SUMMARY OF SELECTED EARLY RESULTS FROM THE ERTS-1 MENHADEN EXPERIMENT[1]

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ABSTRACT

A 15-mo study was initiated in July 1972 to demonstrate the potential of using satellite-acquired environmental data to provide fisheries information. Imagery from ERTS-1 (Earth Resources Technology Satellite) was used in conjunction with aerial photographically sensed menhaden distribution information, sea-truth oceanographic measurements, and commercial fishing information from a 8,670-km^2 study area in the north central portion of the Gulf of Mexico. Objectives were to demonstrate relationships between selected oceanographic parameters and menhaden distribution, ERTS-1 imagery and menhaden distribution, and ERTS-1 imagery and oceanographic parameters. ERTS-1, MSS Band 5 imagery density levels correlated with photographically-detected menhaden distribution patterns and could be explained based on sea-truth secchi disc transparency and water-depth measurements. These two parameters, together with surface salinity, Forel-Ule color, and chlorophyll *a*, also were found to correlate significantly with menhaden distribution. Eight empirical models were developed which provided menhaden distribution predictions for the study area based on combinations of secchi disc transparency, water depth, surface salinity, and Forel-Ule color measurements.

A need of managers and users alike of living marine resources is timely synoptic information about the distribution and abundance of the resources. For users, this need is particularly critical in that daily decisions must be made about where to deploy fishing vessels and less frequent decisions about investment strategies for men and equipment. The increasing pressures placed on living marine resources by domestic and foreign fishing fleets interacting with environmental changes demand that resource managers also be kept fully aware of the current status of the stocks to prevent possible catastrophic fluctuations in specific fish populations. Unfortunately, the tools required to satisfy this need economically are lacking, forcing users to base decisions on inituition and often biased personal knowledge and resource managers to formulate recommendations based on historical rather than current information. In response to this need, a number of relatively new technologies are being examined by the National Marine Fisheries Service and, in particular, the technologies associated with aerial and satellite remote sensing, to determine if they can be used to provide pertinent fisheries resource information.

A 15-mo study was initiated in July 1972 to demonstrate the potential of using satellite-acquired information to predict the distribution and abundance of a fishery resource. The study represented a combined Federal Government and private industry effort and stressed acquisition of data to:

1. determine the reliability of satellite and high-altitude aircraft-supported sensors to provide information about selected oceanographic parameters in coastal waters;
2. demonstrate the feasibility of using remotely-sensed oceanographic information to predict the distribution and abundance of a selected species;
3. demonstrate the potential of using satellite-acquired information for improving the harvest and management of a fishery resource and;
4. identify necessary sensor techniques or developments to satisfy selected needs of resource users and managers.

This paper presents a summary of selected results from the experiment. Earlier publications dealing with the experiment have stressed its management (Stevenson, Atwell, and Maughan,

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1972), relationships between selected oceanographic parameters and fish distribution and abundance (Kemmerer and Benigno, 1973), and commercial fishing operations (Maughan, Marmelstein, and Temple, 1973).

EXPERIMENTAL RATIONALE

With existing technology, fish cannot be detected directly with sensors aboard orbiting satellites. It may be feasible, however, to use satellite sensors to measure selected environmental parameters and then to use these parameters to predict, and in some cases even forecast, the distribution and abundance of a fish species. The quality of these predictions or forecasts would depend on how accurately the parameters are measured with the sensors, how precisely the parameters correlate with the distribution of specific fish populations, and how accurately the values were predicted.

The rationale employed in the experiment was to convert data obtained with ERTS-1 or aircraft-supported sensors into oceanographic parameter information, attempt to derive correlations between these parameters and the distribution and abundance of a selected fishery resource, and then determine if the relationships have meaning for commercial fishing operations and resource management. Data obtained with the satellite were supplemented with data obtained with sensors aboard aircraft to provide a broader spectrum of environmental information. In addition, a massive sea-truth sampling effort was undertaken to provide calibration data for remote sensors and backup information for correlation analyses.

STUDY AREA AND FISHERY

The study area was a 8,670-km^2 rectangle situated in the north central portion of the Gulf of Mexico (Figure 1). It included coastal areas of Alabama, Mississippi, and Louisiana and encompassed all of the Mississippi Sound, the southern portion of Mobile Bay, and extended offshore from the Mississippi Sound to approximately the 18-m depth curve. The study area is divided in half lengthwise by five barrier islands which isolate the typically turbid, low-salinity waters of the Mississippi Sound from the relatively much clearer oceanic waters of the offshore portion of

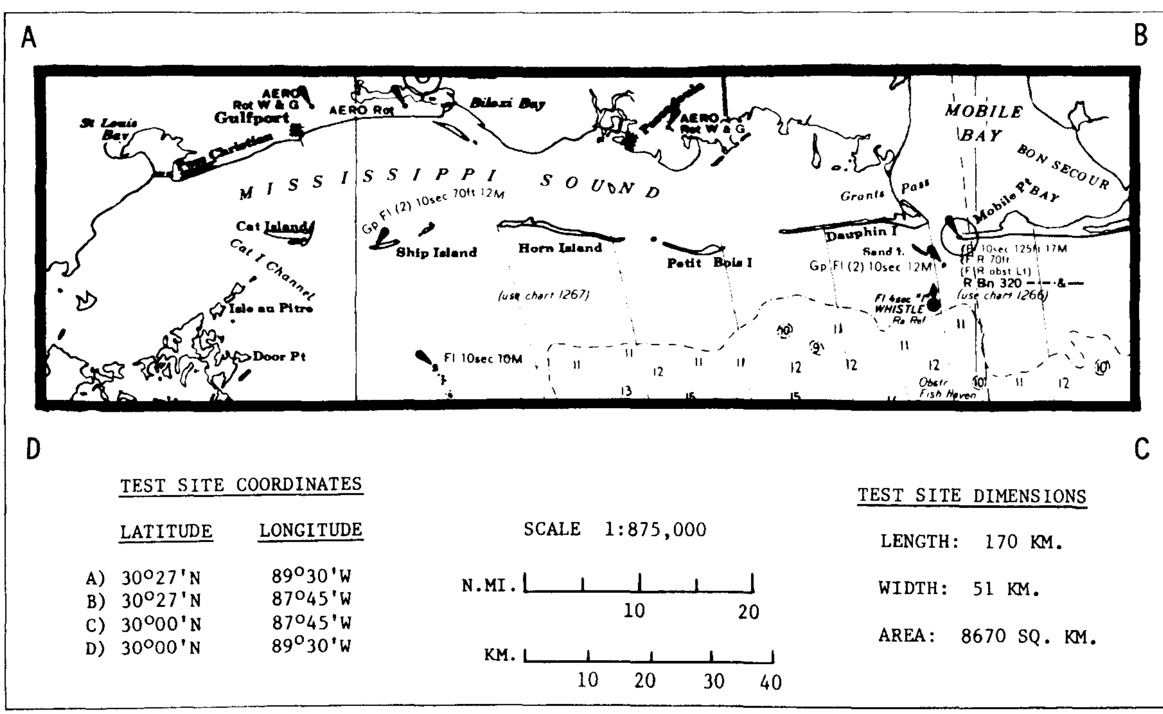


FIGURE 1.—ERTS-1 menhaden experiment study area.

the study area. A comprehensive description of the area is given by Christmas (1973).

The target fish species for the study was the small (mean weight about 85 g), herringlike, surface-schooling Gulf menhaden (*Brevoortia patronus*). These fish occur along the Gulf of Mexico coast and are considered to be an estuarine-dependent species. They are used commercially as a source of fish meal, oil, and condensed soluble proteins. In the Mississippi Sound, menhaden are fished from about mid-April to October by twin purse seine boats assisted by spotter pilots flying light aircraft. The spotter pilots direct the purse boats to the menhaden and then through radios notify the boat captains when to encircle a school with their purse seine. Once a school is captured and concentrated in the net, a larger mother or carrier vessel is brought alongside and the fish are pumped into the hold of the ship.

Menhaden are plankton feeders using a sieve-like branchial apparatus to strain plants and animals from the water (Reintjes, 1969). Their characteristic schooling behavior, which seems innate from late larval stage to old age, makes them particularly available to commercial fishing. School size varies from about 25 to in excess of 2,000 m^2 (surface area) and averages about 125 m^2. Although Gulf menhaden have been the subject of many investigations (Christmas and Gunter, 1960; Gunter and Christmas, 1960; Reintjes, Christmas, and Collins, 1960; and Rounsefell, 1954), little is known about their distribution in relation to environmental parameters.

DATA ACQUISITION

Data acquisition events were divided into four operations categories: main day, secondary day, special purpose, and commercial fishing operations. Main day activities occurred at or near the time of selected ERTS-1 overpasses (7 August, 25 August, and 28 September 1972) and included an intensive sea-truth sampling effort-up to 144 stations were occupied. Only a few sea-truth stations were occupied during secondary day missions, which were conducted weekly, weather permitting, to record temporal environmental and fishery changes. Special purpose missions were designed to satisfy limited objectives and as such did not follow set schedules. Oceanographic and fisheries data were obtained from one to three commercial fishing vessels, usually on three days of each week, June through September 1972.

ERTS-1 and Aircraft Environmental Sensors

A number of oceanographic parameter sensors were used during the experiment from NP3A (NASA) and D18 Beechcraft[4] (NASA/ERL) aircraft at altitudes ranging from 610 to 7,620 m. The sensors included a RC 8 camera, RS-14 scanner, PRT-5 radiation thermometer. KA 62 multiband camera, Hasselblad EL-500 cameras, RS-18 thermal IR scanner, multifrequency microwave radiometer, and an Exotech spectroradiometer. The sensors were configured to measure sea-surface temperature, water color as a function of wavelength, surface current patterns, surface salinity, and surface turbidity patterns.

The ERTS-1 satellite, launched on 23 July 1972, operates in a circular sun-synchronous near polar orbit at an altitude of 915 km. It circles the earth every 103 min, completing 14 orbits per day and providing repetitive coverage of specific areas every 18 d. Two consecutive orbits, 24 h apart, are required for complete coverage of the study area.

The only environmental sensor aboard the satellite operating during the study was a multispectral scanner (MSS) which provided images in four discrete portions of the light spectrum (Freden, 1972): Band 4, 0.5–0.6 micron; Band 5, 0.6–0.7 micron; Band 6, 0.7–0.8 micron; and Band 7, 0.8–1.1 microns.

Sea-Truth Oceanographic Parameter Measurements

Sea-truth measurements during main day data acquisition events were taken from 25 research boats. Because two orbits 24 h apart of ERTS-1 were required for complete coverage of the study area, only about half of these measurements coincided with the passage of the satellite. On 7 and 25 August 1972, coincidental measurements occurred for the western portion of the study area, resulting in a 24-h difference for measurements from the eastern portion. A main day occurred on 28 September 1972, which did not correspond to

[4]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

either orbit of ERTS-1. Orbits instead occurred on the 29th (eastern portion) and 30th (western portion) of September 1972, representing 24- and 48-h differences, respectively.

The 25 research boats generally occupied 95 stations in the Mississippi Sound and 46 stations in the offshore portion of the study area. These stations were spaced to provide a sampling density of about one station per 29 km^2 in the Sound and one station per 60 km^2 in the offshore waters. Parameters measured included surface temperature, salinity, chlorophyll *a*, currents, sea state, water color, water depth, and secchi disc transparency. Surface water temperature, salinity, and chlorophyll *a* measurements were obtained from bucket samples. Temperature was determined immediately in the bucket, and polypropylene bottles were used to store samples for chlorophyll *a* and salinity measurements in the laboratory. Color was estimated with a Forel-Ule color comparator (Hutchinson, 1957), and current speed and direction were measured by timed drifts of neutrally buoyant floats.

Fisheries Data

Aerial photography provided most of the fisheries distribution and abundance information augmented periodically with nighttime, low-light-level television sensor missions and commercial fish-spotter pilot reports. Menhaden are particularly susceptible to aerial sensing techniques because of their characteristic surface or near-surface schooling behavior. Discussions on aerial photography and low-light-level television sensing of fish schools have been published by Bullis (1967), Benigno (1970), Drennan (1969), and Roithmayr and Wittman (1972).

Photographic fish sensing missions were flown to provide 95% coverage of the study area at a scale of 1:16,200. The camera used was a Zeiss RMK-1523 mapping camera with a 15.24-cm focal length lens and 22.86-cm film format. The camera was supplied with GAF-1000 blue insensitive (2575) film, selected for its speed and reported ability to penetrate the hydrosphere (Vary, 1969). Photographic missions were divided into morning and afternoon flights corresponding to sun angles of 15 to 50 degrees, with morning flights covering the Mississippi Sound and afternoon flights covering the offshore section of the study area. A Houston-Feerless film viewer, providing magnifications of 3 × to 33 ×, was used to aid in the search of processed film for imaged menhaden schools. Fish school locations were recorded according to latitude and longitude with an accuracy of ±0.4 km. Menhaden schools could be subjectively differentiated from other schooling species in the study area on the basis of size, shape, and color.

Commercial Fishing Data

Fishery and oceanographic parameter measurements were obtained June through September 1972 from one to three commercial fishing vessels. These measurements were taken at the time and location of capture or attempted capture of a menhaden school. Data collected included surface water temperature and salinity, secchi disc transparency, Forel-Ule color, number of fish captured (visual estimate), date, time, and location. Usually, these observations were made the first three days of each fishing week (Monday through Saturday) except during periods when an ERTS-1 overpass or main day occurred, in which case the sampling period was extended over the entire fishing week.

DATA ANALYSIS AND INTERPRETATION

General Analytical Rationale and Data Limitations

Because the overall success of the experiment depended upon finding relationships between menhaden distribution and abundance and oceanographic parameters, the logical point of departure was with these relationships. Thus, impetus initially was given to finding relationships between fish distribution and abundance and selected oceanographic parameters, and then to determine if parameters which had fisheries meaning could be measured remotely with sufficient accuracy for precise correlation analysis. The last step in the analytical rationale was to determine what, if any, uses these relationships might have for commercial fishing and resource management.

The principal data limitation placed on early analyses was a general lack of remotely acquired synoptic oceanographic parameter measurements. The conversion of remotely acquired oceanographic data into meaningful information has proceeded slowly because of interpretation difficulties. Thus, reported fisheries oceanographiuc–parameter relationship analyses depend primarily upon sea-truth measurements. An essential exception was the photographically acquired menhaden distribution and abundance information.

Oceanographic Parameter–Fish Distribution Relationships

Analysis

The distribution and abundance of menhaden in the study area, principally in the Mississippi Sound, can be placed into a simplified systems context (Figure 2). Factors directly affecting the system, i.e., the distribution and abundance of menhaden, include fish input, fish output (including harvest, death, and emigration), the environment, and the innate behavior of the menhaden not directly or immediately influenced by environmental conditions. Examples of this latter factor include fish age and degree of sexual maturity. This systems concept can be modified slightly and expressed as an algebraic argument as:

$$A_{x,y} = f(E,B,P) \tag{1}$$

where:

A = number of menhaden schools,
x and y = refer to school location coordinates,
E = environmental conditions,
B = innate fish behavior, and

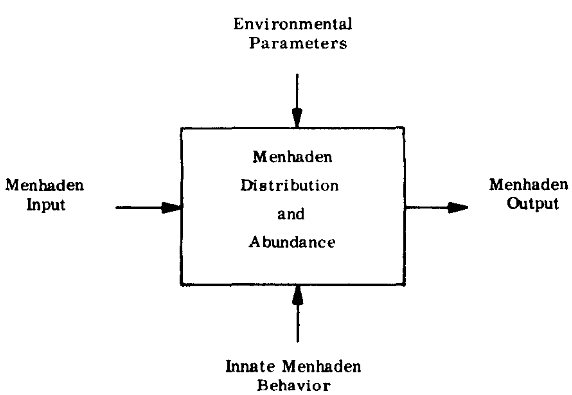


FIGURE 2.—Simplified systems view of the Mississippi Sound menhaden population described only in terms of distribution and abundance.

P = instantaneous menhaden school population.

The problem with the argument is that the dependent variable $A_{x,y}$ is a function of more than just the environment, E, and as such cannot be solved with available information. To simplify the expression, two assumptions were made. First, it was assumed that B was constant (i.e., the innate behavior of the menhaden did not vary significantly) and thus could be ignored in the expression, an assumption which led to the development of a new expression where $A_{x,y}$ became a function of E and P alone. This assumption appeared reasonable because only adult menhaden were considered in the experiment while they were in the Mississippi Sound, a relatively short period of time. The second assumption made was that $A_{x,y}$ could be expressed in relative terms such that:

$$\frac{A_{x,y}}{P} = f(E) \tag{2}$$

This assumption permitted the normalizing of $A_{x,y}$ relative to P and has its roots in many fisheries catch/effort related expressions.

In the subsequent analyses, the number of photographically detected menhaden schools at any given point was used as an estimator of $A_{x,y}$, and the total number of detected menhaden schools was used as an estimator of P. If there was a constant sensor–caused bias in the photography data, the quotient $A_{x,y}/P$ should not be affected seriously, as the bias cancels. However, if the bias was not constant but instead was a variable function of the environment, then the bias would affect the quotient. Whether or not the effect would be significant would depend on the magnitude and variability of the bias.

Because of a concern about the possibility of bias affecting the relationships, a second approach also was used which should have reduced sensor bias. A new dependent variable, D, was defined which reflected only the distribution of menhaden and was related to the environment as:

$$D = f(E) \tag{3}$$

Inherent in this expression is the assumption that P does not affect the distribution of menhaden within the extremes of P characteristic of the menhaden population during the experiment. Neither photographic nor commercial fishing data indicated a major change in P on main days, which lends credibility to this assumption. As defined, D can have two possible outcomes: yes, menhaden are present and no, menhaden are not present. In the analysis, areas where menhaden were detected were assigned a value of 1 and areas where fish were not detected were assigned a value of 0. Although D is clearly a discontinuous dependent variable, the statistical techniques used in the analyses converted it into a continuous variable ranging from about 0 to 1. The general interpretation applied to predicted values is that as the values approached 1, the chance of finding fish increased proportionately.

Regression techniques were used exclusively to define relationships between the abundance and/ or distribution of menhaden and available measurements of oceanographic parameters. Because remotely sensed oceanographic data were not available, environmental conditions where fish were detected had to be interpolated and, in some cases, extrapolated from nearby sea-truth sampling stations. This procedure probably introduced experimental error into the analyses and, as such, may have obscured subtle relationships.

Results

Photographically sensed menhaden distribution and abundance ($A_{x,y}/P$) and distribution (D) information were regressed against available oceanographic parameter measurements (Table 1). These analyses reflect only those data collected on 7 August, 25 August, and 28 September 1972 (i.e., main days) from the Mississippi Sound portion of the study area. Forel–Ule color data were not collected on 7 August 1972; consequently, color analysis was limited to 25 August and 28 September. Clouds and cloud shadow obscured portions of the Sound on 25 August and 28 September; these areas were ignored in the analysis.

In general, the two approaches, i.e., relative abundance and distribution dependent variables, gave similar results. The type of relationship, either positive or negative, was the same in every case. Their precision varied, however, which affected level of significance. Of the two approaches, relationships derived using distribution as the dependent variable probably are the most reliable. Recent work has shown that there may have been a variable bias associated with the photographic sensor system used to obtain the fisheries data (Benigno and Kemmerer, 1973). The bias appeared to relate to school size and atmospheric conditions and apparently affected the number of schools detected more than where they were detected.

Assignment of biological significance to these correlations is difficult in that the parameters may be serving as indices of unmeasured parameters. In other words, there is a question of concomitance. Nevertheless, there does appear to be support for the distribution significant (≥ 90% confidence level) correlations presented in Table 1. Menhaden fishermen frequently are frustrated

TABLE 1.—Correlations between menhaden relative abundance ($A_{x,y}/P$) and distribution (D) estimates and selected oceanographic parameters (E).

Parameter	Degrees of freedom	Correlation coefficient (r) Relative abundance	Correlation coefficient (r) Distribution	Mean conditions where menhaden were detected (±95% confidence limit)
Temperature (°C)	195	0.009	0.044	29.75 (0.33)
Salinity (ppt)	195	−0.257***	−0.222***	25.53 (1.85)
Chlorophyll *a* (mg/m³)	195	0.025	0.119*	5.61 (1.95)
Current speed (cm/s)	195	−0.062	0.027	13.61 (5.50)
Sea state (m)	195	−0.064	−0.103	0.25 (0.08)
Forel—Ule color (units)	113	−0.256***	−0.150*	13.69 (1.21)
Water depth (m)	195	−0.216***	−0.404***	1.91 (0.47)
Secchi disc transparency (m)	195	−0.093	−0.146**	1.25 (0.17)

* 90% significance level
** 95% significance level
*** 99% significance level

in attempts to capture schools because the schools often inhabit waters too shallow for efficient boat and net operations (negative correlation associated with depth). Spotter pilots tend to concentrate their fish-searching efforts on turbid waters because of a relatively high frequency of fish encounter in these waters (negative correlation associated with secchi disc transparency). The positive correlation associated with chlorophyll *a* seems reasonable in that menhaden are plankton feeders. Salinity is a questionable concomitant factor although, because these fish are euryhaline organisms and inhabit estuarine waters throughout most of their lives, a preferred association with waters of low salinity seems plausible (negative correlation associated with salinity). Christmas and Gunter (1960) reported that 70% of the catch from 87 sets in the Mississippi Sound came from waters ranging from 5 to 24 ppt salinity, suggesting also a menhaden preference for low salinity waters. No biological significance can be attached directly to Forel–Ule color (negative correlation) yet, although this color may manifest water transparency and chlorophyll content. Correlation coefficients between Forel–Ule color and secchi disc transparency and chlorophyll *a* were −0.404 and 0.369, respectively, significant at the 99% confidence level.

The lack of statistical significance for several of the parameters listed in Table 1 should not necessarily be construed as meaning that no such correlations exist. For example, surface water temperature was relatively constant spatially throughout the study period and therefore its effect, if any, on the distribution and abundance of menhaden may not have been sufficient to gain statistical significance. In the long run, however, temperature may be a very important parameter. One also should be reminded that the correlations were developed from linear expressions for the sake of statistical tractability. The correlations, therefore, may not factually represent real world situations where most responses probably are nonlinear.

The concern over a possible significant sensor bias in the menhaden distribution estimates prompted attempts to substantiate the results through other approaches. The set of commercial fishing data which included measurements of selected oceanographic parameters provided the only avenue through which substantiation could be accomplished. However, these data were noticeably biased in that environmental measurements were obtained only from areas where catches were made or attempted. In addition, the boats did not fish randomly throughout the study area; rather, they fished according to fish availability, distance from home port (minimized to reduce operating expense), day of the week (tendency to fish farther from home port as the fishing week progressed), and water depth (usually about 2 m for efficient boat operation). Nevertheless, if caution is used in the analysis, the data can be used to substantiate some of the results gained through photographic sensing of the menhaden stocks.

In the classical statistical situation, one generally attempts to differentiate between two presumably different populations, e.g., with and without menhaden. As noted previously, the principal problem with the commercial fishing data is that data were not obtained from areas without fish. However, if the assumption is made that all other environmental measurements collected throughout the study period (main and secondary day events) were taken at random in terms of temporal and spatial coverage, then it is logical to assume that these latter measurements included areas with and without menhaden. The commercial fishing data can then be handled as a "with fish" subset of the total data population, i.e., with and without fish.

The difficulty in this approach is that differences are difficult to demonstrate with a high level of statistical significance because the subset (with fish) is not discrete from the total population (with and without fish). The hypotheses which can be tested are that the means ($\bar{x}$) and standard deviations (s) of the subset and total population are different, resulting in the following four general conditions and accompanying conclusions:

1. Means and standard deviation are not significantly different; conclusion: fish distribution is not related to the parameter tested.
2. Means are significantly different but standard deviations are not; conclusion: fish distribution is related to the parameter tested.
3. Means are not significantly different but standard deviations are; conclusion: fish distribution is related to the parameter tested.
4. Means and standard deviations are both significantly different; conclusion: fish distribution is related to the parameter tested.

A note of caution should accompany the conclusions, however. They are valid only for the data collected under the conditions of the experiment, and therefore extrapolation to other areas or to the same area under different experimental conditions might not be valid.

The commercial fishing data demonstrated a Condition 4, i.e., means and standard deviations different with respect to water depth, salinity, Forel–Ule color, and secchi disc transparency (Table 2). Temperature and sea state were not tested, and data were not available for chlorophyll *a* and currents. The subset of fishing data included measurements from 237 "fish sets" and the total population of oceanographic conditions included measurements from 29 June, 30 June, 6 July, 7 August, 25 August, and 28 September 1972. For each parameter, a negative correlation is indicated as the mean parameter values for the fishing subsets were significantly less than the mean values for the total parameter populations. The lack of high significance levels for mean salinity and Forel–Ule color value differences was not particularly surprising in that the subset approach tends to preclude such significance. In any case, the relationships shown in Table 2 substantiate those shown in Table 1.

A second approach was used to substantiate still further the correlations formed between fish distribution and salinity, Forel–Ule color, secchi disc transparency, and water depth. Mean parameter values for conditions where menhaden were photographically detected (Table 1) were compared with similar values from the fishing subset (Table 2). None of these values were significantly different at levels down to 80% (*t*-test).

In summary, water depth, secchi disc visibility depth, surface salinity, and Forel–Ule color were found to correlate negatively with the distribution of menhaden. Chlorophyll *a* correlated positively with fish distribution, although independent data were not available with which to corroborate this relationship as in the case of the other four parameters.

ERTS– Imagery and Fish Distribution Relationships

Analysis

The only complete docket of quality ERTS–1 MSS imagery coincidental with main day acquisition events was from 7 August 1972. Band 5 imagery from 25 August 1972 was of poor quality and no imagery was available for 28 September 1972.

The four MSS bands from 7 August 1972 were examined to determine if their density levels related to fish distribution. Bands 6 and 7 did not contain any readily apparent useful density detail. Band 4, for reasons which are still unclear, seemed to contain too much density detail. Density levels in Band 5, however, appeared to relate to menhaden distribution.

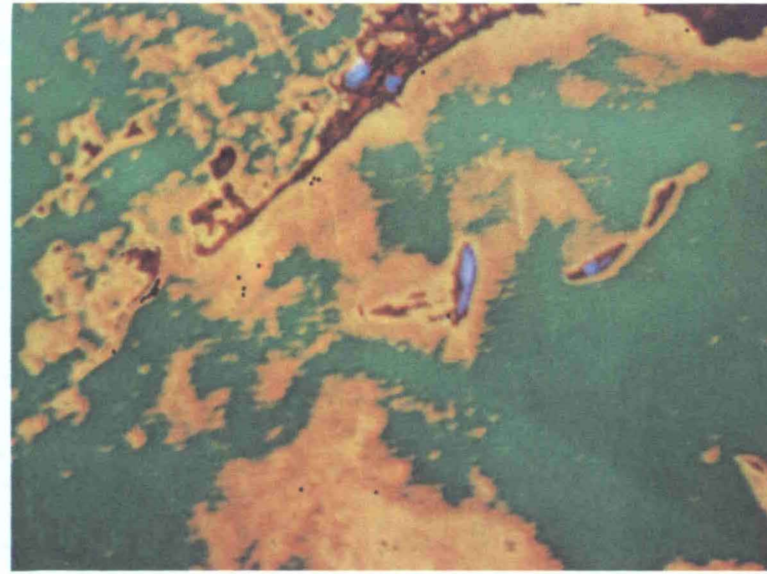
Results

Figure 3a shows a portion of the ERTS–1 Band 5 imagery covering the western portion of the Mississippi Sound and adjacent offshore waters as displayed on a I^2S DIGICOL video screen. Superimposed on the image are locations of 23 photographically detected menhaden schools. Water imagery densities were divided into two density ranges and color-enhanced (Figure 3b). All menhaden schools were found to lie in the less dense range, enhanced as orange. This density range was further reduced by slicing it to the narrowest range possible with the instrument. All of the fish schools can be found to either lie in or immediately adjacent to this range, enhanced as

TABLE 2.—Comparison of total parameter populations (with and without fish) and fish parameter population subsets (with fish).

	Total population			Fishing subset population			Level of significant difference (%)[1]	
Parameter	n	$\bar{x}$	s	n	$\bar{x}$	s	$\bar{x}$	s
Water depth (m)	354	3.41	1.27	237	2.19	1.17	99	90
Secchi disc transparency (m)	348	1.45	0.71	237	1.10	0.32	99	99
Salinity (ppt)	357	26.30	4.15	237	25.85	2.95	80	99
Forel–Ule color (units)	166	14.16	3.04	237	13.78	2.44	80	99

[1] *t*-tests for differences between means for populations with unequal variances and *F*-tests for differences between standard deviations (Ostle, 1963).



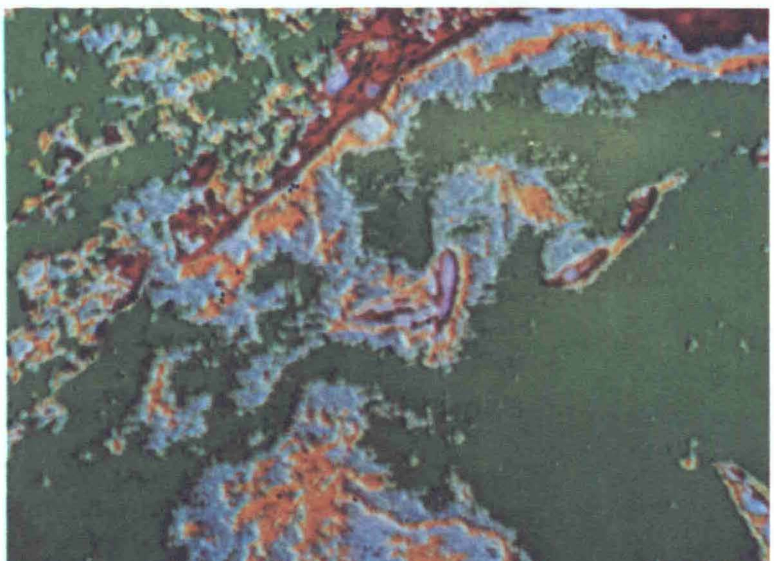


FIGURE 3.—ERTS–1, Band 5, 7 August imagery of the western portion of the study area (fish school locations are shown as small black dots). St. Louis Bay is in the upper left portion of the imagery, Cat Island is mid–center, and the western tip of Horn Island protrudes into the upper right portion.

a (upper left). I²S DIGICOL television screen image.

b (upper right). Image water densities divided into two ranges and color enhanced.

c (lower left). Enhancement of a narrow density range within the range containing the fish school locations. Note how the fish schools either fall adjacent to or within this narrow range.

orange (Figure 3c). The 10 tightly grouped school location indicators in the middle-left portion of the image overlie a small orange enhanced area making the latter difficult to see.

Unfortunately, the lack of additional data to test the persistence of the relationship between menhaden distribution and MSS Band 5 imagery density levels precludes any but the most tentative of conclusions. However, the data are sufficient to warrent an observation that the imagery does appear to contain information relating to the distribution of menhaden schools.

ERTS–1 Imagery and Oceanographic Parameter Relationships

Analysis

An analysis was performed on the MSS Band 5 imagery for 7 August 1972 to determine if image densities could be explained based on oceanographic parameter measurements. An isodensity tracing was made of that portion of the imagery covering the study area to provide quantitative relative density data. The tracing was not particularly satisfactory because of instrument limitations which caused more than one density range to be represented by the same color trace, but accurate enough to demonstrate relationships.

Results

Water depth, secchi depth visibility, and the interaction between the two parameters (formed by their product, Mott, 1967) were regressed against relative image densities. Simple correlations *(r)* between these parameters and image density were 0.56, 0.73, and 0.69, respectively, significant at the 99% confidence level. A slight improvement in precision ($r = 0.77$) was realized when the parameters were combined through multiple regression (Table 3) into the following equation:

$$\text{Image Density} = 0.5776 + 0.0222B + 0.0762T - 0.0051BT \quad (4)$$

where:

B = water depth in meters,

T = secchi disc transparency in meters,

BT = interaction formed as the product of B and T

Of the parameters, secchi disc transparency was the most important one in the equation as indicated by the relative magnitude of the coefficients and the simple correlation coefficients. The most meaningful facet of this analysis is that the two parameters correlating significantly with image density levels also correlated significantly with menhaden distribution (Tables 2 and 3). Thus, it appears that the apparent correlation between menhaden distribution and Band 5 density levels (Figure 3) is more than a chance occurrence and can be explained based upon secchi disc transparency and water depth measurements.

TABLE 3.—Analysis of variance for the relationship between ERTS–1 image density and two oceanographic parameters.

Source of variation	Degrees of freedom	Mean square	*F*-value
Total	47	0.0051	
Regression (secchi disc transparency, water depth, and interaction)	3	0.0469	21.040***
Error	44	0.0022	

PREDICTION MODELS FOR RESOURCE MANAGEMENT AND UTILIZATION

A potential management and utilization benefit from this experiment is identification of an approach through which remotely sensed environmental data could be used to provide distribution information about menhaden stocks in the study area. This information could be used to reduce search time for commercial concentrations of menhaden by fishermen and as a means to develop efficient survey designs by resource managers. Ideally, distribution information should be valid for the entire Gulf Coast menhaden fishery; however, this ideal case cannot be supported with results from this experiment but can be realized only through future experiments specifically designed to test demonstrated relationships in other areas.

Model Development

Demonstrated menhaden distribution–oceanographic parameter relationships (Table 1) were placed into a context potentially useful to commercial fishermen and resource managers. Multiple regression analysis was used to develop eight empirical models to predict menhaden distribution (D) in the study area based on four oceanographic parameters: water depth, secchi disc transparency, Forel-Ule color, and salinity (Table 4). The models contain selected 2-factor interactions formed as products between parameters and treated as additional independent variables. Interaction selection was based on whether or not an interaction significantly increased the precision of the estimate ($\hat{D}$). The models were constructed from data collected on main days (i.e., 7 August, 25 August, and 28 September 1972) and are presented separately and in combination and with and without the inclusion of color as an independent variable.

Model Testing and Interpretation

The models were tested by playing them with oceanographic data collected during commercial fishing operations and main day sea-truth station data stratified to include only those stations where menhaden were not detected photographically (Figure 4). Ideally, model products for fishing data should have grouped close to 1, and products for the "without fish" sea-truth stations should have grouped close to 0; obviously, this type of grouping is not demonstrated in Figure 4, indicating a general lack of accuracy and precision in the models. Product populations, however, are significantly

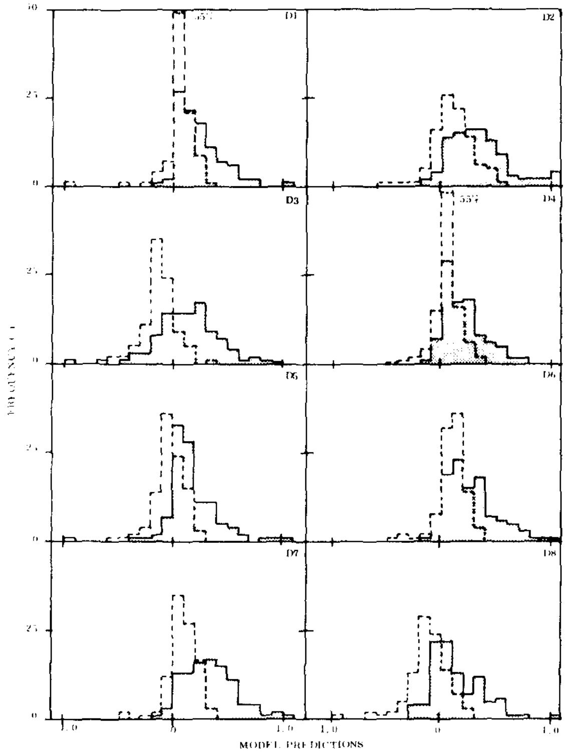


FIGURE 4.—Histogram plots of "with fish" (shaded) and "without fish" (unshaded) model products.

TABLE 4.—Empirical regression models which predict menhaden distribution (D) in the ERTS-1 study area.

B = water depth (m) S = salinity (ppt)
T = Secchi disc transparency (m) C = Forel-Ule color (units)
BT, BS, ST, CT, and CS = interactions formed as the products of the respective parameters.

Model	Inclusive dates (1972)	n	Regression model	Standard error of $\hat{D}$	Model correlation coefficient	Significance level (%)
D1	7 Aug.	82	$\hat{D} = 1.9959 - 0.0664S + 0.7453T - 0.6820B - 0.0233ST - 0.0144BT + 0.0230BS$	0.2492	0.596	99
D2	25 Aug.	42	$\hat{D} = 5.1537 - 0.1740S - 0.9195T - 0.0371C - 0.4350B + 0.0502ST - 0.1243BT + 0.0195BS$	0.3793	0.630	99
D3	28 Sept.	73	$\hat{D} = 2.3473 - 0.0934C - 0.8117B - 0.0358ST - 0.0007CS + 0.0528CT + 0.0516BT + 0.0235BS$	0.2443	0.409	90
D4	7 and 25 Aug.	124	$\hat{D} = 2.4691 - 0.0855S + 0.3948T - 0.6477B - 0.0054ST - 0.0441BT + 0.0223BS$	0.3009	0.584	99
D5	7 Aug. and 28 Sept.	155	$\hat{D} = 1.8559 - 0.0577S + 0.5604T - 0.6954B - 0.0191ST - 0.0079BT + 0.0232BS$	0.2489	0.480	99
D6	25 Aug. and 28 Sept.	115	$\hat{D} = 2.9396 - 0.1024S + 0.1522T - 0.7486B - 0.0026ST - 0.0547BT + 0.0268BS$	0.3118	0.488	99
D7	25 Aug. and 28 Sept.	115	$\hat{D} = 3.6035 - 0.0987S - 0.1249T - 0.0416C - 0.6717B + 0.0087ST - 0.0441BT + 0.0234BS$	0.3090	0.508	99
D8	7 and 25 Aug. and 28 Sept.	197	$\hat{D} = 2.3759 - 0.0797S + 0.3928T - 0.7051B - 0.0086ST - 0.0326BT + 0.0242BS$	0.28560.515	99	

different for each model even though the distributions overlap without a wide margin of difference between means (Table 5).

A number of factors probably contributed to the failure of the models to group fishing data closer to 1. It should be pointed out first, however, that no seasonally caused variation in products was noted, suggesting that the nonparametric grouping was caused by factors prevalent throughout the June through September commercial fishing sampling period. One of these factors may have been the effect of commercial fishing operations on the distribution of fish as evidenced by visual observations made during the photographic surveys of the study area. Menhaden schools frequently were observed being chased by purse boats through waters of varying visual qualities (i.e., turbidity). In addition, oceanographic parameter measurements generally were taken from the mother vessel rather than the purse boats, which often was several kilometers distant from the actual site of fish capture. Another of these factors is that there is no biological reason to suspect menhaden distribution to be wholly a deterministic function of environmental conditions; rather, there most likely is a probability associated with how and where fish are distributed in response to these conditions. Also, there were errors associated with all of the parameter measurements used to develop and test the models as well as a distinct possibility that other parameters having a direct influence on menhaden distribution might not have been measured (e.g., zooplankton biomass, presence or absence of predators, oxygen tensions, etc.). And finally, there is the linear additive nature of the models which at best probably only approximates the real world situation.

Selection of a best model was difficult in that they all provide similar products. On the basis of sample size, number of parameters (minimum), and difference between means (Table 5), Model D8 would have to be given selection priority, however.

A number of interpretations and presentation methods can be applied to model products as long as they recognize the imprecision of the models. An example of one method applied to Model D8, for 7 August 1972 sea-truth data, is presented in Figure 5. The categorization of model products was done by dividing the values shown in Figure 4 for Model D8 into three ranges based upon a direct comparison of fishing and nonfishing histograms:

high potential	$= > 0.2$
moderate potential	$= -1.0$ to 0.2
low potential	$= < -1.0$

The interpretation applied to high, moderate, and low potential areas is related to relative probability. In high potential areas, the probability of fish capture is higher than in moderate or low potential areas and higher in moderate than in low potential areas. Incomplete commercial fishing reports from 7 August 1972 indicate that most, if not all, fishing occurred in the high potential areas.

An additional analysis was performed on the commercial fishing data to determine if relationships could be demonstrated between catch size and the four oceanographic parameters which made up the models. Catch size ranged from 5 to 225 and averaged about 38 thousand fish. Catch

TABLE 5.—Tests of empirical models played with oceanographic data taken near sites of commercial fish capture (with fish) and during main day events, the latter stratified to include only those areas where fish were not detected photographically (without fish).

Model	With fish			Without fish			Significance level for difference between means (%)[2]
	n	$\bar{D}$	C.V.(%)[1]	n	$\bar{D}$	C.V.(%)[1]	
D1	225	0.202	86	165	0.071	147	99
D2	225	0.371	78	94	0.100	187	99
D3	225	0.146	184	94	−0.115	132	99
D4	225	0.305	67	165	0.139	80	99
D5	225	0.175	106	165	−0.017	755	99
D6	225	0.288	79	165	0.089	165	99
D7	225	0.338	70	94	0.093	151	99
D8	225	0.145	163	165	0.111	160	99

[1]Coefficient of variation.
[2]t-test for populations with unequal variances (Ostle, 1963).

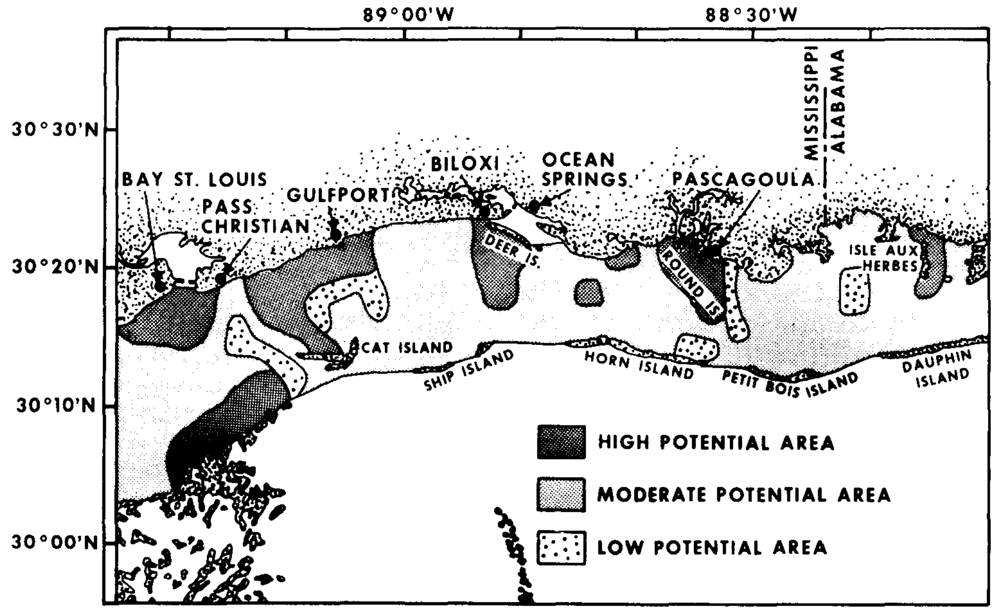


FIGURE 5.—Model D8 predictions for menhaden distribution in the Mississippi Sound on 7 August 1972, between 0900–1500 h (CDT) (based on 95 sea-truth measurements).

size was divided into three categories: 0–50, 50–100, and more than 100 thousand fish, and an analysis of variance applied to the categories to test for differences between mean parameter conditions. No significant differences were found between catch size and salinity, Forel–Ule color, and depth parameters at significance levels down to 50%. However, a significant difference at 95% was found between the first and third catch size category for averaged secchi disc transparency values ($\overline{T}_{0\text{-}50K}$ = 1.09 m and $\overline{T}_{>100K}$ = 1.32 m). This significance probably does not have biological meaning, however. It probably reflects changes in the ability of fishermen to selectively detect and capture fish schools with respect to water clarity.

SUMMARY AND CONCLUSIONS

The feasibility of using satellite-supported environmental sensors to predict fish distribution was demonstrated. ERTS–1, MSS Band 5 imagery was shown to contain density levels which correlated with menhaden distribution. These density levels were further shown to correlate significantly with sea-truth measurements of secchi disc transparency and water depth, two parameters which also correlated significantly with menhaden distribution. Additionally, surface salinity, Forel–Ule color, and chlorophyll *a* were found to correlate significantly with menhaden distribution. Independent tests of four oceanographic parameter–menhaden distribution relationships with oceanographic information taken at or near sites of commercial menhaden captures corroborated these relationships. The correlation between chlorophyll *a* and menhaden distribution could not be substantiated because of insufficient data.

Eight empirical regression models which predict menhaden distribution in the study area were constructed from combinations of four oceanographic parameters: water depth, secchi disc transparency, surface salinity, and Forel–Ule color. Although the models did not provide particularly precise predictions about menhaden distributions, their predictions nevertheless were statistically significant. The importance of the models is that they demonstrate a potential means or direction through which remotely sensed oceanographic information can be used to provide menhaden distribution information on a real–time basis. This information could be used by the commercial industry to reduce spotter-pilot search time by identifying likely areas for concentrations of menhaden and by resource managers as an aid in planning assessment surveys.

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