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EARTH RESOURCES LABORATORY

SHORELINE AS A CONTROLLING FACTOR IN COMMERICAL SHRIMP PRODUCTION

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NATIONAL SPACE TECHNOLOGY LABORATORIES

ERL REPORT 175

SHORELINE AS A CONTROLLING FACTOR IN COMMERCIAL SHRIMP PRODUCTION

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SHORELINE AS A CONTROLLING FACTOR IN COMMERCIAL SHRIMP PRODUCTION

by

KENNETH H. FALLER[1]

ABSTRACT

An ecological model has been developed that relates marsh detritus export and shrimp production. It is based on the hypothesis that the shoreline is a controlling factor in the production of shrimp through regulation of detritus export from the marsh. Landsat data were used to develop measurements of shoreline length and area of marsh having more than 5.0 km shoreline/km^2 for the coast of Louisiana, demonstrating the capability of remote sensing to provide important geographic information. These factors were combined with published tidal ranges and salinities to develop a mathematical model that predicted shrimp production for nine geographic units of the Louisiana coast, as indicated by the long term average commercial shrimp yield. The mathematical model relating these parameters and the shrimp production is consistent with an energy flow model describing the interaction of detritus-producing marshlands with shrimp nursery grounds and inshore shrimping areas. The analysis supports the basic hypothesis and further raises the possibility of applications to coastal zone management requirements.

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[1] NASA, Earth Resources Laboratory, National Space Technology Laboratories

EXECUTIVE SUMMARY

The coastal zone of the United States is an area subject to tremendous pressures, as population centers expand and the impact of residential, agricultural, industrial and commercial factors propagate through coastal wetlands, bays and estuaries. Federal, and in many instances state and local, legislation has established the requirement for management and monitoring of coastal resources, including the most basic life forms and processes. In response to these requirements, efforts are being made by many to develop a detailed understanding of basic coastal processes and the influence of man's activities on these processes, and to develop techniques for monitoring them. The research effort described in this work was conducted to develop an understanding of the importance of a single process in the overall system and to demonstrate a technique by which a controlling factor in that process can be monitored synoptically using satellite data.

Using the systems ecology approach, it is possible to trace the flow of energy from the marsh ecosystem to the estuary ecosystem, and to relate secondary production in the estuary to this influx of energy. We have performed an analysis of the influence of shoreline as a limiting factor on the flow of energy-carrying nutrients from the marsh to the marine ecosystem as reflected by the commercial harvest of shrimp in Louisiana bays and estuaries. Data acquired by the Landsat multispectral scanner was computer processed to develop statistics relating to detritus production on the marshlands and the length of the marsh-water interface.

These statistics were found to correlate at a high significance level with the commercial shrimp harvest, and were used to develop a mathematical model based on detritus production and export to predict the long-term average commercial shrimp harvest for nine segments of the Louisiana coast. Detritus production was estimated to be proportional to the area having more than 5.0 kilometers shoreline per square kilometer, and export to the marine ecosystem was modelled as the product of shoreline length and mean tidal range. The result was an excellent agreement between reported and predicted harvest, with the root mean square deviation between the reported and predicted values being 4.36 kg/ha over a range of 0.29 to 45.16 kg/ha. The analysis thus indicates that the production of detritus on the marshlands and its export, as regulated by the tidal flow across the shoreline, are controlling factors in the production of shrimp in the Louisiana bays and estuaries.

With further research, it should be possible to extend the analysis to provide an important tool for coastal zone management. Remote sensing can be used to monitor marshlands and routinely assess bio-geographical factors. Trends of changes taking place in the marsh, whether natural or anthropogenic, and proposed modifications to the marsh could be analyzed with an ecosystem model similar to the one developed in the present work to forecast possible changes in future shrimp production.

SHORELINE AS A CONTROLLING FACTOR IN COMMERCIAL SHRIMP PRODUCTION

I. INTRODUCTION

The coastal zone of the United States is an area subject to tremendous pressures, as population centers expand and the impact of residential, agricultural, industrial and commercial factors propagate through coastal wetlands, bays, and estuaries. Federal, and in many instances state and local, legislation has established the requirement for management and monitoring of coastal resources, including the most basic life forms and processes. In response to these requirements, efforts are being made by many to develop a detailed understanding of basic coastal processes and the influence of man's activities on these processes, and to develop techniques for monitoring them. The research effort described in this paper was conducted to develop an understanding of the importance of a single process in the overall system and to demonstrate a technique by which a controlling factor in that process can be monitored synoptically using satellite data.

The advent of systems ecology has made possible the analysis of the various components of natural ecosystems. While adequate data are seldom available for complete mathematical treatment of a model ecosystem, it is still possible to assess the significance of individual elements. To model an ecosystem, one identifies the subsystems which can be separated as discrete entities and the processes and paths of energy flow relating them. As a first level analysis, the marsh-estuary system may be divided into two major subsystems, the terrestrial and the aquatic, linked by the flow of organic and mineral nutrients carrying chemical potential energy. The principal transport mechanism linking the terrestrial and aquatic systems is the flow of water across the shoreline under the influence of tidal fluctuation and rainfall. It is generally recognized that an important factor contributing to the tremendous productivity of salt marsh estuaries is the interaction between the marsh and the water (e.g. Schelske and Odum, 1961; Teal, 1962; Day, Smith, and Hopkinson, 1972). This paper presents an analysis of the influence of shoreline as a limiting factor on the flow of energy-carrying nutrients from the marsh to the bays and estuaries as reflected by the commercial shrimp harvest in the Louisiana estuaries and bays. This analysis is based on data derived from published statistics relating to the marsh-estuary biology and from computer analysis of satellite mappings of the Louisiana coast.

Mapping of coastal wetlands is a very difficult problem. In addition to the tremendous difficulty of performing field surveys in the wetlands, these areas are subject to constant change. Maps prepared from data acquired during the 1950-1960 time period show significant deviations from current aerial photography. The use of multispectral scanner data from the Landsat satellite ameliorates the problem by providing the capability to routinely monitor the wetlands, to update existing maps, or to generate original maps based on identifiable control points located on existing maps. From computer analysis of the data acquired by the Landsat multispectral scanner (MSS), thematic maps showing land and water, various species of vegetation and residential or industrial development can be produced. Computer processing of the Landsat MSS data, available initially in computer compatible form, makes feasible the routine monitoring of extensive areas, such as the entire coast of a state.

The research upon which this report is based required the mapping of nearly the entire coast of Louisiana, a task that would have been impossible by any conventional techniques within the constraints of reasonable funding. Analysis based on existing maps would have been questionable due to significant changes that have taken place in the coastal wetlands since the maps were produced and significant errors in the initial mapping. The Landsat MSS data provide the opportunity to develop geographic parameters over very large areas, with good accuracy, at a reasonable cost.

II. THEORY

Ecosystem models for marsh-estuary environments have been developed by various researchers, including Carter, et.al. (1973), Teal (1962), and Day, et.al. (1973). Each of these models emphasizes the importance of the link between terrestrial and aquatic subsystems. Figure 1 is the simplified energy flow diagram of the marsh-estuary system in Barataria Bay published by Day, et.al. (1973). Tide, water level, and rainfall are important forcing functions which drive the flow of inorganic nutrients, salt and detritus between the subsystems. Nutrients carried by river waters find their way into the estuary under the influence of tidal action and fertilize the marsh, whereas under the same influence, detrital material is washed from the marsh into the estuary and eventually the Gulf of Mexico. Human involvement occurs with the harvest of estuarine fauna and discharge of waste material. This general form developed for Barataria Bay is applicable to the entire Louisiana coast, the study area for the subject analysis.

Figure 2 is a detailed schematic of the portion of the ecosystem centered at the land/water interface, developed to show the energy flow leading to the only consumer studied in the subject analysis, penaeid shrimp. The marine subsystem is further subdivided into the bay-estuary subsystem, consisting of semi-enclosed water bodies and interconnecting bayous and channels; the coastal subsystem, including the open waters along the coast, outside the bays and sounds; and the deep Gulf. These shrimp, together with other species including amphipods, mysids, ostracods, planktonic copepods, crabs, filter-feeding bivalves and a few species of fishes, are detritus consumers, deriving a significant amount of their nourishment from the ingestion of vascular plant detritus together with small

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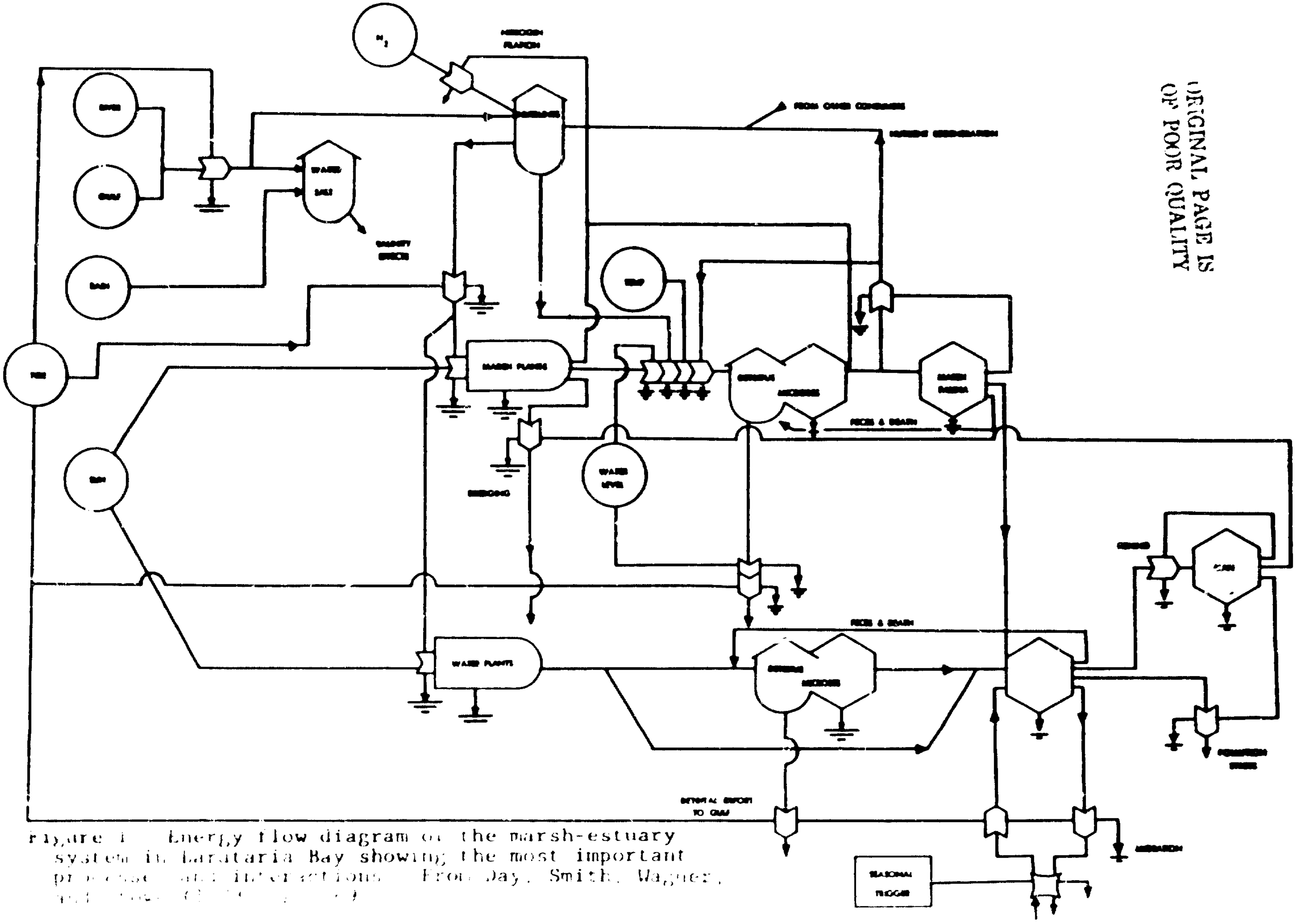
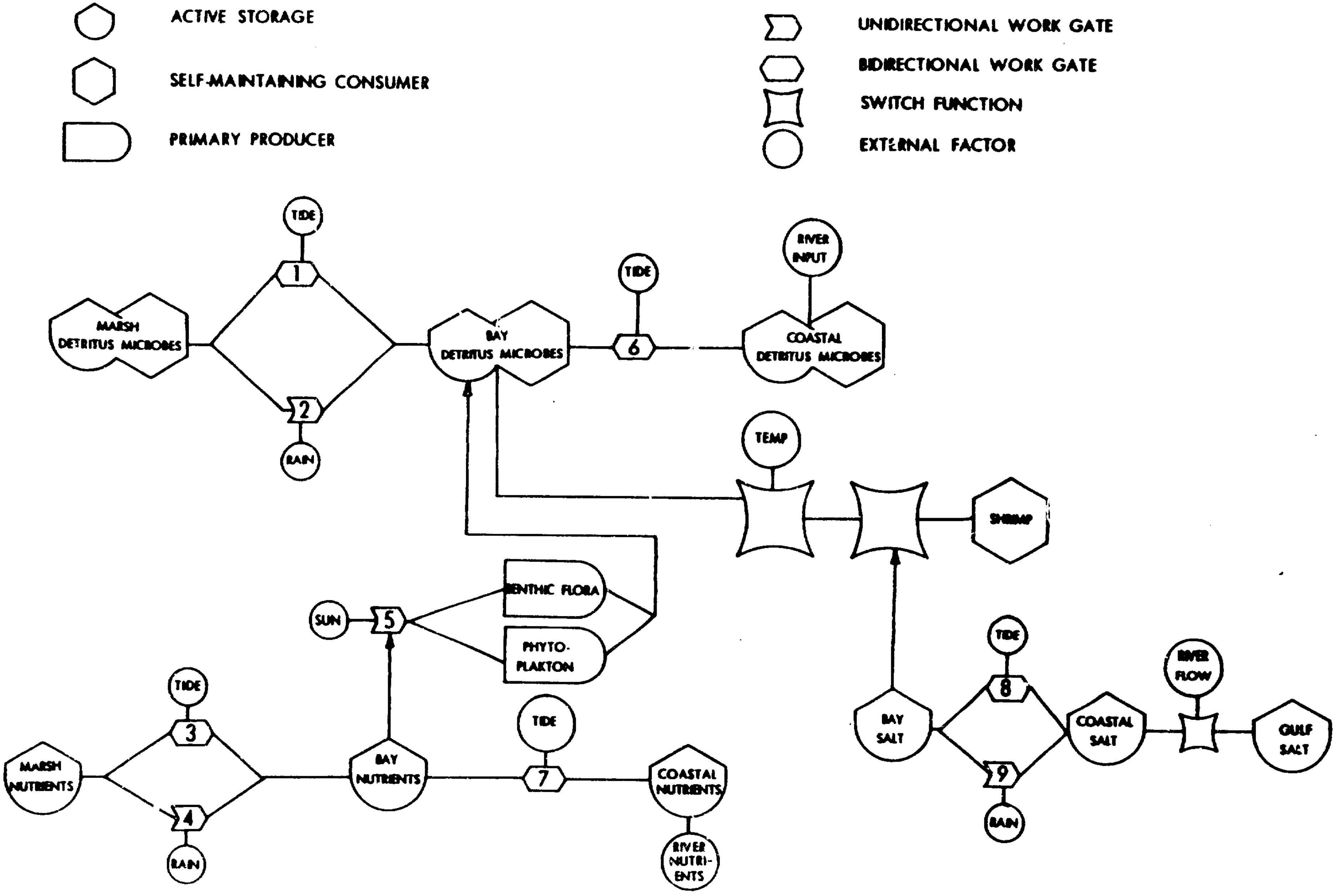


Figure 1. Energy flow diagram of the marsh-estuary system in Barataria Bay showing the most important processes and interactions. From Day, Smith, Wagner, and [illegible]

Figure 2. Energy flow diagram leading to in-shore shrimp.



quantities of live algae (Odum, Zieman, and Heald, 1972). Most of the detritus available to the shrimp finds its way into the bays and estuaries from the marsh, as tidal flow and rainfall wash dead plant material from the marsh subsystem into the bay-estuary subsystem. For one bay in Louisiana, Day (1973) estimated that as much as 70% of the total organic production available in the water was detritus from marsh grasses. The remainder is produced by plankton and benthic vegetation directly in the bay subsystem. Some detritus is riverborne, and is carried into the bays from the coastal waters by tidal action. The river water is rich in inorganic nutrients, which are also carried into the bays by the tides. There is evidence that potassium, magnesium and phosphate from these waters fertilize the marshland, whereas nitrates appear to be leached from the land by rain and tidal flow (Palmisano, 1970). River discharge also regulates the salinity of the coastal and bay waters. As indicated by Figure 2, the model is based on the hypothesis that the production of shrimp (a self-maintaining consumer) represents a direct flow of energy from detritus (an active energy storage factor) when salinity and temperature are in the proper range. If this hypothesis is correct, shrimp production should be related to the production and transport of detritus from the marsh into the bay.

The transport of detritus into the bay from the marsh is controlled by two work gates, labelled 1 and 2 in figure 2, which operate under the influence of tidal action and the runoff of rainfall, respectively. The first gate is bi-directional, whereas the second permits rain-induced flow only from the marsh to the bay. Some detritus is carried into the coastal waters by the rivers, and consequently is transported into the bays by incoming tides. The transport of this terrigenous detritus is controlled by work gate 6. Similar work gates control the flow of inorganic nutrients and salt.

Let us attempt to define the form of the mathematical function describing these work gates to a first approximation by synthesizing the significant factors influencing the transport mechanisms. The first factor to consider is the "conductivity" of the interface between the marshland and the water (represented in the figure as work gates 1, 2, 3, and 4). The conductivity of the interface is analogous to electrical conductivity. The conductivity of the interface is directly proportional to its length and to the thickness of the sheet of water flowing across the interface, as the conductivity of an electrical wire is proportional to its cross sectional area. Thus, for a given hydraulic head, the rate of flow will be determined by the length of the land/water interface. For the case of work gate 6, the transport is impeded by a complex shoreline, as opposed to the first three gates. The more tortuous the path the flow must follow, the greater is the resistance to flow. Thus, there is an inverse relationship between flow and shoreline length or complexity for transport between the coastal waters and the bay-estuary system.

Work gate 1 is bi-directional. Ebb tides remove material from the marsh and flood tides deposit material, with net transport being determined by the initial relative concentrations of material. Work gate 3 is also bi-directional. A controlling factor in the transport of inorganic nutrients is the concentration of those nutrients in the bay water and in the interstitial water of the marshland. Lower concentrations in the interstitial waters results in a fertilization of the marsh by the flood tide and little effect by the ebb, whereas a higher concentration of nutrients in the interstitial waters leads to removal of the nutrients by the tidal action. Work gates 2 and 4 are unidirectional, as rainwater falling on the marsh washes both detritus and inorganic nutrients across the shoreline into the bay.

According to this reasoning, work gate 1, representing the interface conductivity, may be defined by the expression

$$(1) \quad W1 = T \cdot S \cdot C_1$$

where C_1 is a constant, T is the mean tide stage range, and S is the shoreline length. The expression for work gate 2 is

$$(2) \quad W2 = R \cdot S \cdot C_2$$

where R is the amount of rainfall. The conductivity of the marsh-bay interface will therefore be defined by the composite function

$$(3) \quad W_{mb} = T \cdot S \cdot C_1 + R \cdot S \cdot C_2 = S \cdot (T \cdot C_1 + R \cdot C_2)$$

The analogy of the ecosystem to an electronic circuit may be continued by comparing the concentration or amount of detritus to voltage or electrical potential. The amount of detritus on the marshland is a function of the area of land interacting with marine system and the primary production of the marshland. If there is more detritus in the bay than on the marshland subject to flooding, detritus will be left behind by the ebb tide. Conversely, higher levels of detritus on the marsh bottom will result in suspension of detritus by the flood tide and its removal to the bay subsystem by the ebb tide. Thus, the import of detritus I (analogous to an electrical current) is related to the conductivity of the shoreline and detritus level V for the marsh and bay subsystems according to the simple equation

$$(4) \quad I = (V_m - V_b) \cdot W_{mb}$$

The factor V_m is proportional to the amount of detrital material per unit area of marsh and the area subject to inundation or flushing by rainfall. It is normally significantly greater than the "detritus potential" of the bay, V_b, although in some instances, V_b may be greater. I positive indicates net flow from the marsh and I negative indicates net flow to the marsh. Assuming V_b negligible with respect to V_m, equation (4) becomes

$$(5) \quad I = W_{mb} \cdot V_m$$

A similar relationship can be derived for export of detritus E from the bay to the coastal waters, where the detritus level V_c is much lower than in the bays; the conductivity of the bay-coastal interface is defined as W_{bc}.

$$(6) \quad E = W_{bc} \cdot (V_b - V_c)$$

The equilibrium detritus level D in the bay can then be written as

$$(7)\quad D = f(I - E)$$

The function f includes consumption and sedimentation of detritus.

The remaining factors of importance in Figure 2 are the two switches controlled by salinity and temperature. Studies by the Louisiana Wildlife and Fisheries Commission (Barret and Gillespie, 1973) indicate brown shrimp production is strongly affected by the number of hours water temperatures are below 20°C after the first week of April, and that salinities over 10ppt are required for a successful season, with 19ppt close to the optimum salinity for the brown shrimp. To a first approximation, the switching functions might be represented as Gaussian curves

$$(8)\quad K = \frac{1}{\sqrt{2\pi}\xi} \quad \exp\left[-\tfrac{1}{2}(p-\bar{p})^2/\xi^2\right]$$

where $\bar{p}$ represents the optimun salinity or temperature and ξ defines the broadness of the curve, and hence the steepness of the switching function. An approximation of this type, although obviously crude, requires careful selection of the salinity and temperature values to be used, as shrimp growth and production are related to these factors in a seasonal manner.

If we make the simplifying assumption that shrimp production is not affected significantly by predation and that there are no other factors important to the inshore production of shrimp, then it is possible to describe shrimp production P in Louisiana inshore waters mathematically as

$$(9)\quad P = g(D) \cdot K_{temp} \cdot K_{salinity}$$

where g(D) is a presently undefined mathematical function. Because D is essentially determined by I, the flow of detritus from the marsh, shrimp production is closely related to I, and hence determined by marsh productivity, shoreline complexity, and tidal and rain-induced flow.

The commercial shrimp harvest is an indication, although probably not perfect, of shrimp productivity. Because the productivity P is related to the import of detritus I, a mathematical relationship should exist between the factors determining I and the commercial harvest. These relationships should be apparent as significant correlations and should make possible a predictive model.

III. DATA

The data analyzed fall into three categories: biological, physical, and geographical. The biological data consist of the average inshore commercial shrimp landings for the years 1967 through 1972 reported by the National Marine Fisheries Service and tabulated as shrimp yield per acre in Barret and Gillespie (1973). Pink, brown, and white penaeid shrimp contribute to these totals. Because of the intense fishing pressure and the economic factors involved, the yield data are very closely related to shrimp production and are used here as a measure of production. Temperature and salinity data reported by Barret (1971) were averaged for the period of April through August, 1968. Mean tidal ranges listed for various points along the Louisiana coast in the National Ocean Survey Tide Tables were averaged for each geographic unit into which the coast was divided for this study, except for one area, where only a rough estimate of tidal range was available. The biological and physical data are presented in Table 1. The geographic data are derived from Landsat images of the Louisiana coastal region. The dates and scene identification codes of the Landsat data used in the study are listed in Table 2.

The Louisiana coast has been divided into nine geographic units. Shown in Figure 3, they correspond to (1) Lakes Pontchartrain and Maurepas; (2) Lake Borgne and Chandeleur Sound; (3) Breton Sound; (4) the southern portion of the Mississippi River Delta; (5) Barataria Bay; (6) Terrebonne and Timbalier Bays; (7) the area extending from west of Terrebonne Bay to Atchafalaya Bay, including Caillou Bay; (8) Atchafalaya Bay through Vermilion Bay; and (9) from Vermilion Bay through Calcasieu Lake. In general, the northern limit of the study area was taken to be the Intracoastal Waterway. The unleveed marsh west of Lake Salvador and west and north of Lakes Pontchartrain and Maurepas were also included, whereas the leveed areas south of Lake Pontchartrain and along the Mississippi River were excluded. The nine areas include nearly all of the shrimp nursery grounds and inshore shrimping area of the state.

The Landsat data available for use consist of photograph-like images and computer compatible tape recordings of earth

TABLE 1

SHRIMP YIELD AND PHYSICAL FACTORS

GEOGRAPHIC UNIT	SHRIMP YIELD* kg/ha	SALINITY** ppt	TEMPERATURE** °C	RANGE[†] Feet
1	0.29	4.6 (a)	28.	0.5
2	2.17	13.14	28.01	1.17
3	9.82	15.14	27.87	1.33
4	7.88	2.12 (b)	28.30	1.25
5	35.57	14.52	27.06	1.03
6	45.16	20.33	27.38	1.28
7	30.64	15.84	28.00	1.65
8	1.10	2.12	28.30	1.72
9	16.82	9.20	28.65	2.25

*From Barret and Gillispie (1973) 1967-1972 commercial landings

**From Barret (1971) April through August, 1968 except (a) from Stern and Atwell (1968) June and July 1968

(b) estimated to be the same as salinity for unit 4

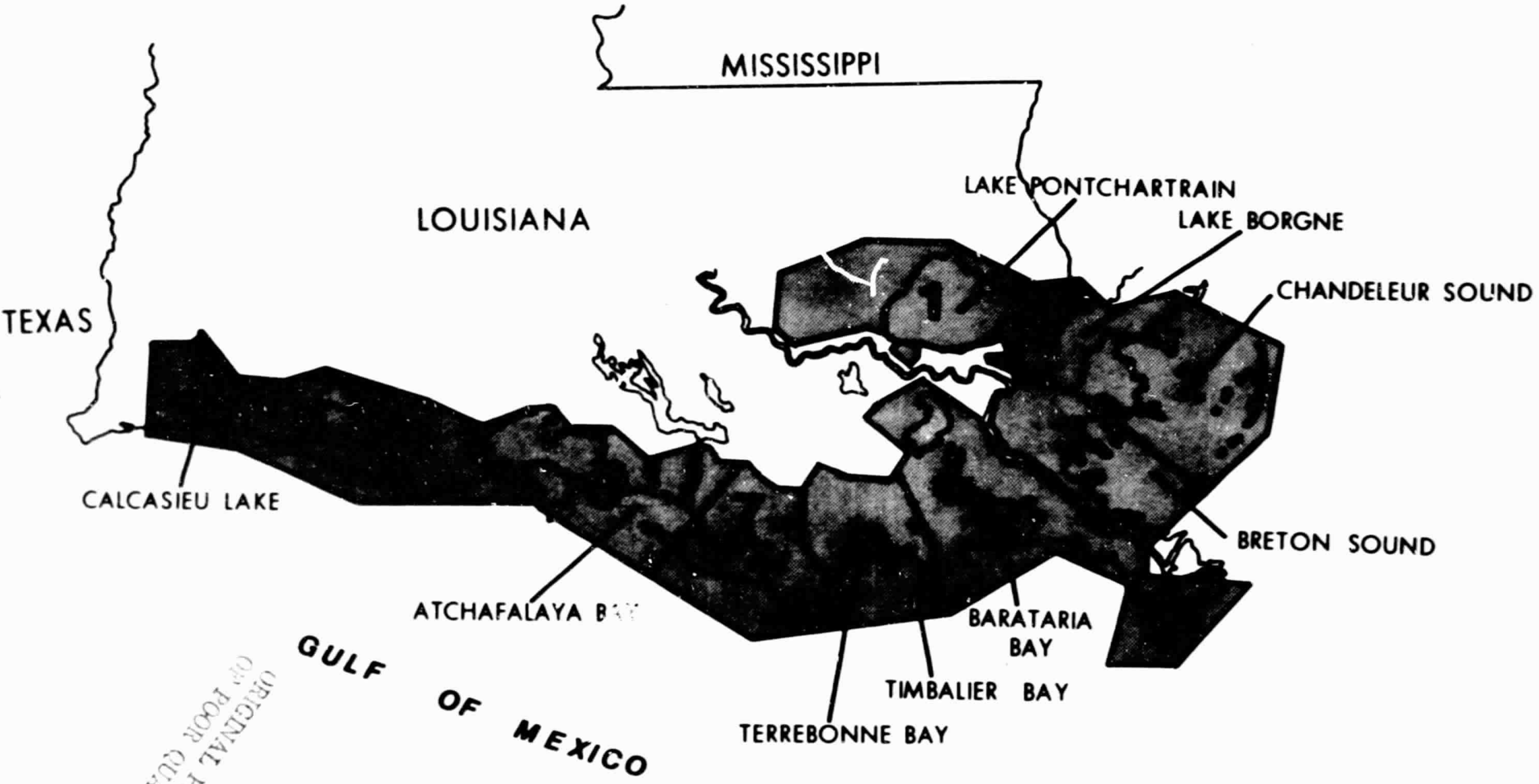
[†] From NOS Tide Tables

TABLE 2

LANDSAT DATA USED IN ANALYSIS

DATE	SCENE IDENTIFICATION	COVERS AREAS
12 Oct 75	2263 - 15491	1, 2
22 Oct 75	5185 - 15323	2, 3, 5
21 Oct 75	5185 - 15325	3, 4, 5, 6
25 Sept 75	2246 - 15550	5, 6, 8
25 Sept 75	2246 - 15553	6, 7, 8
26 Sept 75	2247 - 16005	8, 9
27 Sept 75	2248 - 16063	9

Figure 3. Coast of Louisiana divided into nine geographic units.



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scenes. Each scene consists of registered images in four spectral bands: the green, the red, and two bands in the near infrared. Figure 4 is an example of the images obtainable from Landsat. Each image is composed of individual sample cells, referred to as picture elements. A picture element is approximately 57m wide (approximately the east-west direction) and 79m high (approximately the north-south direction). Computer analysis of the data permits conversion of the color data of the original scene into various thematic renditions. Using a standard computer-implemented image classification procedure, referred to as Water Search, land-water thematics were produced for the coastal region. A second computer program was used to geographically reference the data to the Universal Transverse Mercator System. This analysis permits the translation of points located on a map into the satellite coordinate system defining the thematic. The geographic coordinates defining the boundaries of the nine geographic units were read from standard maps and translated into the satellite system to define the same boundaries in the thematics. A third computer program was then used to measure the shoreline length within the boundaries defining each geographic unit and to compute the shoreline density for each resolution element within each unit. A detailed description of the processing required to develop the shoreline length measurement is contained in Faller (1977).

Shoreline density is defined as the length of shoreline per unit area. It is measured in the computer by scanning a

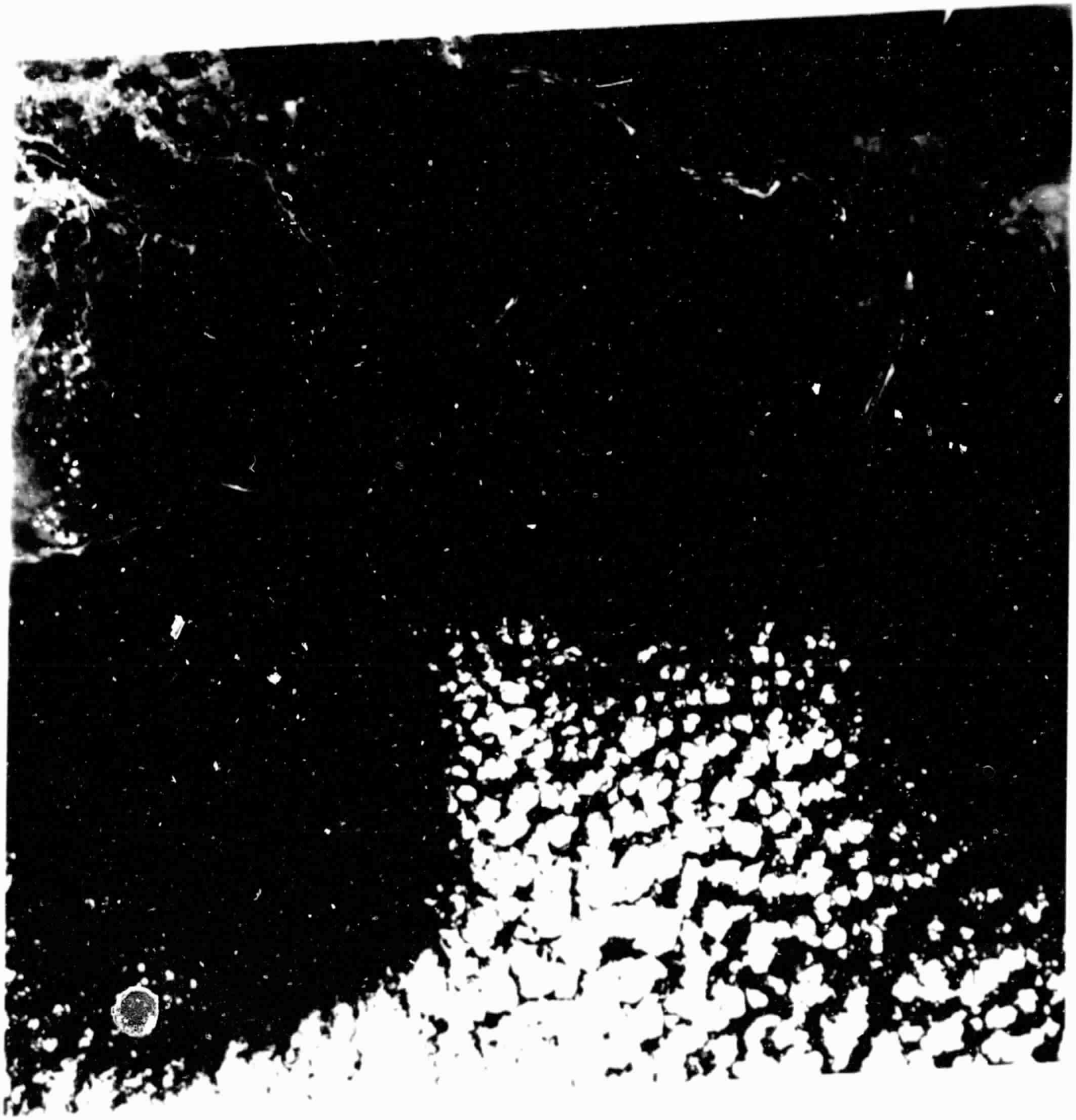

Figure 4. Landsat frame 5185-15325, Channel 5 (Red spectral band).

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window of predetermined size over the thematic (still in digital, computer compatible form) and accumulating the shoreline length within that window, then dividing by the area of the window. The shoreline density within the window is recorded for the reference picture element at the center of the window. The number of elements falling within each predefined range of densities is accumulated, and from this the total area described by each density range within a geographic unit is computed. The limits of the ranges of shoreline density used to analyze the Landsat data for this study are found in Table 3. The first range had less than one km shoreline/km^2, the second between one and two, and so on. The window used was six picture elements high and eight wide yielding a nearly square window about 465m on a side.

Approximately 10 man weeks of effort were expended in processing the Landsat data to generate the shoreline length and density products from the original data.

The shoreline length and areas of land and water derived from the Landsat imagery are presented in Table 4 for each geographic unit. The normalized area of each unit falling within each shoreline density category, the normalized shoreline length and the shoreline complexity factor are the data used in the study. The shoreline complexity factor is defined as the ratio of the actual shoreline length to that which would result from all the water being contained in a single circular lake, and is computed from the equation $Q = \frac{1}{2}S/\sqrt{\pi A}$, where S is the actual

TABLE 3

SHORELINE DENSITY RANGE

RANGE	1	2	3	4	5	6	7	8	9	10
CLASSIFICATION										
MIN DENSITY	--	1	2	3	4	5	6	7	9	11
MAX DENSITY	1	2	3	4	5	6	7	9	11	--

Density in kilometers shoreline per square kilometer

TABLE 4

BASIC LANDSAT MEASUREMENTS

GEOGRAPHIC UNIT	LAND AREA	WATER AREA	SHORELINE LENGTH
	KM^2	KM^2	KM
1	521	494	619
2	751	4344	2723
3	1080	1512	3419
4	225	1044	1318
5	2973	2243	8023
6	1268	1419	4005
7	1503	1806	4292
8	1125	1538	1642
9	2825	2516	4446

shoreline length and A is the area of water, both determined from the satellite data. It has a minimum value of 1.0, for the case of a perfectly circular lake, and increases as the number of lakes of decreasing size increases, or as the number of islands increases, or as the shoreline becomes convoluted with small bays. Shoreline length is normalized by dividing the length measurement by the total area of the geographic unit. The shoreline density measurements were normalized by dividing the area classified into each density range by the active area of the geographic unit, defined as the total area of the unit from which is subtracted the area of land not falling within 230m of the shoreline. The area of land more distant from the shoreline than 230m was a byproduct of the shoreline density measurement, as the reference element at the center of the scanning window must be at least 230m from water for the window to be completely filled with land. These data are presented in Table 5. Also included in Table 5 is the total area having shoreline density greater than 5.0 km shoreline/km^2 (range 6 and greater), normalized by the active area.

IV. ANALYSIS

The initial analytical effort was to examine correlations between the various parameters described in previous sections and the shrimp productivity as indicated by the commercial shrimp yield. Linear correlation coefficients were computed according to the relation

TABLE 5

DERIVED LANDSAT MEASUREMENTS

GEO-GRAPHIC UNIT	NORMALIZED SHORELINE LENGTH	SHORELINE COMPLEXITY FACTOR	NORMALIZED AREA X10^{-2} FOR SHORELINE DENSITY RANGE									
			1	2	3	4	5	6	7	8	9	Σ
1	0.61	7.86	9.76	10.6	11.6	5.13	3.52	1.43	.563	.198	.0017	2.2
2	0.53	11.66	3.33	3.52	4.83	2.99	1.97	1.24	.547	.275	.022	2.1
3	1.32	24.81	7.35	8.58	9.57	7.70	6.10	4.35	2.33	1.39	.095	8.2
4	1.04	11.51	4.40	4.98	7.07	4.79	3.70	2.81	1.61	1.28	.143	5.8
5	1.54	47.79	8.88	10.2	11.9	8.77	7.52	6.08	4.07	3.62	.455	14.2
6	1.49	29.00	6.74	8.16	8.77	7.92	7.16	5.99	3.69	2.71	.245	12.6
7	1.30	28.50	10.2	12.4	12.0	8.07	6.60	4.49	2.29	1.27	.0455	8.1
8	0.62	11.81	7.66	7.98	8.94	3.82	1.81	1.81	.527	.231	.0130	2.6
9	0.83	25.00	8.84	9.88	10.7	5.68	4.70	3.28	1.78	1.10	.0706	6.2

$$r = \frac{\frac{1}{n} \sum_{i=1}^{n} (x_i-\bar{x})\ (y_i-\bar{y})}{s_x\ s_y}$$

where $\bar{x}$ and $\bar{y}$ are the mean values of the parameter being tested and the shrimp yield, and s_x and s_y are the sample deviations for the parameter and the shrimp yield. They are listed in Table 6 together with the significance level of the correlations. Shrimp yield was plotted against some of the parameters with regression lines computed from the data. Figure 5 is a graph of shrimp yield as a function of the normalized shoreline length, S; figure 6 shows yield as a function of shoreline complexity, Q; and figure 7 is a plot of normalized area having a shoreline density between 5.0 and 6.0 km shoreline/km^2. Statistical models 1, 2, and 3, found in Table 7, are the least square error relationships between the shrimp yield and the respective parameters. Root mean square (r.m.s.) deviations for these models are 8.24, 8.62, and 5.73 kg/ha, respectively. The range of recorded shrimp yields is 0.29 to 45.16 kg/ha. Statistical model 4 was developed relating the area falling into ranges six through ten (>5km shoreline/km^2) to shrimp yield. R.M.S. deviation for this model was 6.49, not as good as Model 3.

The theoretical energy flow analysis discussed in Section II suggests that shrimp production should be related to the product of the area producing detritus transported into the bay-estuary system, the tidal range, and the length of the shoreline (work gate 1, equation 1). We shall assume that the area

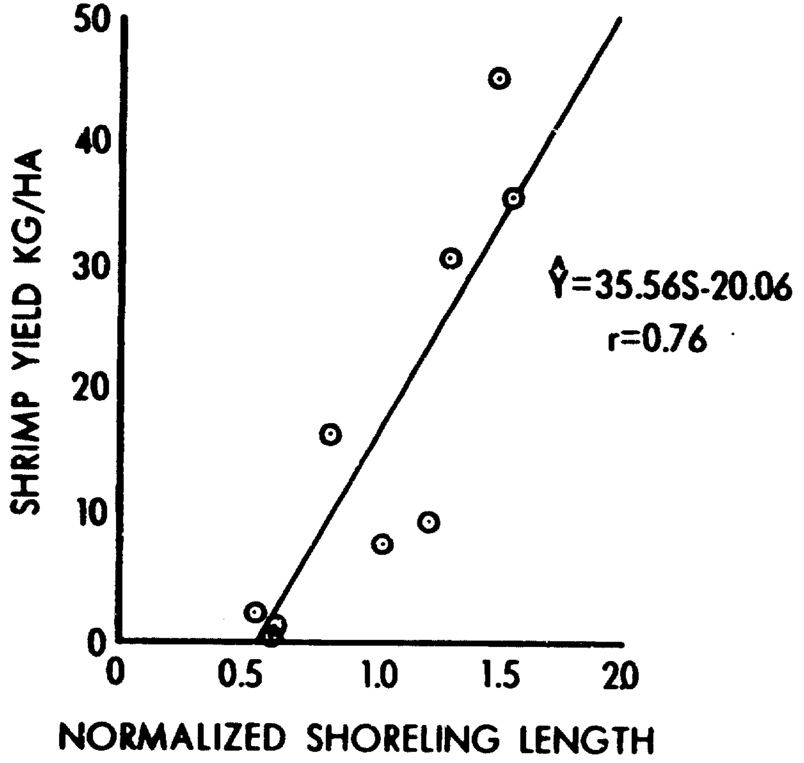

FIGURE 5. Shrimp yield plotted against normalized shoreline length, S.

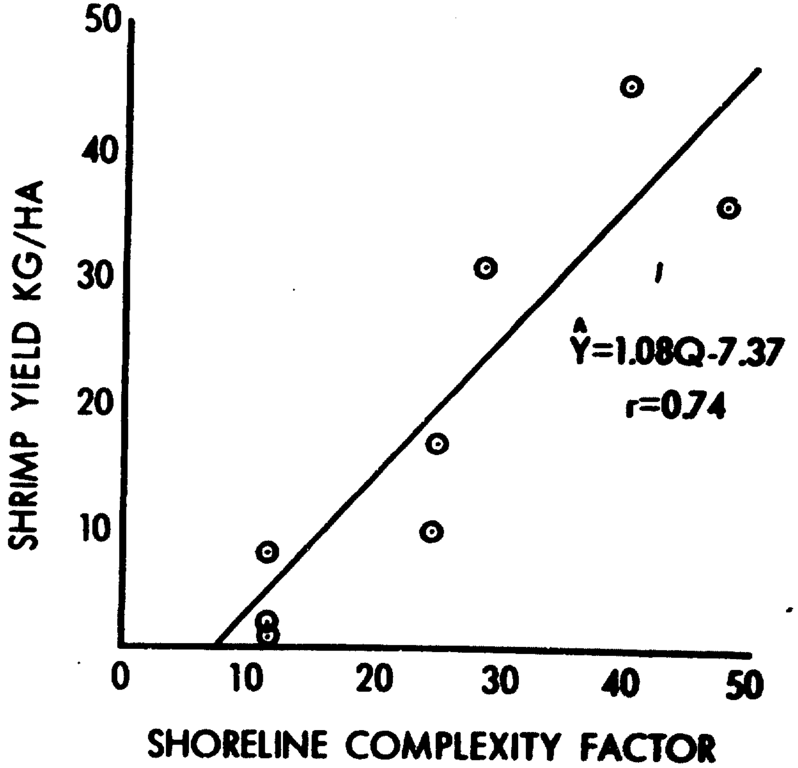

FIGURE 6. Shrimp yield plotted against Shoreline complexity factor, $Q=\frac{1}{2}S/\sqrt{\pi A}$.

TABLE 6

SHRIMP YIELD CORRELATION ANALYSIS

FACTOR			CORRELATION COEFFICIENT	SIGNIFICANCE LEVEL
Normalized Shoreline Length		S	0.76	.98
Shoreline Complexity Factor		Q	0.74	.98
Land/Water Ratio		L/W	0.43	<.80
Normalized area for Shoreline Density Range	1	a_1	0.26	<.80
	2	a_2	0.37	<.80
	3	a_3	0.23	<.80
	4	a_4	0.73	.98
	5	a_5	0.78	.99
	6	a_6	0.83	.995
	7	a_7	0.81	.99
	8	a_8	0.76	.98
	9	a_9	0.28	<.80
Tide		T	0.11	<.80
Salinity		σ	0.67	.95
Temperature		K	-0.58	.90
Normalized area for the sum of Shoreline Density Ranges 6-9		Σ	0.81	.99
		$T\Sigma$	0.77	.98
		$S\Sigma$	0.78	.99
		$ST\Sigma$	0.84	.995

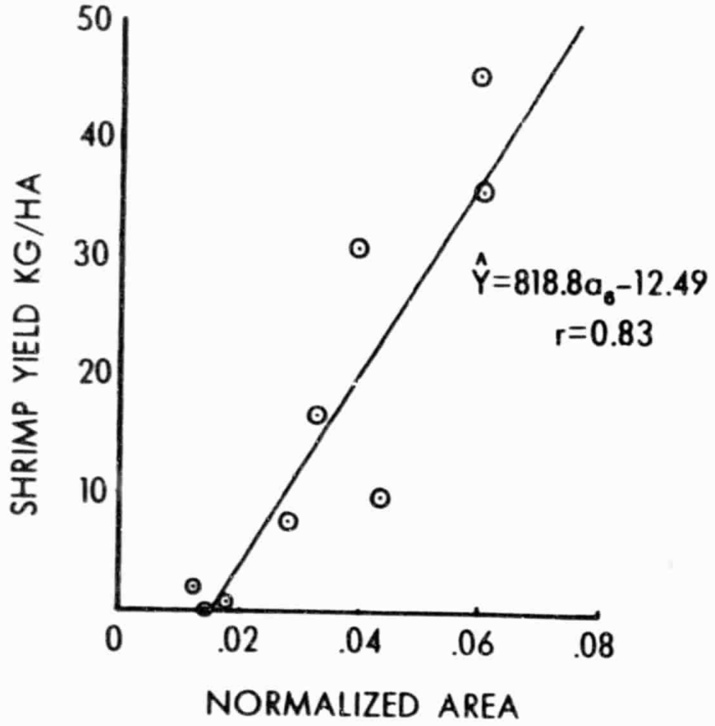

FIGURE 7. Shrimp yield plotted against normalized area with shoreline density greater than 5.0 and less than 6.0 Km shoreline/Km², a_6.

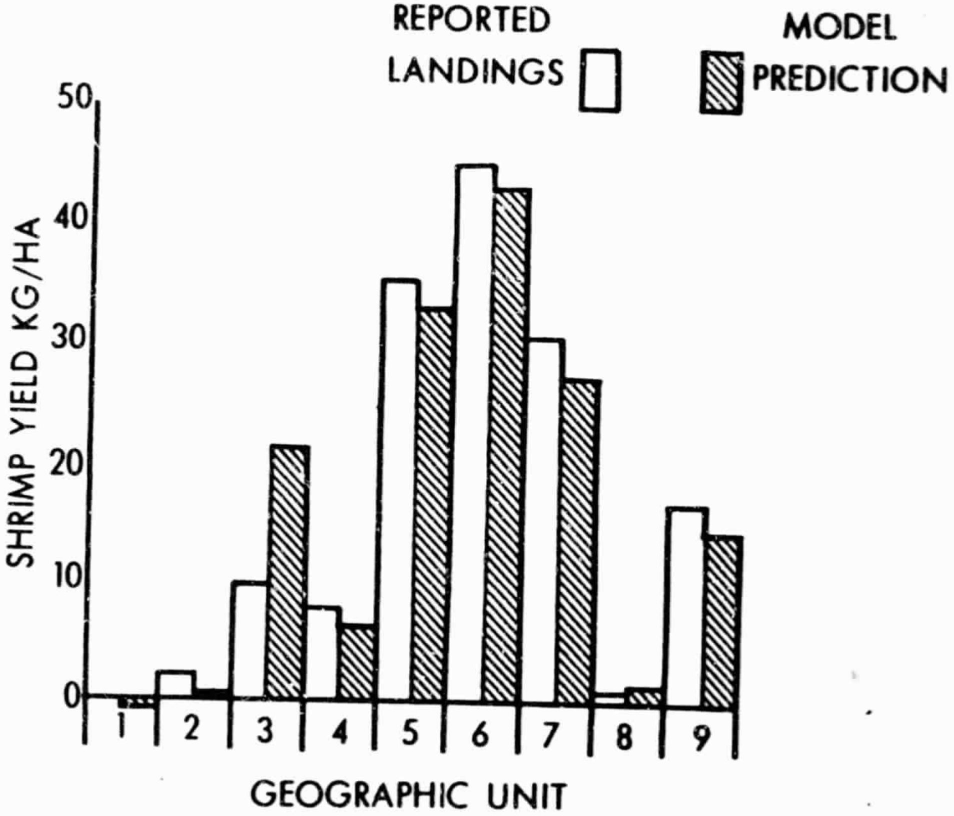

FIGURE 8. Comparison of reported commercial shrimp landings with predicted yield from Model 7, based on shoreline length, area with shoreline density greater than 5.0Km shoreline/Km², tidal range, and salinity.

TABLE 7

SHRIMP YIELD MODELS

MODEL	EQUATION	R.M.S. DEVIATION kg/ha
1	$\hat{Y} = 35.56S - 20.06$	8.24
2	$\hat{Y} = 1.08Q - 7.37$	8.62
3	$\hat{Y} = 818.8\, a_6 - 12.49$	5.73
4	$\hat{Y} = 344\, \Sigma - 7.13$	6.49
5	$\hat{Y} = 177.5\, S\Sigma T - 3.56$	4.94
6	$\hat{Y} = (186.7T - 11.35)\, S\Sigma - 3.64$	4.93
7	$\hat{Y} = (1.849\text{x}10^4\, T - 2.026\text{x}10^3) S\Sigma - 208.2\, K_\sigma$	4.36

where $K_\sigma = \dfrac{1}{27.89\sqrt{2\pi}} \exp\left\{-\tfrac{1}{2}[(\sigma - 39.57)/27.89]^2\right\}$

$$\text{R.M.S. deviation} = \sqrt{\frac{1}{N}\sum_{i=1}^{N} (Y_i - \hat{Y}_i)^2}$$

$\hat{Y}$ = predicted commercial shrimp harvest

S = normalized shoreline length

Q = shoreline complexity factor = $\frac{1}{2}S/\sqrt{\pi A_w}$

A_w = area of water

a_6 = normalized area with shoreline density greater than 5.0 and less than 6.0 km shoreline/km^2

Σ = normalized area with shoreline density greater than 5.0 km shoreline/km^2

T = mean tidal range

σ = salinity

producing detritus for export to the marine environment is proportional to the area having a shoreline density greater than 5.0 km shoreline/km^2. The product of these parameters was computed, and its correlation with shrimp yield was then determined to be 0.84, the highest of any of the parameters, and significant at 99.5% level. Model 5, the first statistical model based on ecological principles, was developed from this product and had a r.m.s. deviation from the actual shrimp yield of 4.94 kg/ha, a significant improvement over the first four models.

The theoretical discussion also suggests that the product of shoreline length and the detritus-producing area should be related to shrimp production (work gate 2, equation 2). The correlation coefficient for this factor is 0.78, but its inclusion improves the agreement between the prediction and the reported shrimp yield only slightly, resulting in a r.m.s. deviation of 4.93 kg/ha.

As stated in the theoretical discussion, salinity and temperature are controlling factors in determining shrimp production. Models were generated which incorporated these two parameters in the form of Gaussian switches. These switches were represented by factors

$$K_t = \frac{1}{\sqrt{2\pi}\ \xi_t} \qquad \exp\ \{-\tfrac{1}{2}\left[(t-\bar{t})/\xi_t\right]^2\}$$

$$K_\sigma = \frac{1}{\sqrt{2\pi\xi_\sigma}} \qquad \exp \{-\tfrac{1}{2} \left[(\sigma-\bar{\sigma})/\xi_t \right]^2\}$$

where $\bar{t}$, $\bar{\sigma}$, ξ_t and ξ_σ are fitting parameters. The first two determine the point at which the switch is completely closed, i.e., the mathematical value is maximum, whereas the latter two determine the steepness of the switching function. The temperature switch did not contribute to the model, and in fact worsened the agreement between predicted and measured shrimp yield values. The salinity switch did improve the agreement, with model 7 giving a r.m.s. deviation of 4.36 kg/ha. The model 7 prediction and reported shrimp yield are shown in Figure 8.

V. DISCUSSION

The high correlations between the shoreline-related parameters (i.e. shoreline length and complexity factor and areas with high shoreline densities) and the shrimp yield are very convincing arguments in support of the hypothesis that the shoreline is a controlling factor in the flow of energy, stored in the form of detritus and its associated micro-organisms, from the marsh ecosystem into the bay-estuary ecosystem. The accuracy of Model 5, based simply on the product of shoreline length, tidal range and area with high shoreline density, supports the hypothesis that the detritus level in the bay-estuary subsystem is the main factor in determining the relative long term shrimp productivity along the Louisiana coast and that these levels are controlled by the area producing detritus for export from the marsh and the interface between marsh and marine subsystems.

The small improvement of Model 6 over Model 5, i.e. the improvement resulting from the incorporation of the second work gate, indicates that the tide-independent flow of detritus from the marsh is not significantly different from the tide-dependent flow. The coefficients associated with the two types of flow (tide and rain driven) were very highly correlated, and in fact the coefficient associated with the rain driven flow is negative, indicating that rain driven flow of detritus is from the water to the land, an untenable conclusion. It is, of course, always dangerous to attempt to attach meaning to regression weights. This is particularly true when the two variables under consideration are highly correlated, as is the case with the two types of flow. We can conclude only that, given the small tidal range typical of the study area, the tide-dependent flow and the tide-independent flow are not statistically separable in terms of their effect on shrimp production. A single work gate would therefore suffice in place of work gates 1 and 2.

The incorporation of the salinity switch resulted in some improvement in the prediction, although this improvement is small when one considers the importance of salinity in determining the success of one season as opposed to another. The effect of salinity is most apparent in geographic unit 6, the unit having the highest salinity and greatest shrimp yield.

Model 6 predicted a yield of 39 kg/ha and Model 7 predicted 43 kg/ha, whereas the actual yield was 45 kg/ha. Models 6 and 7 differ only in the incorporation of the salinity switch. Selection of salinity data for the analysis may influence the significance implied by this analysis, as the year for which data were available may not have been typical of the five years over which the yield data were averaged. If salinity data for all five years were available, the importance of salinity in determining shrimp productivity might be more apparent in the model results. Another consideration is the salinity sampling locations. The points at which the measurements were made may not completely represent the nine geographic units, as some important portions of a given area may have a much different salinity from any of the points sampled in the unit. A mathematical form other than the Gaussian expression may also be more appropriate.

The failure of the temperature switch in the model is probably due to the fact that the temperature data used represented the season average for a single year of the five for which the shrimp data were accumulated. Replacement of these data with the average number of hours water temperature were below 20° C after the first week of April for each of the five seasons for each geographic unit would probably result in the improvement in the model.

It is apparent that the predictions for geographic unit 3, Breton Sound, are significantly higher than the actual yield. According to the model, this area should be very productive, although in fact the shrimp yield is relatively low. A possible explanation of this involves migration patterns of the larval and postlarval shrimp offshore. The higher yield areas open directly on the Gulf of Mexico west of the Mississippi River, from the mouth of which flows tremendous volumes of fresh water, whereas Breton Sound is partially cut off from the open Gulf by the discharge of the river. It has been suggested by Barret (personal communication) that the discharge of cold, fresh water by the Mississippi River may serve as a barrier interfering with the migration of postlarval shrimp found offshore, preventing them from entering the inshore waters of Breton Sound.

Unfortunately, there is no adequate data to rigorously test the statistical significance of the models. Further research should be done to include other coastal areas with large inshore and nearshore commercial shrimp harvests in the analysis so that data points not used in the determination of the model coefficients can be used in testing the model. Despite the absence of independent test data, the accuracy of the models is such that the hypothesis that the shoreline is a controlling factor in the production of shrimp through its regulation of the transport of detritus from the marshlands to the bays and estuaries (which constitute the shrimp nursery grounds and inshore harvest area) is strongly supported.

A more rigorous analysis of the satellite data would probably result in slightly better agreement between yeild predictions and actual yield, and would improve the physical interpretation of the model significantly. The current analysis assumed that the entire land area near the shoreline produced detritus uniformly. A more detailed analysis of the satellite data would differentiate vegetation species using a currently available technique and possibly estimate vegetation density (stems per square meter) using a technique under development, combine the resulting thematic with a measure of distance from shore (a measurement technique that is more available), and provide a better estimate of detritus production. With the development of the mathematical relationship between detritus production and shrimp yield, the assignment of economic value to each unit of marsh land in terms of the shrimp industry would be possible, and the impact on shrimp production of a proposed modification of the marsh could be predicted. Trends of changes taking place in the marsh, whether natural or anthropogenic, could be analyzed in the light of this relationship to forecast possible changes in future shrimp production. Satellite data can be processed quickly at a reasonable cost to survey wide areas, even in the remote coastal wetlands. The result is, quite possibly, a very powerful tool for resource management.

VI. SUMMARY

The flow of detritus from the marsh to the bays and estuaries of Louisiana appears to be a critical factor in determining the inshore shrimp productivity. The commercial harvest of shrimp reported over a five year period is highly correlated with shoreline length and complexity, and the area of land and water separated by a complex shoreline. Remote sensing techniques were used to develop a quantitative assessment of coastal shoreline features. Computer analysis of Landsat MSS data generated a map of the Louisiana coastal wetlands coordinated with shoreline length and density measurements. The techniques provided a current and accurate mapping of an area typified by constantly changing geography, at a very reasonable cost, demonstrating their potential for wide-area monitoring applications.

The geographic data derived through these remote sensing techniques were used in correlation studies to examine the relationships between them and the commercial shrimp harvest. The geographic data were then used in several statistical models in conjunction with other physical data to predict the harvest.

Landsat-based measurements of shoreline length and area of land and water having more than 5.0 km shoreline/km^2 were developed and used with published tidal ranges and salinities to predict the commercial shrimp yield for nine geographic units along the Louisiana coast with a root mean square deviation from the reported yield of 4.36 kg/ha over a range of 0.29 to 45.16 kg/ha. The mathematical model relating these parameters and the shrimp yield is consistent with an energy flow model describing the interaction of detritus-producing marshlands with shrimp nursery grounds and inshore shrimp fishing areas. The analysis of the geographic and physical parameters with the shrimp yield data thus supports the hypothesis that the shoreline is a controlling factor in the production of shrimp through its regulation of the transport of detritus.

Day et.al. (1973) observed that the most productive area of the estuary he studied in the Barataria Bay region was along the marsh-water interface. He noted that marsh grasses were often twice as high near the shore than on the interior marshlands, that the highest standing crops of marsh macrofauna and meiofauna occur in the same general area, that standing crops of organic matter and meiobenthos in the submerged sediments are higher near shore, and that benthic populations are densest near the shore. He states, "These factors suggest that overall marsh production will increase as the amount of marsh edge habitat is increased. The familar picture of salt marshes with many twisting and dendritic channels probably reflects a tendency of the estuary system to develop maximum production." What Day observed in a broad range of species of flora and fauna over a very restricted area, this study has demonstrated quantitatively for a single organism of Louisiana bays and estuaries, the penaeid shrimp, over the entire Louisiana coast.

REFERENCES

Barret, Barney B. 1971. Cooperative Gulf of Mexico Estuarine Inventory and Study, Louisiana. Phase II, Hydrology and Phase III, Sedimentology. Louisiana Wildlife and Fisheries Commission, New Orleans, La.

Barret, Barney B., and Marilyn C. Gillespie. 1973. Primary Factors which Influence Commercial Shrimp Production in Coastal Louisiana. Technical Bulletin No. 9. Louisiana Wildlife and Fisheries Commission, New Orleans, La.

Carter, M.R., L.A. Burns, T.R. Cavinder, K.R. Dugger, P.L. Fore, D.B. Hicks, H.L. Revells, and T.W. Schmidt. 1973. Ecosystems Analysis of the Big Cypress Swamp and Estuaries. United States Environmental Protection Agency Region IV. Atlanta, Ga.

Day, J.W., Jr., W.G. Smith, and C.S. Hopkinson, Jr. 1972. Some Trophic Relationships of Marsh and Estuarine Areas. Proceedings of the Coastal Marsh and Estuary Management Symposium. Louisiana State University. pp 115-135.

Day, J.W., W.G. Smith, P.R. Wagner, and W.C. Stowe. 1973. Community Structure and Carbon Budget of a Salt Marsh and Shallow Bay Estuarine System in Louisiana. Publication No. LSU-SG-72-04. Louisiana State University, Baton Rouge, La.

Faller, K.H. 1977. A Procedure for Detection and Measurement of Interfaces in Remotely Acquired Data Using a Digital Computer. NASA TR R-472.

National Ocean Survey, 1978. Tide Tables. High and Low Water Predictions, East Coast of North and South America including Greenland. U.S. Department of Commerce, National Oceanic and Atmospheric Administration.

Odum, W.E., J.C. Zieman, and E.J. Heald. 1972. The Importance of Vascular Plant Detritus to Estuaries. pp 91-114. Proceedings of the Coastal Marsh and Estuary Management Symposium, R.H. Chabreck, ed. Louisiana State University.

Palmisano, A.W., Jr. 1970. Plant Community-Soil Relationships in Louisiana Coastal Marshes. PhD. Dissertation, Louisiana State University.

Schelske, C.L. and E.P. Odum. 1961. Mechanisms Maintaining High Productivity in Georgia Estuaries. Proc. Gulf Carib. Fish. Inst., 1975-80.

Stern, D.H., and B.H. Atwell. 1968. A Summer Limnology Study of Lake Pontchartrain, Louisiana. Louisiana Water Resources Research Institute, Technical Report No. 3, Louisiana State University.

Teal, J.M. 1962. Energy Flow in the Salt Marsh Ecosystem of Georgia. Ecology, 43(4): 614-624.