledgements

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