Estuaries: Case Studies

RECLAIMING FILLED ESTUARINE AREAS THROUGH DEVELOPMENT: PORT LIBERTÉ, A CASE STUDY

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Introduction

In 1985, construction began on a residential community that was to be located along a series of interconnected canals excavated from a previously filled estuarine area. The area, Caven Point in southern Jersey City, N.J., presently comprises an approximately 154-acre waterfront site along Upper New York Bay. However, only the extreme northern end of the project site occupies a natural land surface. Approximately 95 percent of the site, or more than 145 acres, had been filled into the estuary since the mid-1800s. This paper seeks to demonstrate that initial canal excavation has created or, rather, reclaimed previously filled estuarine area and, further, that the canal habitat created constitutes a valuable aquatic habitat.

Background

Between the years 1940 and 1945, the site achieved its present-day configuration due to the activities of the U.S. Army. The 1846 Map of New York Bay (Figure 1) illustrates the future Port Liberté project site as a trapezoidal figure jutting out into the Upper Bay. Beginning in 1941, the U.S. Army, spurred by World War II, purchased this last undeveloped portion of the Jersey City Waterfront and immediately embarked on a land reclamation and construction program. The early stages of the Army's filling operation are reflected on maps dating from the early 1940s (Figure 2) (Kardas and Larrabee, 1978).

The property acquired by the Army in 1941 was largely made up of land submerged under several feet of water. "The army filled it in and dredged both sides of the terminal sufficiently to dock vessels drawing 40 feet ...," creating a facility of some 700 acres. "The terminal, a vital army transport center during the war, served as an ordnance loading depot and later as a staging area for German and Italian prisoners of war (*Jersey Journal* Aug. 17, 1948)." With the end of the war, however, the Caven Point Army Terminal quickly fell into disuse, and by 1948 the Army was reportedly considering selling the property.

However, the Army decided to maintain the terminal, possibly as a result of the threat of war in Korea. The U.S. Geological Survey map of Jersey City in 1955 depicted the Caven Point Army Terminal as it had been created during World War II (Figure 3). Visible on the map was the huge land mass between the petroleum tank farm and the Claremont Terminal Channel which held the Army Terminal. Roads and railways ran generally southeast to the very tip of the "new" Caven Point where an extremely long dock, Caven Point Pier, provided the necessary connection to the deepwater Claremont Terminal Channel. Army structures were clustered at the west end of the terminal and at the tip of the point. The "old" Caven Point had been totally buried (with the narrow strip of upland having possibly been levelled) during the Army's filling activities (Kardas and Larrabee, 1978). Such was the present configuration of the site when the westernmost portion was re-acquired by Jersey City and slated for residential development.

Ecological Significance of the Site

Immediately to the east and northeast and contiguous with the Port Liberté site, the New Jersey Department of Environmental Protection and Energy acquired the Caven Point Natural Area; an area comprised of 22 upland acres and 214 riparian acres within Caven Cove. Within the natural area, the upland beach area, fronting the eastern edge of the site, is primarily vegetated with panic grass (*Panicium* sp.) and beach grass (*Ammophila* sp.) with a band of *Phragmites* running parallel to the shoreline. The natural area is bounded on the south by the Caven Point Pier, extensively used by fisherman throughout the year and by birdwatchers searching for rare gulls or Snowy Owls in the winter. On the north is Liberty State Park.

Stretching waterward from the upland beach, small but elegant tidal marshes fringe part of Caven Cove. Both low marsh cordgrass (*Spartina alterniflora*), and high marsh salt hay (*S. patens*) are present and healthy. The marsh is exceedingly important because it provides habitat for such species as the ribbed mussels (*Modiolus demissus*), bait fish, including Atlantic silversides (*Menidia menidia*) and killifish (*Fundulus* sp.), young game fish and waterbirds. The marshes are continuing to build as new, colonizing rhizomes stretch out into the tidal mudflat. The *S. patens* area (about 3/4 acre) is the northernmost salt hay community on the Hudson River Estuary.

A tidal mudflat fringes the sandy beach, extending the full length of the beach from the Caven Point Pier to the end of the peninsula and wrapping around to a small cove that is almost entirely exposed on a low tide. Though small in area, the benefits from the Caven Point Natural Area are great, precisely because it is protected and is not designated as a recreation area. Caven Cove is important as: a year-round residence for fish that are important food sources for larger fish, such as Bluefish (*Pomatomus saltatrix*) and Striped Bass (*Morone saxitilis*), a nursery for a large number of fish species—almost 70 percent of the fish collected prior to its designation as a Natural Area were juveniles—and a wintering and migrating stop-over area for geese, ducks, gulls, terns and shorebirds. The New Jersey Division of Fish, Game and Wildlife has assessed Caven Cove as one of the most important habitats in the New Jersey portion of the lower Hudson River for diving ducks (DRT, Inc., 1984). Indeed Caven Point is one of the last relatively undisturbed examples of the Hudson River estuary (Clarke and Burger, 1987).

The Development

Thus, within the context of the Caven Point Natural Area and the significance of its ecological aspects, the canal development of Port Liberté was spawned.

To date, Phase I of the five-phase project has been completed, representing approximately four to five acres of open water canal of the planned 25-acre total (Figure 4). The Phase 1 canal system has been excavated to a depth of approximately 10 feet mean low water. The upper 8 to 10 feet of material excavated consists of the original marine sands that were dredged from other areas of the New York Bight and used as fill. The lowermost extent of excavation roughly corresponds to the location of the meadowmat or original marine substrate.

Sampling Programs

Beginning in 1985 and concurrent with Phase 1 construction, a comprehensive monitoring program was conducted which included avian, aquatic resource, and water quality studies. Avian studies consisted of regular shorebird and waterfowl censusing and specific "disturbance" studies to determine the effects of certain phases and types of construction activity (Burger, 1989).

Water quality studies are conducted bi-weekly from May through October and bi-monthly thereafter. Parameters evaluated include dissolved oxygen; total and fecal coliform and fecal strep; BOD; pH; salinity; conductivity and temperature at surface and bottom depths (DRT Inc., 1991).

Aquatic resource studies consisted of originally seven, now five, fisheries surveys per year. Fisheries resources are sampled with a variety of techniques including trawl, seine and trap net. The final fall fisheries surveys of each year also include collection and analysis of benthic samples at eight locations (CES Inc., 1989).

Discussion

Comparison of the Phase 1 canal ecosystem with data collected outside the canal system indicated that the canal is functioning to provide very suitable aquatic habitat.

Regarding water quality (Figure 5), the summer dissolved oxygen (DO) levels within the canal tended to remain within an acceptable range except for a late July/early August period in 1988. Since recording these DO values, Port Liberté has experimented with two types of aeration systems to prevent future depressions. Coliform and fecal strep counts within the canal system (not illustrated) have generally been below the values recorded within the outside ambient waters.

Fisheries resources within the canal system (Area V) tend to be similar in number, when compared to non-canal locations as measured by Catch-per-Unit-Effort, but greater in diversity of species (Table 1).

Benthic resource data, though not included in this paper, likewise indicate that the benthic assemblage of the canal system was similar in density and species composition to samples collected along the Caven Point Pier. The canal bulkheads, floating docks and pilings provide substrate for a wide range of encrusting organisms, including barnacles, tunicates and various macro-invertebrates.

Thus, from review of the data collected to date, excavation of the canal system at Port Liberté is providing significant reclaimed, productive estuarine habitat in this portion of the Upper New York Bay.

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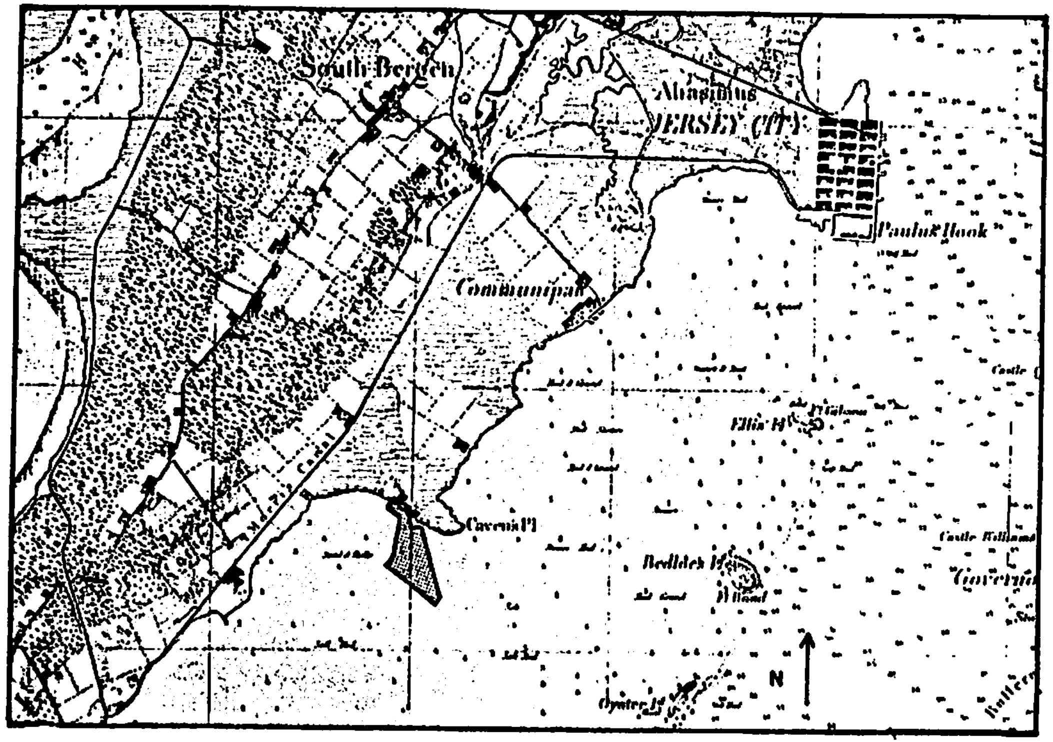

Figure 1. 1846 map of New York Bay illustrating the future Port Liberté project site as a trapezoidal figure juttingout into the Upper Bay (Kardas and Larrabee, 1978).

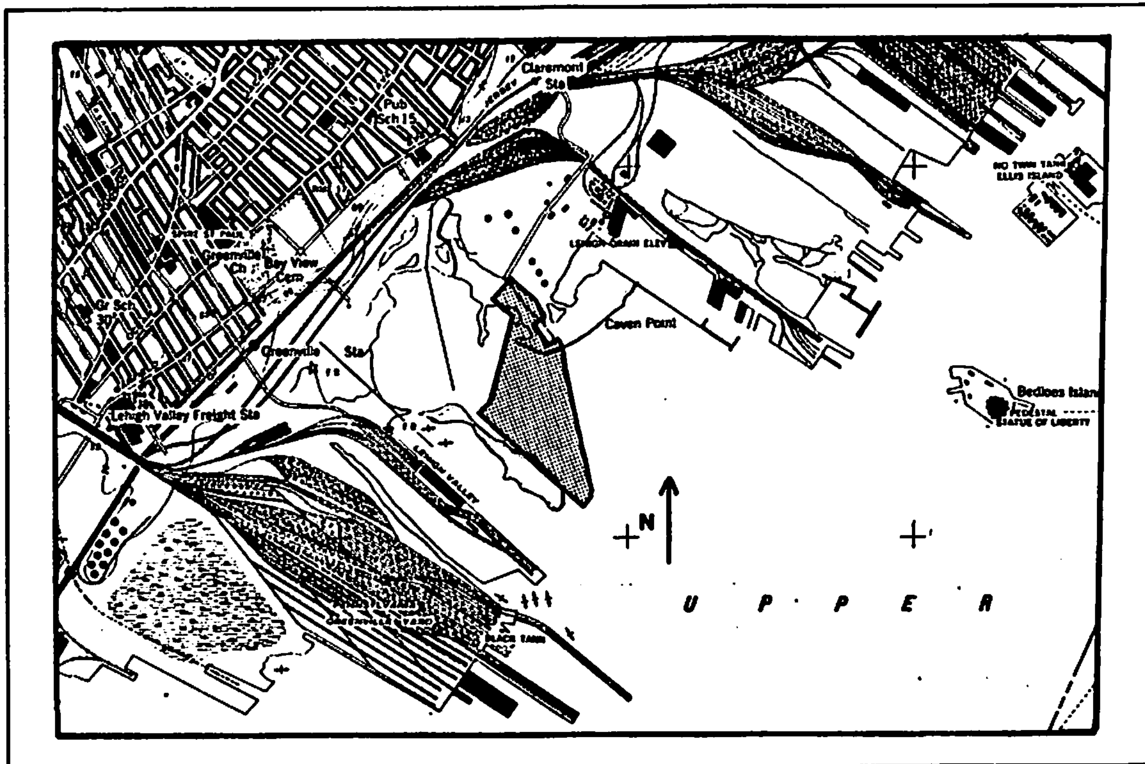

Figure 2. Map of New York Bay from the early 1940s reflecting the early stages of the Army's filling operation (Kardas and Larrabee, 1978).

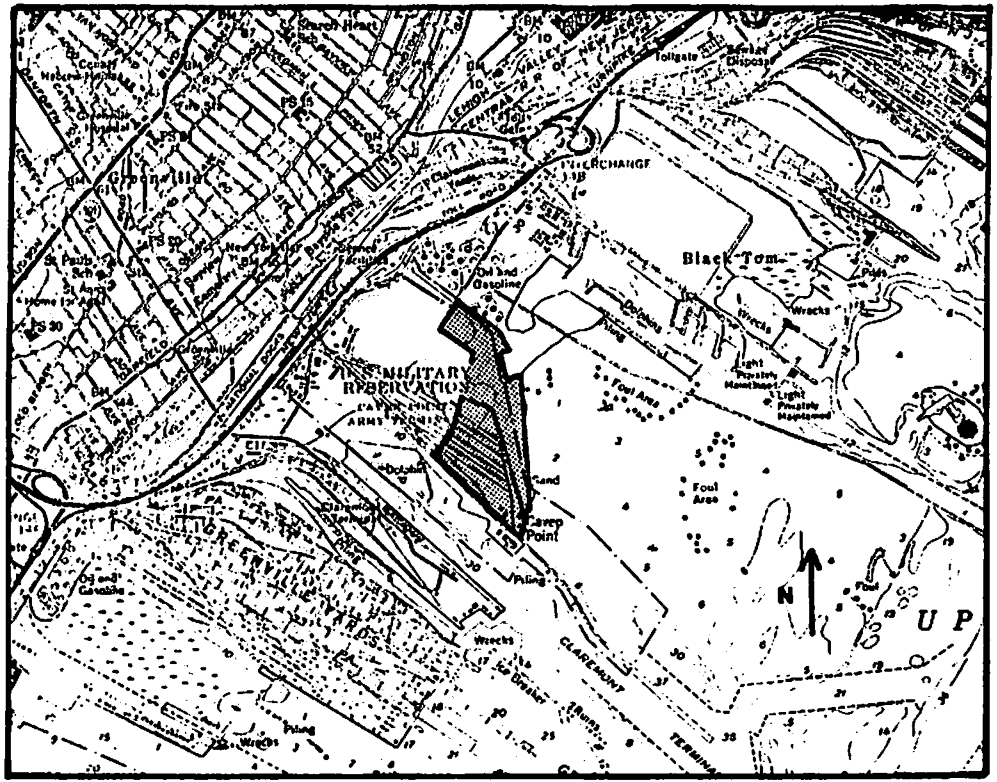

Figure 3. 1955 U.S. Geological Survey map of Jersey City, depicting the Caven Point Army Terminal created during World War II.

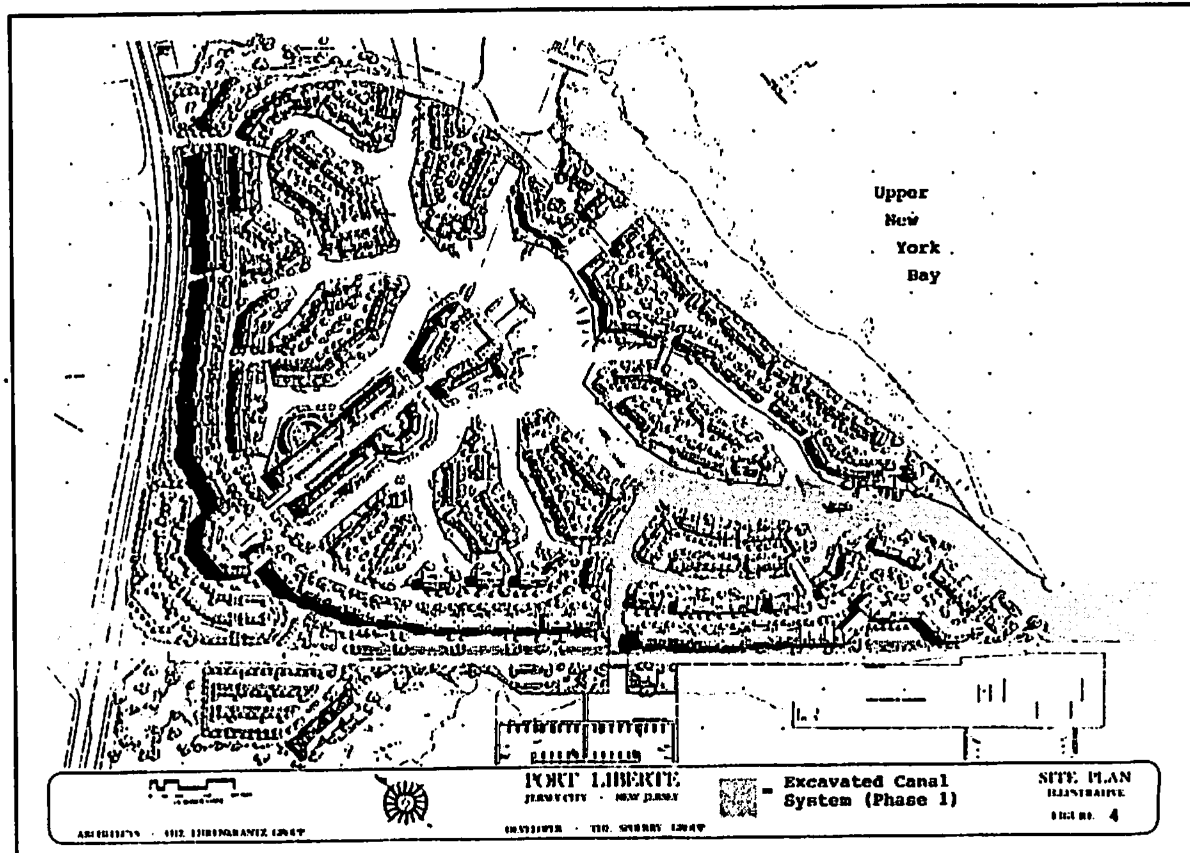

Figure 4. Architect's plan for Phase I of the Port Liberté project.

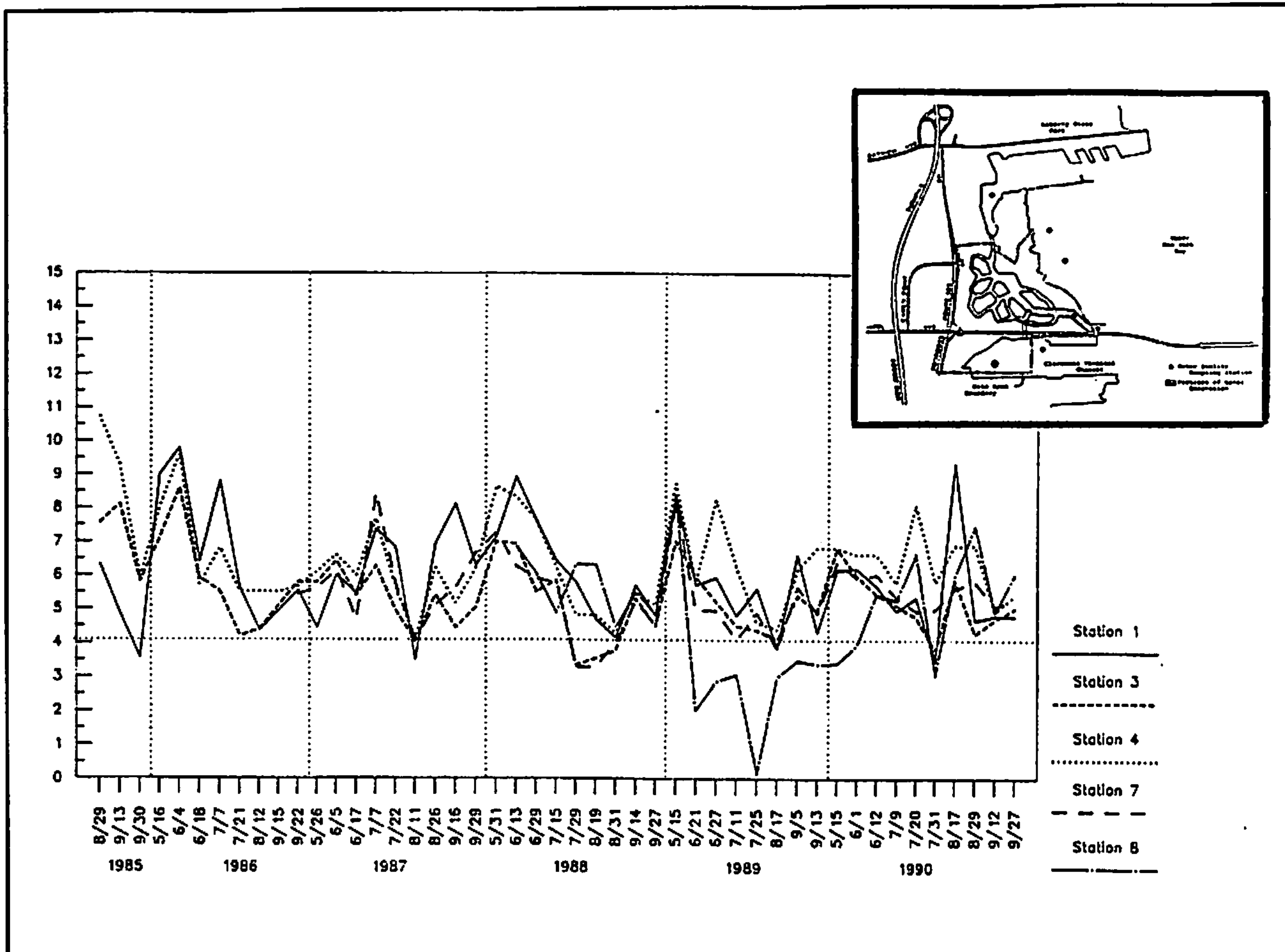

Figure 5. Summer dissolved oxygen levels at Port Liberté, 1985-1990.

Area I

Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Striped Bass	1	.	.	.	.	3	.	6	1	.	.	.	.	15	2	1
W. Flounder	5	1	1	.	.	4	1	.	2	.	1	4	9	17	6	.
S. Flounder	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.
A. Tomcod	97	.	.	.	.	.	.	.	.	.	4	8	5	12	.	.
A. Silversides	.	.	.	.	.	.	.	.	.	4	.	.	2	.	.	.
B. Anchovy	119	2	32	.	.	.	.	6	1	.	.	2	27	.	.	.
A. Shad	1	.	.	1	.	1	.	.	.	.	.	.	.	.	.	.
Tautog	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
W. Perch	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Weakfish	.	.	.	.	.	.	.	.	.	.	.	.	103	.	.	.
A. Herring	2	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.
Blueback Herring	.	.	.	.	.	.	.	.	7	.	1	.	.	.	.	.
Bluefish	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Pollack	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Pipefish	.	.	.	.	.	.	.	.	.	.	.	1	1	.	.	.
Oyster Toadfish	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Goby	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.
Red Hake	.	.	.	.	.	.	.	.	.	.	2	.	.	1	.	.
Small-Mouth Flounder	.										1	.	.			
Cunner	.										.	.	.			
Kingfish	.										.	.	.			
Puffer	.										.	.	.			
Crevallejack	.										.	.	1			
Lookdown	.										.	.	1			
Butterfish	.										.	.	5			
Spot	.										.	.	11			
Searobin	.										.	.	2			
Windowpane	.										.	.	1			
Threadfin	.										.	.	.			
Hogchoker	.										.	.	.			
Longhorn Sculpin	.										.	.	.			
American Eel	.										.	.	.			
A. Menhaden	.										.	.	.			
Inshore Lizard Fish	.	.	.	.	.	.	.	.	.	.	.	.	.			

Area IV

Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Striped Bass	.	.	.	.	.	2	.	.	2	.	1	.	.	6	.	.
W. Flounder	.	.	.	.	.	1	.	.	1	.	1	.	.	6	.	2
S. Flounder	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.
A. Tomcod	.	.	.	.	.	.	5	.	.	.	.	.	.	.	.	.
A. Silversides	.	.	.	14	1	.	.	.	.	.	.	.	.	.	.	.
B. Anchovy	3	.	.	.	.	.	.	73	.	.	.	.	13	.	.	.
A. Shad	.	.	.	16	.	.	.	.	.	.	.	.	.	.	.	.
Tautog	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
W. Perch	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.
Weakfish	.	.	.	.	.	.	.	.	.	.	.	.	3	.	.	.
A. Herring	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Blueback Herring	.	.	.	.	.	.	.	.	6	.	.	.	.	.	.	.
Bluefish	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Pollack	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Pipefish	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Oyster Toadfish	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.
Goby	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Red Hake	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Small-Mouth Flounder														.	.	.
Cunner														.	.	.
Kingfish														.	.	.
Puffer														.	.	.
Crevallejack														.	.	.
Lookdown														.	.	.
Butterfish														.	.	.
Spot														.	.	.
Searobin														1	.	.
Windowpane														.	.	.
Threadfin														.	.	.
Hogchoker														3	.	.
Longhorn Sculpin														.	.	.
American Eel														.	.	.
A. Menhaden														.	.	.
Inshore Lizard Fish														.	.	.

Area V (Canal Trawl)

Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Striped Bass	.	.	.	.	.	1	1	.	2	1	1	.	.	49	.	3
W. Flounder	.	.	2	1	.	.	4	.	7	1	2	.	4	8	1	1
S. Flounder	.	1	.	1	.	.	1	.	.	.	.	14	.	2	.	.
A. Tomcod	.	.	.	.	.	.	40	.	.	.	87	.	2	.	.	.
A. Silversides	.	.	.	.	1	.	6	.	.	25	.	.	13	.	.	.
B. Anchovy	.	6	22	.	.	.	.	.	.	.	.	.	.	.	.	.
A. Shad	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Tautog	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
W. Perch	.	2	.	.	.	.	.	.	.	.	.	.	.	1	.	.
Weakfish	.	.	.	.	.	.	.	.	.	.	.	.	40	.	.	.
A. Herring	.	.	.	.	.	.	4	.	7	6	.	.	.	.	.	.
Blueback Herring	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Bluefish	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.
Pollack	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Pipefish	.	.	.	.	.	.	.	.	1	.	.	.	2	.	.	.
Oyster Toadfish	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Goby	.	.	.	.	.	.	.	.	.	1	.	.	2	.	.	1
Red Hake	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.
Small-Mouth Flounder	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.
Cunner	.	.	.	.	.	.	.	.	.	.	.	.	2	.	.	.
Kingfish	.	.	.	.	.	.	.	.	.	.	.	.	3	.	.	.
Puffer	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Crevallejack	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Lookdown	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Butterfish	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Spot	.	.	.	.	.	.	.	.	.	.	.	.	6	.	.	.
Searobin	.	.	.	.	.	.	.	.	.	.	.	.	4	.	.	.
Windowpane	.	.	.	.	.	.	.	.	.	.	.	.	2	.	.	.
Threadfin	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Hogchoker	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Longhorn Sculpin	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
American Eel	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A. Menhaden	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Inshore Lizard Fish	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1

1 = 5/15/86
2 = 8/05/86
3 = 10/22/86
4 = 11/19/86
5 = 2/02/87
6 = 4/01/87
7 = 5/13/87
8 = 9/09/87
9 = 11/18/87
10 = 3/22,23/88
11 = 4/27,28/88
12 = 6/23,24/88
13 = 8/23,24/88
14 = 11/28 - 30/88
15 = 3/14,15/89
16 = 9/21,22/89

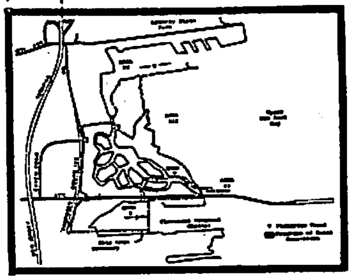

Table 1. Port Liberté trawl results for selected species, May 1986-Sept. 1989 fisheries monitoring trawls. Insets list dates of surveys and depict sampling areas.

DISTRIBUTION OF SUSPENDED SEDIMENT AND CHLOROPHYLL-A IN NORTH INLET, S.C.: A BIOLOGICAL AND PHYSICAL APPROACH

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Abstract

Multivariate regression analysis was used to test for relationships between the biological, physical and optical properties in the water column of the North Inlet estuary. Light transmissivity measurements were made at a wavelength of 630 nm over a 10-cm-pathlength cell. Suspended sediment, chlorophyll-a and tidal angle influenced 70 percent of the variability in transmissivity. The methodology used in this study may provide other scientists with a way of correlating biological and physical constituents with light transmissivity and consequently reducing the amount of field work that goes into a water quality analysis study.

Introduction

Light transmissivity has been used as a measure of different water quality constituents by physical geographers, hydrologists and oceanographers for the past few decades. Numerous attempts have been made to quantify the optical measurements made by a transmissometer (Wells and Kim, 1991; Vant, 1990; Campbell and Spinrad, 1987; Bishop, 1986; Hoskin et al., 1978). Most of the studies used light transmissivity as an indicator of suspended sediment concentrations. In most cases, the regression of transmissivity on suspended sediment produces less-than-desirable coefficients of determination. Quantification of these measurements is important because it allows scientists to understand the relationships between different water quality constituents assessed in the x, y and z spatial planes of a water body.

It is important to understand how radiant energy is transferred as it passes through the water column, because most photosynthetic activity will occur above a certain intensity (Thompson et al., 1979). The amount of light at any given depth is controlled by absorption and scattering within the water column (Lillesand and Kiefer, 1987). In estuarine waters, particulate matter, such as suspended sediment, humic acids, and nutrients, can cause selective absorption and scattering, reducing the amount of short-wavelength energy reaching a given depth in the water column. Large concentrations of dissolved and suspended matter in surface waters limit light availability to the bottom waters of the estuary, resulting in reduced phytoplankton concentrations (Peterson and Festa, 1984). Phytoplankton absorb light at wavelengths between 400 nm and 700 nm. Because most transmissometers have beams that operate at wavelengths between 600 nm and 700 nm, phytoplankton affect the amount of light measured by such transmissometers.

The main benefit of relating transmissivity to the aforementioned water quality constituents is the ease at which a transmissometer can be used in field studies. When a transmissometer is coupled with a CTD unit and in situ fluorometer, direct measurements of the different water quality constituents can be easily made. Otherwise, measurement requires collecting numerous water samples and lengthy, time-consuming laboratory analyses. Thus it becomes important to derive accurate statistical correlations between the biological/physical variables and transmissivity.

This study focused on the biological and physical processes related to the distribution of total suspended sediment and phytoplankton in North Inlet, S.C. During three days of June 1991, an intensive field study was conducted on the physical, biological and optical properties within the water column of North Inlet. The purposes of this study were to determine the spatial distribution of suspended sediment and chlorophyll and to establish multivariate statistical correlations between the different biological/physical constituents and transmissivity.

Methods

Study Site. North Inlet, S.C., (lat N33° and long W77°) is an estuarine system located on the southeastern coast of the United States, and has been a National Science Foundation Long Term Ecological Research site since 1981. The inlet is used for recreational boating and fishing. Extensive salt marshes and creeks are located throughout it, and the surrounding watershed is primarily devoid of industry and urban development. It is extremely diverse in terms of its species and dissolved/suspended material within the water column. No major rivers or streams empty directly into it, but the system receives some fresh water from Winyah Bay to the south (Kjerfve et al., 1982). The estuary experiences semidiurnal tides with a mean range of 1.7 m (NOAA, 1992).

Sampling and Measurement. The field sampling program involved longitudinal sampling along Town Creek, from the mouth of North Inlet to 5.5 km inland, (Figure 1) to measure longitudinal-vertical chlorophyll, salinity, suspended sediment, temperature, transmissivity and velocity. Longitudinal sampling along Town Creek was scheduled on three days: 16 June, 22 June and 30 June 1991, providing sampling during spring, normal and neap tides, respectively. Depth profiles (surface, mid-depth and bottom) of chlorophyll, salinity, suspended sediment, temperature and transmissivity were taken at 10 stations (Table 1) along Town Creek using a Niskin water sampling bottle, SeaTech transmissometer and YSI temperature probe. Samples were taken during both slack high and slack low at each station, beginning at Station 1 near the mouth of North Inlet and ending approximately two hours later at Station 10 near Sixty Bass Creek.

Sixty profiles were obtained during the longitudinal cruises. Whenever samples were contaminated by mud-fouling, surface readings were recorded before sensors had equilibrated, or transmissivity readings were altered by reflected sunlight, data were discarded and the area was resampled immediately. Temperature, transmissivity (10-cm-pathlength) measurements were made and recorded in situ. Water samples collected in the field were refrigerated at constant temperature for later analysis.

Chlorophyll-a Analysis. Ten ml of water was extracted from each water sample and filtered through a 0.45-μm-pore-size glass-fiber filter. The filter was placed in a scintillation vial and 1 ml of magnesium carbonate added. Each scintillation vial, holding one filter, was frozen for 48 hours, after which 9 ml of acetone (100% extract) was added. The samples were then placed in a refrigeration unit for an additional 48 hours and stirred once every 24 hours. After 48 hours, the fluorescence of the samples was determined using a Turner fluorometer and following the procedures of Parsons et al. (1985). The amount of chlorophyll-a was determined from the expression:

$$\text{mg chlorophyll-a/m}^3 = F_D \times 2.10(R_B\text{-}R_A)v/V$$

with F_D: 1x = 0.8523, 3x = 0.3012, 10x = 0.1175 and 30x = 0.0403. Standard deviation between field replicates was determined to be 0.5 mg/m^3 in a previous study (Althausen and Pinckney, unpubl. data).

Salinity Analysis. Twenty ml of water was run through a Custom Acoustics Induction Salinometer Model 2100 for salinity determination. Each sample was run in duplicate, and the mean tabulated. Instrument accuracy was ±0.05 ppt.

Suspended Sediment Filtration. The techniques of Schubel (1967) for measuring suspended sediment concentrations by filtration were followed. Pre-weighed, dried, and desiccated glass-fiber, 0.45-µm-pore-size filters were used. For each analysis, as much as 500 ml of water was pumped through the filter. Each filter with sediment was dried, desiccated and re-weighed. The weight of suspended sediment per volume of water (mg/l) was calculated for each sample, using the difference between "after" and "before" filter weights divided by the volume of the water sample. Standard deviation between field replicates was determined to be 2.0 mg/l in a previous study (Althausen and Pinckney, unpubl. data).

Data Analysis. Each of the water quality constituents examined can cause selective scattering and absorption of light in an estuary. The amount of light transmitted through a water column is thus dependent upon the biological and physical elements present. Chlorophyll-a, salinity, suspended sediment, temperature and tidal angle (Pinckney and Zingmark, 1991) were chosen as independent variables representing the biological and physical elements, because each varies in quantity in three spatial dimensions and does not usually significantly influence the others in an estuary. Statistical analysis was performed on each data set to see if any correlations could be found for the different variables. To carefully examine the critical effects that chlorophyll-a, salinity, suspended sediment, temperature and tidal angle can have on transmissivity, a stepwise multiple regression (Wolpert, 1964) was performed on each data set. The regression analysis was aimed at determining the extent to which independent variables explain the variance in transmissivity (dependent variable).

Results and Discussion

Summary statistics for the water quality variables measured in this study are given in Table 2. Average water temperatures for the June sampling period were between 25°C and 31°C, and no temperature stratification was identified. Salinity values ranged between 32 ppt and 35 ppt, and no stratification was observed due to the well-mixed conditions of the system. Suspended sediment concentrations varied between 5 mg/l and 55 mg/l. Greatest concentrations were found near the bottom during low tide. Chlorophyll-a values fluctuated throughout the estuary (5 mg/m^3 to 15 mg/m^3); in general, low-tide values exceeded high-tide values. The greater concentrations of suspended sediment and chlorophyll during low tide is most likely due to the resuspension of phytoplankton and sediment during ebb tide.

The relationship between chlorophyll-a and suspended sediment is important for an estuary that has a well-developed turbidity maximum zone (TMZ) and chlorophyll maximum zone (CMZ) (Cochlan et al., 1990). High concentrations of chlorophyll-a are usually found near the upstream boundaries of the TMZ (end of the estuarine mixing zone), where the nutrient-limiting/light-limiting boundary occurs in an estuary (Pennock, 1985). Because North Inlet receives very little fresh water discharge, partially mixed conditions, usually associated with the TMZ and CMZ, do not exist. The persistent well-mixed conditions, identified with Town Creek, reduce the likelihood that a TMZ or CMZ will form.

A transmissometer was used to make optical measurements at a wavelength of 630 nm over a 10-cm-pathlength cell. Variables that can affect light transmissivity in an estuary include suspended sediment, salinity, nutrients, humic acids, chlorophyll and plankton patches/blooms (Fisher et al., 1988). Variability in transmissivity can be attributed to the high residuals associated with a transmissometer reading. The transmissometer used in this study showed a ±5-percent variation in reading over a 30-second period over a fixed position near the bottom of the water column.

When suspended sediment was linearly regressed on transmissivity (Figure 2), a relatively poor correlation was found (r^2 = 0.37). This poor correlation suggested that other variables were involved in explaining the variance associated with light transmissivity. A stepwise multiple regression analysis was then carried out to see if a statistical model could be found to explain most of the variance associated with light transmissivity. Chlorophyll-a, salinity, suspended sediment, temperature and tidal angle were placed into the stepwise regression with the hopes of separating the variables causing the critical effects, from the variables that were not playing a significant role in explaining the light transmissivity. The t-values were used for significance testing of all five independent variables. The stepwise regression showed that chlorophyll-a (CHLA), suspended sediment (SS) and tidal angle (TANG) all play a significant role in explaining the variance (R^2 = 0.70) associated with light transmissivity (TMS) (Figure 3). The multiple regression is expressed by:

$$TMS = 83.75 - (0.94 * CHLA) - (0.90 * SS) + (4.24 * TANG)$$

Salinity and temperature were rejected by the stepwise regression because of their collinearity with chlorophyll-a. The collinearity most likely resulted from the estuary's well-mixed conditions.

Conclusions

When multiple regression analysis is used to evaluate correlations between biological/physical water constituents and transmissivity, significant coefficients of multiple determination are found. In past studies, transmissivity usually has been used to determine the amount of suspended sediment present in the water column (Campbell and Spinrad, 1987; McCarthy et al., 1974). Although those studies produced some meaningful results, the present study suggests that if other biological/physical variables had been included with suspended sediment in a regression with transmissivity, the results would have been more significant. It is hoped that future studies will be able to use the methods described here to correlate biological and physical constituents with transmissivity and, consequently, to reduce the amount of field work required for a water quality analysis study.

Some of the unexplained variability associated with transmissivity that was not accounted for can most likely be associated with the other biological/physical constituents, such as humic acids, nutrients and freshwater discharge, that were not tested for in this study.

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Table 1. Location of longitudinal sampling stations.

Station	Name	Distance (km) from Mouth
1	North Inlet Mouth	0.0
2	Jones Creek	1.1
3	Debidue Creek	2.0
4	Lone Tree	2.7
5	Old Man's Creek	3.0
6	Shoal Point	3.3
7	Shoal Bend	3.7
8	Clambank Creek	4.2
9	Oyster Landing	5.0
10	Sixty Bass Creek	5.5

Table 2. Basic summary statistics for North Inlet data set.

Variable	n	Mean	Std. Dev.	Minimum	Maximum
Chlorophyll-a (mg/m^3)	179	7.48	3.01	3.82	15.81
Salinity (‰)	179	34.00	0.87	31.98	35.23
Suspended sediment ($mg \cdot l^{-1}$)	179	17.20	4.78	7.50	33.50
Temperature (°C)	179	28.61	1.99	25.30	33.60
Tidal angle ($\cos\theta$)	179	0.10	0.77	-1.00	+1.00
Transmissivity (%)	179	61.59	9.27	36.79	77.12

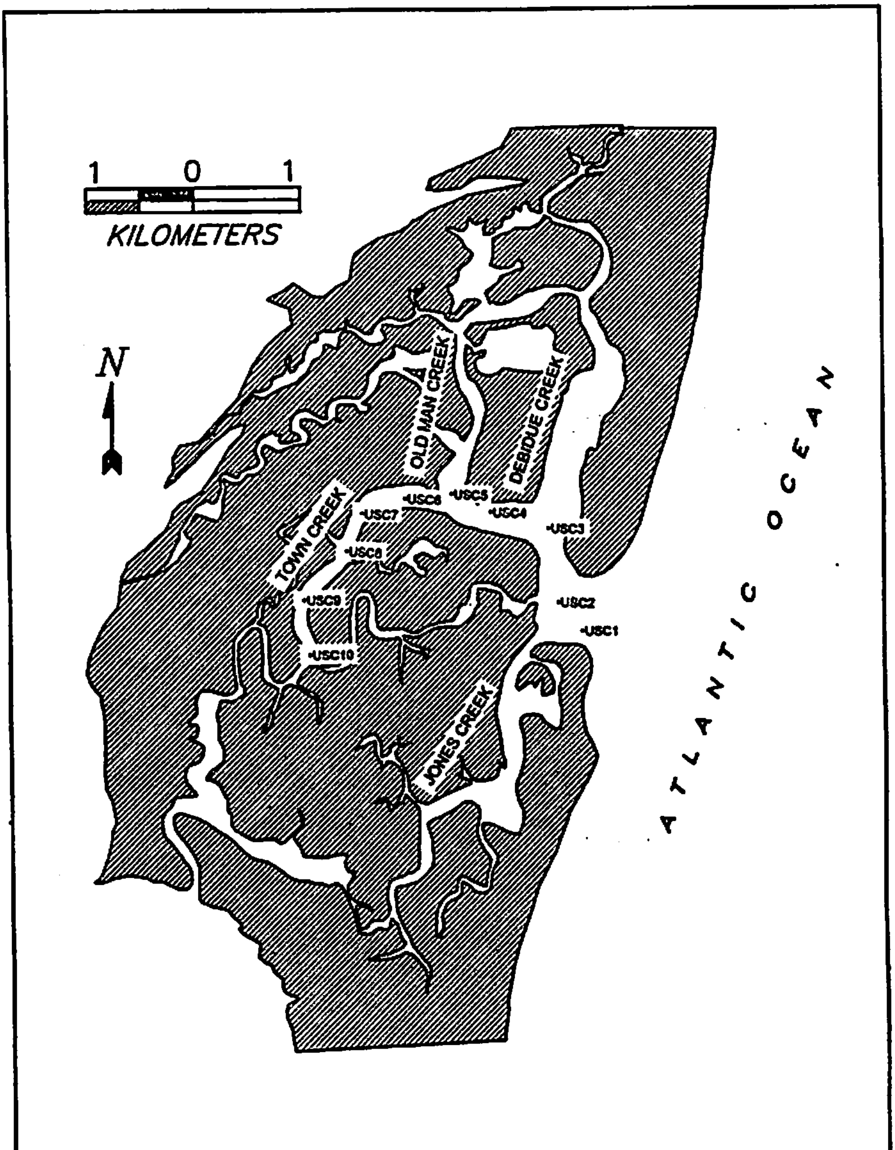

Figure 1. Map of North Inlet indicating the 10 sampling stations along Town Creek. Three small tributaries that feed into Town Creek are Debidue Creek, Jones Creek and Old Man Creek.

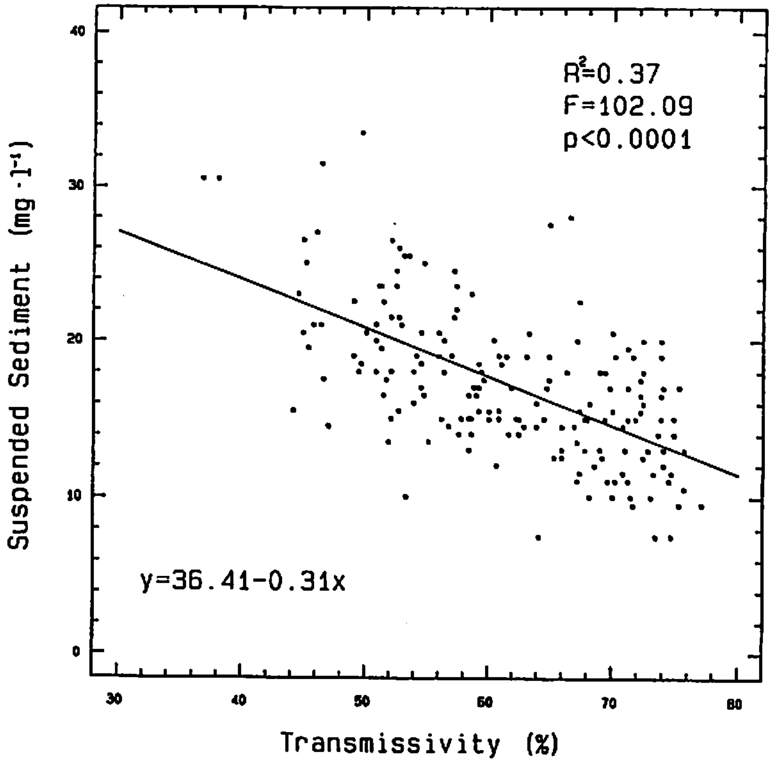

Figure 2. Linear regression of suspended sediment (mg·l^{-1}) on transmissivity (%) for North Inlet (R^2 = 0.37).

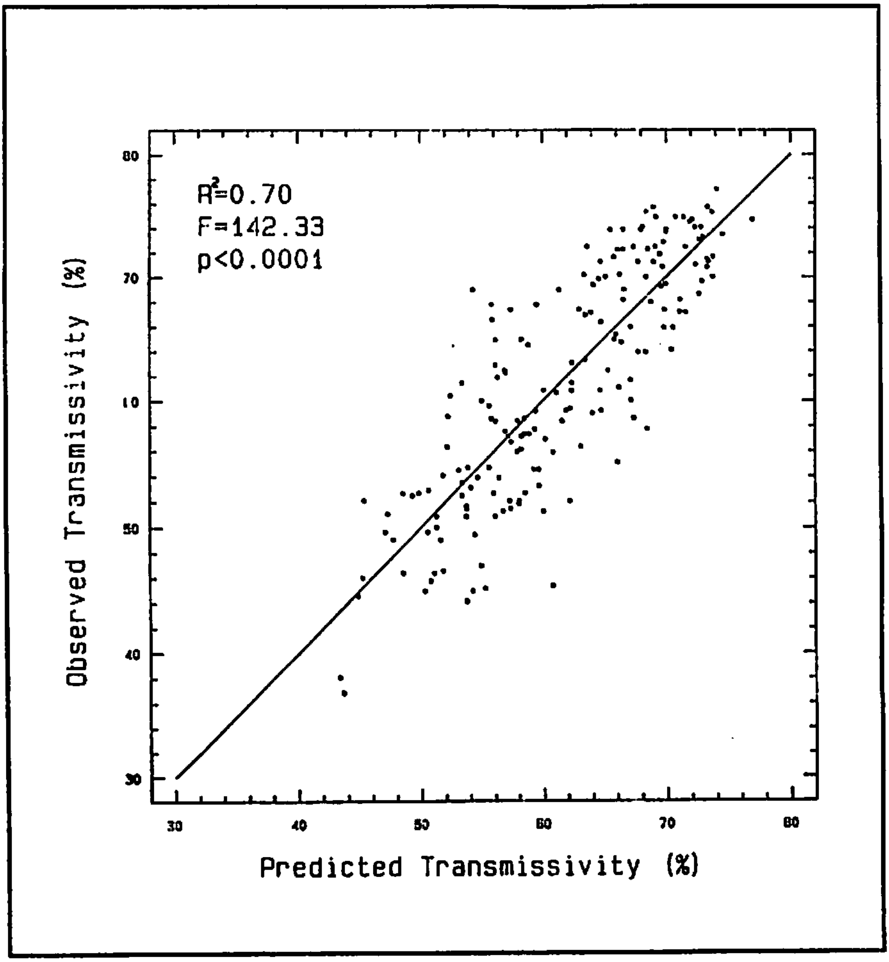

Figure 3. Regression of chlorophyll-a, suspended sediment and tidal angle on transmissivity for North Inlet (R^2 = 0.70). Two variables excluded from the step-wise regression analysis were salinity and temperature.