# ECOLOGICAL STUDY OF LAGOONS AROUND JOHN F. KENNEDY SPACE CENTER

NGR 10-015-008

VOLUME 1

## EXPERIMENTAL RESULTS AND CONCLUSIONS

FLORIDA INSTITUTE OF TECHNOLOGY
MELBOURNE, FLORIDA

NASA-CR-147889

Final Report

to

John F. Kennedy Space Center

National Aeronautics and Space Administration

Kennedy Space Center, Florida

# An Ecological Study of the Lagoons Surrounding the John F. Kennedy Space Center Brevard County, Florida

April, 1972 to September, 1975

Volume I

Experimental Results and Conclusions

December 31, 1975

NGR 10-015-008

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# INTRODUCTION

This final report is submitted to the John F. Kennedy Space Center, NASA, in fulfillment of the requirements of NASA Grant number NGR 10-015-008, dated April 11, 1973 and Amendments 1 through 7 thereto. The purpose of this report is to set forth the work done under the Grant and to document the findings drawn from the data so obtained.

For the convenience of the user, this report has been organized as a series of individual reports by field of investigation. There are separate reports on water chemistry, microbiology, benthic populations, sediments and current studies. While this causes some repetition of background data from chapter to chapter, each chapter is thus more complete within itself and more readily understood. The material presented is further divided into three volumes, again as a matter of convenience. Volume I contains a short history of the project, and chapters setting forth the findings and conclusions of the Principal Investigators. Volume II presents those Master's Theses that were written as a direct result of and were in direct support of the overall project. These theses are organized by fields into Sections corresponding to the Chapters of Volume I. Volume III, Appendices, is a compilation of data gathered during the project, and is published in a limited number of copies to preserve and to make available to future researchers the details of the baseline conditions as they existed during the period of this investigation.

We wish to acknowledge the ever-present help and encouragement of Col. W. H. Lee, who as the Technical Director of the grant for Kennedy Space Center, was at once our most enthusiastic supporter and constant critic. Through his efforts, valuable equipment was made available to us, without which much of the investigation would have been impossible. We wish also to acknowledge and extend our thanks to the people of the Kennedy Space Center who generously made their technical expertise and laboratory facilities available to us whenever we requested help. We wish especially to thank Mr. J. R. Puleo, Laboratory Director, Planetary Quarantine Laboratory, Jet Propulsion Laboratory, for his assistance in identifying bacteria in the microbiological investigations; Dr. J.B. Gayle, Director, Laboratories Division and Mr. J. F. Jones, Head, Microchemical Analysis Section, for their assistance and for making their laboratory facilities available for a number of chemical investigations; and to Dr. Karl Sendler, now retired, and his staff for numerous instrument calibrations and adjustments that were beyond our capabilities.

Chapter 1

# HISTORY OF THE PROJECT

M. R. Carey

## 1.0 Introduction

The studies reported here are the result of a three year effort to define the major biological, microbiological, chemical and geological characteristics of the water of the Indian River lagoon around the Kennedy Space Center and to determine the movements of those waters within and between the various basins. This work was the result of a jointly funded agreement between the Florida Institute of Technology and John F. Kennedy Space Center, NASA under NASA Grant NGR 10-015-008, dated April 11, 1972. This cost sharing grant was renewed for each of two successive years. Sampling operations were terminated August 31, 1975.

## 1.1 Area of Study

The area studied included all of the lagoonal waters surrounding the Kennedy Space Center. These waters were divided into four major areas, based upon their geography (Figure 1-1). Area 1 was that part of the Indian River between the Orsino Causeway and the Titusville Causeway, including Banana Creek as far upstream as State Road #3. Area 2 was the extreme northern end of the Indian River from the Titusville Causeway northward to the Haulover Canal and the shallow tidal flats to the northwest of the Haulover Canal. Area 3 was the Indian River Lagoon, more commonly known as the Mosquito Lagoon. The sampling area was limited to the open waters beginning slightly north of the Haulover Canal and extending to the southeast tip of the lagoon. Area 4 was the north of Banana River, beginning at the Bennett Causeway (State Road #528) and extending northward to its headwaters near Pad 39A.

After a review of the various maps and charts of the area that were available, the National Fish and Wildlife Service Chart number 4R-FLA-632-406, "Merritt Island National Wildlife Refuge" was selected to be the basic reference chart for the program. A sample site network was established by drawing a grid of intersecting lines on this chart at intervals of one minute of longitude and latitude. Each intersection of the grid falling in the open water was designated as a sample site, and was given a compound number indicating its area and its sequential location in the net beginning at the southeast corner of the area, thus the most southeasterly site in Area 1 is number 1-1. These sites and their geographic coordinates are listed in Table 1-1, at the end of this chapter. The Table is also


Figure 1.1 Photomosaic of John F. Kennedy Space Center, NASA, and Cape Canaveral, Brevard County, Florida. Water areas surrounding the Space Center are numbered to correspond to the usage in this report.

repeated in Volume III, Appendices, for convenience of reference.

Shortly after the beginning of initial sampling operations, F.I.T. was requested to include a series of water impoundments located on Merritt Island in our studies. While the sampling net just described was entirely adequate for the open waters, it was found that many of the impoundments were so small that no grid intersection fell inside them. It was believed necessary that each impoundment be sampled at least once, therefore a series of additional sites were selected, one in each impoundment, based on what were thought to be easily recognized terrain features. These additional sites were given three digit numbers, beginning with 111 at the southern edge of Area 1 and extending northward around Area 1 and 2. A single site was established in Area 3, and three werefound necessary in Area 4. The terrain features selected from the map frequently proved impossible to recognize or to reach in the densely overgrown impoundments, so the impoundment sites shown on the various maps throughout this report must be considered approximate only.

## 1.2 People on the Study

The principal investigators for this study, and their fields of investigation were:

Dr. T. A. Nevin; microbiology
Dr. J. A. Lasater; chemistry
Dr. K. B. Clark; biology
Dr. E. H. Kalajian; sediments
Dr. P. S. Dubbelday; currents

During the period of the study, a total of seventeen graduate students were employed to lead sampling and laboratory teams. In addition to their duties under the project, each of these students selected thesis research subjects based on questions that had arisen during the primary investigations. In addition, the project aroused a widespread interest among the student body at F.I.T. that has resulted in eight other masters theses and approximately forty senior research studies. A roster of all the students employed on the project is included as Table 1-2 at the end of this Chapter.

## 1.3 Operations

The first year of operations was shaped around the perceived need to survey the entire area, securing representative data for each of the four major disciplines involved. Water chemistry samples were taken at two foot intervals in the water column at each sample site and were analyzed in a houseboat laboratory that accompanied the fleet of small sampling boats. This sampling operation was repeated three times during the first summer, once in December and once again in April. Samples of the water column for microbiological studies were taken in parallel with the water chemistry samples. In addition, a sample of the bottom mud was taken at each site for studies of the microbial population. In addition, a Ponar Grab sample was taken at each site, mud and sand washed out and the benthic population fixed and stained for later determinations of density and diversity. A sediment core sample, approximately 36 inches in length, was taken at every sixth site, and the core capped and sealed for later analysis. Because different sites were sampled on each successive sampling round, eventually every sample site was cored for sediment analysis.

During the second year of the study, the water chemistry program again sampled all open water sites in the grid three times during the summer, once in December and again the spring. As before, samples were taken at two foot intervals downward from the surface. The microbiological survey was continued at a reduced level until all sites had been sampled once more, then efforts were redirected to a study of the effects of bacteria on the various forms of the sulfur ion present in the waters and muds of the area. Biological studies were directed toward the determination of plant biomass in rivers and the relationship between plant growth, detritus and benthic populations. The benthic population study of the previous year was continued but at a lower level of effort. Sediment coring and laboratory analysis were continued until all sites had been sampled and described. Water movement studies, using current crosses fixed at various depths were carried out throughout the year. In general, massive sampling campaigns that characterized the first year's efforts to describe the entire area were replaced during the second year by more specific studies in much greater depth, designed to answer questions raised by the first year's work.

During the third year, extensive field sampling was continued in the fields of benthic and water movement studies. The water chemistry and sediment studies were directed toward the determination of the amounts of heavy metals present in the water column, muds, and in the leaves of plants growing in the water's edge. Microbiological studies were terminated on 31 December 1974, when Dr. T. A. Nevin resigned from the program.

At the time of writing (December 1975), there are three research projects nearing completion in the Oceanography Department that are a part of this Baseline study. In addition, a special two year study of Banana Creek is being performed in connection with the Morrison-Knudsen Company contract to build the Space Shuttle Landing Facility. This study will be completed in May 1976 and its data and findings will be made a part of this study also.

## 1.4 Turning Basin Study

In addition to the general studies reported here, and at the request of the Design Engineering Division, Kennedy Space Center, F.I.T. conducted a a special investigation of the ecological conditions in the Turning Basin near the Vehicle Assembly Building, the borrow pit near Pad 39A and the Barge Canal connecting them. Samples of the waters were taken on October 6, November 3, and December 11, 1973. The results of this investigation were reported in a Special Report issued January 15, 1974. The area covered and the specific sites sampled are shown in Figure 1-2. In as much as the data and findings were reported in the Special Report, they are not included in this Volume, however, the data will be reported in Volume III, Appendices.

Table 1-1
KSC Baseline Study
Station/Position Index

Section I (Indian River)

| Station No. | Position | |
|---|---|---|
| | Latitude | Longitude |
| 1-1 | 28°32'N | 80°44'W |
| 1-2 | 28°32'N | 80°45'W |
| 1-3 | 28°32'N | 80°46'W |
| 1-4 | 28°33'N | 80°44'W |
| 1-5 | 28°33'N | 80°45'W |
| 1-6 | 28°33'N | 80°46'W |
| 1-7 | 28°33'N | 80°47'W |
| 1-8 | 28°34'N | 80°44'W |
| 1-9 | 28°34'N | 80°45'W |
| 1-10 | 28°34'N | 80°46'W |
| 1-11 | 28°34'N | 80°47'W |
| 1-12 | 28°35'N | 80°44'W |
| 1-13 | 28°35'N | 80°45'W |
| 1-14 | 28°35'N | 80°46'W |
| 1-15 | 28°35'N | 80°47'W |
| 1-16 | 28°35'N | 80°48'W |
| 1-17 | 28°36'N | 80°44'W |
| 1-18 | 28°36'N | 80°45'W |
| 1-19 | 28°36'N | 80°46'W |
| 1-20 | 28°36'N | 80°47'W |
| 1-21 | 28°36'N | 80°48'W |
| 1-22 | 28°37'N | 80°47'W |
| 1-23 | 28°37'N | 80°48'W |
| 1-24 | 28°37'20"N | 80°46'30"W |
| 1-25 | 28°35'40"N | 80°43'36"W |

Table 1-1 (continued)

| Station No. | Position | |
|---|---|---|
| | Latitude | Longitude |
| 1-26 | 28°35'31"N | 80°43'W |
| 1-27 | 28°35'18"N | 80°42'W |
| 1-28 | 28°35'N | 80°41'W |
| 1-29 | 28°35'19"N | 80°40'W |

Section II (Indian River)

| Station | Position | |
|---|---|---|
| | Latitude | Longitude |
| 2-1 | 28°38'N | 80°49'W |
| 2-2 | 28°38'N | 80°48'W |
| 2-3 | 28°39'N | 80°49'W |
| 2-4 | 28°39'N | 80°48'W |
| 2-5 | 28°40'N | 80°49'W |
| 2-6 | 28°40'N | 80°48'W |
| 2-7 | 28°40'N | 80°47'W |
| 2-8 | 28°41'N | 80°49'W |
| 2-9 | 28°41'N | 80°48'W |
| 2-10 | 28°42'N | 80°49'W |
| 2-11 | 28°42'N | 80°48'W |
| 2-12 | 28°42'N | 80°47'W |
| 2-13 | 28°42'N | 80°46'W |
| 2-14 | 28°42'N | 80°50'W |
| 2-15 | 28°43'N | 80°49'W |
| 2-16 | 28°43'N | 80°48'W |
| 2-17 | 28°43'N | 80°47'W |
| 2-18 | 28°43'N | 80°46'W |
| 2-19 | 28°43'N | 80°45'W |
| 2-20 | 28°44'N | 80°50'W |
| 2-21 | 28°44'N | 80°49'W |
| 2-22 | 28°44'N | 80°48'W |
| 2-23 | 28°44'N | 80°47'W |
| 2-24 | 28°44'N | 80°46'W |

Table 1-1 (continued)

| Station No. | Position Latitude | Position Longitude |
|---|---|---|
| 2-25 | 28°45'N | 80°50'W |
| 2-26 | 28°45'N | 80°49'W |
| 2-27 | 28°45'N | 80°48'W |
| 2 28 | 28°45'N | 80°47'W |
| 2-29 | 28°46'N | 80°50'W |
| 2-30 | 28°46'N | 80°49'W |
| 2-31 | 28°46'N | 80°48'W |

Section III (Mosquito Lagoon)

| Station No. | Position Latitude | Position Longitude |
|---|---|---|
| 3-1 | 28°40'N | 80°40'W |
| 3-2 | 28°40'N | 80°39'W |
| 3-3 | 28°41'N | 80°41'W |
| 3-4 | 28°41'N | 80°40'W |
| 3-5 | 28°42'N | 80°42'W |
| 3-6 | 28°42'N | 80°41'W |
| 3 7 | 28°43'N | 80°43'W |
| 3-8 | 28°43N | 80°42'W |
| 3-9 | 28°44'N | 80°44'W |
| 3-10 | 28°44'N | 80°43'W |
| 3-11 | 28°44'N | 80°42'W |
| 3-12 | 28°45'N | 80°45'W |
| 3-13 | 28°45'N | 80°44'W |
| 3-14 | 28°45'N | 80°43'5"W |
| 3-15 | 28°46'N | 80°46'W |
| 3-16 | 28°47'N | 80°45'W |
| 3-17 | 28°48'N | 80°44'W |
| 3-18 | 28°42'N | 80°43'W |

Table 1-1 (continued)

Section IV (Banana River)

| Station No. | Position | |
|---|---|---|
| | Latitude | Longitude |
| 4-1 | $28^{o}26'N$ | $80^{o}36'W$ |
| 4-2 | $28^{o}26'N$ | $80^{o}37'W$ |
| 4-3 | $28^{o}26'N$ | $80^{o}38'W$ |
| 4-4 | $28^{o}26'N$ | $80^{o}39'W$ |
| 4-5 | $28^{o}27'N$ | $80^{o}36'W$ |
| 4-6 | $28^{o}27'N$ | $80^{o}37'W$ |
| 4-7 | $28^{o}27'N$ | $80^{o}38'W$ |
| 4-8 | $28^{o}27'N$ | $80^{o}39'W$ |
| 4-9 | $28^{o}28'N$ | $80^{o}36'W$ |
| 4-10 | $28^{o}28'N$ | $80^{o}37'W$ |
| 4-11 | $28^{o}28'N$ | $80^{o}38'W$ |
| 4-12 | $28^{o}29'N$ | $80^{o}36'W$ |
| 4-13 | $28^{o}29'N$ | $80^{o}37'W$ |
| 4-14 | $28^{o}29'N$ | $80^{o}38'W$ |
| 4-15 | $28^{o}30'N$ | $80^{o}35'W$ |
| 4-16 | $28^{o}30'N$ | $80^{o}36'W$ |
| 4-17 | $28^{o}30'N$ | $80^{o}37'W$ |
| 4-18 | $28^{o}30'N$ | $80^{o}38'W$ |
| 4-19 | $28^{o}31'N$ | $80^{o}35'W$ |
| 4-20 | $28^{o}31'N$ | $80^{o}36'W$ |
| 4-21 | $28^{o}31'N$ | $80^{o}37'W$ |
| 4-22 | $28^{o}32'N$ | $80^{o}35'W$ |
| 4-23 | $28^{o}32'N$ | $80^{o}36'W$ |
| 4-24 | $28^{o}33'N$ | $80^{o}35'W$ |
| 4-25 | $28^{o}33'N$ | $80^{o}36'W$ |
| 4-26 | $28^{o}34'N$ | $80^{o}36'W$ |
| 4-27 | $28^{o}35'N$ | $80^{o}36'W$ |
| 4-28 | $28^{o}36'N$ | $80^{o}36'W$ |
| 4-29 S* | $28^{o}35'N$ | $80^{o}38'36''W$ |
| 4-30 S | $28^{o}35'33''N$ | $80^{o}36'56''W$ |
| 4-31 S | $28^{o}35'6''N$ | $80^{o}36'30''W$ |
| 4-32 S | $28^{o}34'19''N$ | $80^{o}35'27''W$ |
| 4-33 S | $28^{o}26'31''N$ | $80^{o}36'W$ |

Table 1-1 (continued)

| Station No. | Position | |
|---|---|---|
| | Latitude | Longitude |
| 4-34 S | 28°25'6"N | 80°36'31"W |
| 4-35 | 28°25'N | 80°37'W |
| 4-36 | 28°25'N | 80°38'W |
| 4-37 | 28°25'N | 80°39'W |
| 4-39 S | 28°35'42"N | 80°36'42"W |

*S indicates special station not located on one minute grid

Section I (Impounded Waters)

| Station No. | Position | |
|---|---|---|
| | Latitude | Longitude |
| 111 | 28°32'N | 80°42'50"W |
| 112 | 28°33'39"N | 80°42'50"W |
| 112 A** | 28°33'N | 80°42'50"W |
| 113 | 28°34'N | 80°42'50"W |
| 114 | 28°34'N | 80°41'49"W |
| 115 | 28°35'N | 80°42'34"W |
| 115 A | 28°35'N | 80°43'W |
| 116 | 28°35'N | 80°42'W |
| 117 | 28°35'N | 80°40'W |
| 118 | 28°36'N | 80°42'49"W |
| 119 | 28°36'52"N | 80°46'W |
| 120 | 28°37'6"N | 80°45'W |
| 121 | 28°37'N | 80°44'W |
| 122 | 28°38'N | 80°46'W |
| 123 | 28°38'N | 80°46'44"W |
| 124 | 28°35'38"N | 80°41'45"W |
| 125 | 28°35'45"N | 80°42'25"W |

**A Indicates an alternate station selected to secure deep water

Table 1-1 (continued)

Section II (Impounded Waters)

| Station No. | Position | |
|---|---|---|
| | Latitude | Longitude |
| 210 | 28°38'N | 80°47'W |
| 211 | 28°38'50"N | 80°47'W |
| 212 | 28°39'N | 80°46'W |
| 213 | 28°40'N | 80°46'2"W |
| 214 | 28°41'N | 80°47'W |
| 215 A | 28°41'16"N | 80°46'3"W |
| 216 | 28°42'N | 80°45'W |
| 216 A | 28°42'N | 80°44'12"W |
| 217 | 28°40'19"N | 80°46'46"W |
| 218 | 28°40'27"N | 80°46'35"W |
| 219 | 28°40'37"N | 80°46'22"W |
| 220 | 28°40'29"N | 80°46'12"W |

Section III (Impounded Waters)

| Station No. | Position | |
|---|---|---|
| | Latitude | Longitude |
| 311 | 28°40'38"N | 80°41'47"W |

Section IV (Impounded Waters)

| Station No. | Position | |
|---|---|---|
| | Latitude | Longitude |
| 412 | 28°34'44"N | 80°36'37"W |
| 413 | 28°36'5"N | 80°39'6"W |
| 414 | 28°36'28"N | 80°38'34"W |

Table 1-1 (continued)

Bacterial Study (BS)

| Station No. | Position | |
|---|---|---|
| | Latitude | Longitude |
| BS-8 | 28°35'29"N | 80°39'21"W |
| BS-9 | 28°36'36"N | 80°39'50"W |
| BS-10 | 28°36'45"N | 80°38'3"W |
| BS-11 | 28°36'3"N | 80°37'36"W |

KSC Turning Basin Study

| Station | Position | |
|---|---|---|
| | Latitude | Longitude |
| C-1 | 28°35'5"N | 80°38'33"W |
| C-2 | 28°35'2"N | 80°38'30"W |
| C-3 | 28°35'5"N | 80°38'4"W |
| C-4 | 28°35'29" | 80°37'28"W |
| C-5 | 28°35'19"N | 80°36'23"W |
| C-6 | 28°36'N | 80°35'44"W |

Table 1-2

Roster of Persons Working on the Project

Principal Investigators

Dr. T.A. Nevin. Research Professor of Microbiology

Dr. J.A. Lasater, Professor of Oceanography

Dr. P.S. Dubbleday, Peofessor of Oceanography

Dr. K.B. Clark, Assistant Professor of Biology

Dr. E.H. Kalajian, Assistant Professor of Oceanography

Graduate Students

| | |
|---|---|
| R.W. Beazley | S.O. Peffer |
| D.R. Browne | J.. R. Salituri |
| R.L. Camphell | R.J. Saudy |
| M.R. Carey | J.C. Sherman |
| J.M. Daggett | D.R. Sias |
| R.E. Dill | J.R. Thomas |
| S.M. Fettes | D.A. Tower |
| J.B. Hutchinson Jr. | C.N. Wiederhold |
| | G.C. Woodsum |

Undergraduate Students

| | |
|---|---|
| Cynthia L. Barnett | Constance Horton |
| Roger A. Barrios | Douglas A. Hower |
| Linda K. Bassett | David R. Motschmann |
| John Brodie | Cheryl Moble |
| Cynthia J. Candreva | James Schooley |
| Susan E. Fowler | Allan E. Schrieber |
| Steven S. Gihbert | Steven Slasor |
| Andrew Gaetzfried | Jeanette Vanderzwann |
| Robert S. Heidinger | Greg Waugh |
| F. Scott Hoover | Deborah N. Wojciechowski |

Site Location Map

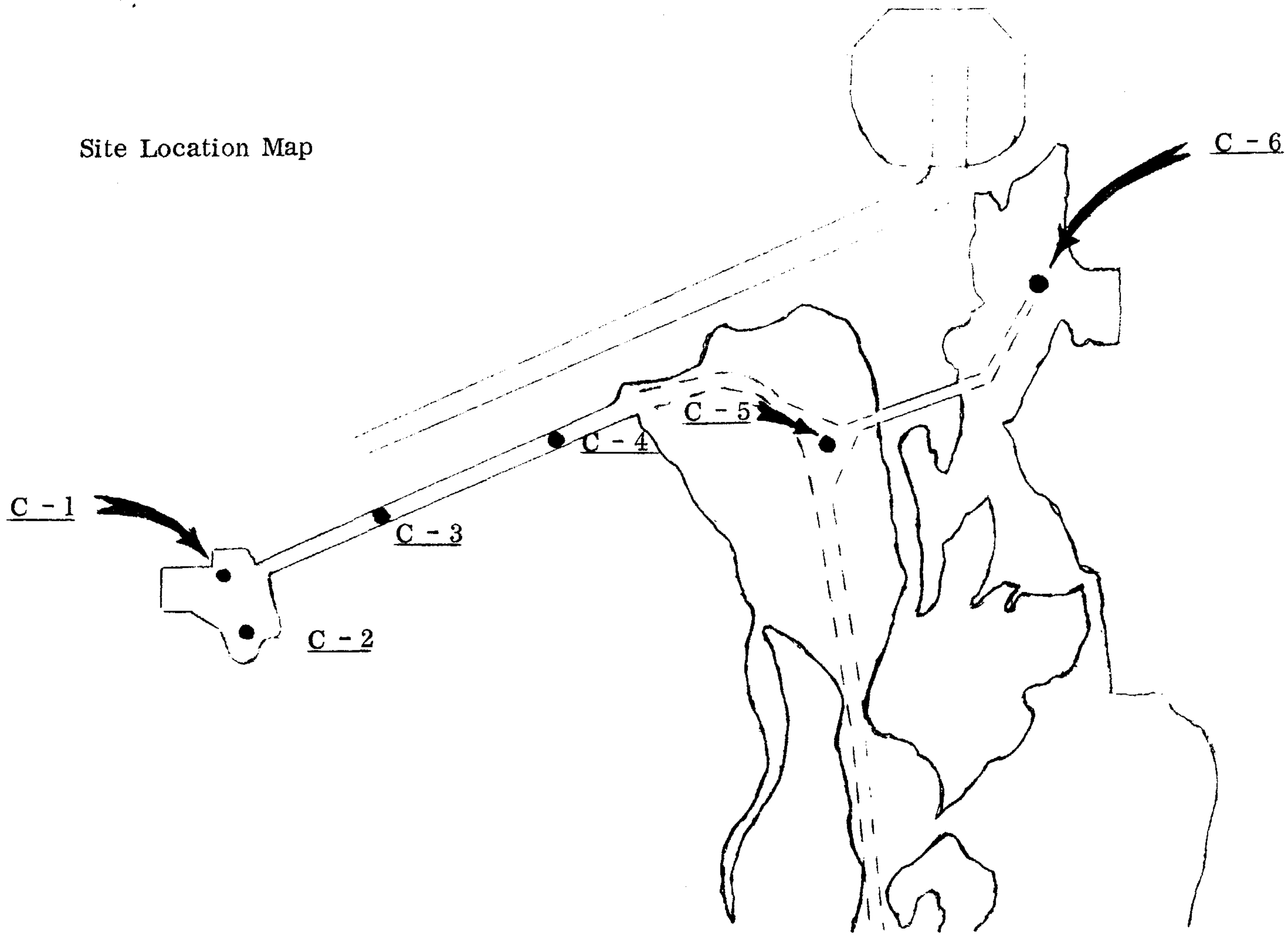


Figure 1-2

Chapter 2

# BENTHIC COMMUNITY STRUCTURE AND FUNCTION

K.B. Clark

SUMMARY

Analysis of the benthic community of the North Indian River showed that the system is controlled by the annual production cycle of seagrasses. A detrital surge follows peak seagrass biomass (September) by two months (November). Many invertebrate populations are synchronized with this surge.

Maximum seagrass density (c. 500 $g/m^2$) occurs between 40 and 60 cm, in the transition zone between Syringodium and Diphanthera. Production is lower (2-400 $mgC/m^2/day$) than other reported seagrass systems, possible due to carbonate limitation.

Dredging and filling operations have been the major disturbances to this ecosystem, and have substantially reduced benthic invertebrate populations near causeways, urban shores, and the Intracoastal Waterway.

## 2.0 Introduction

The Indian River is a large mesohaline lagoon which extends from Edgewater to Stuart, Florida, a distance of about 200 km. Despite the size of this marine ecosystem, there is little published information concerning its biota or its ecology. The intent of this study is to characterize the benthic community of one portion of this lagoon, the North Indian River, near Titusville, Florida.

The major physical feature of the Indian River is its broad, shallow basin; width varies, but is generally several kilometers, and mean depth of the North Indian River is about 1.3 meters. Dense beds of seagrasses, mostly manatee grass (*Syringodium filiforme*), cover most of the basin.

The high biomass and production of seagrass beds exert a major influence on the physical, chemical, and biological processes in marine ecosystems (Thayer, Wolfe, and Williams, 1975). As these seagrass beds are the major biotic component of the Indian River, analysis of the growth and decay cycle of seagrasses provides a logical framework for study of ecological processes in the river as a whole. The major focus of this study will be the factors affecting the growth cycle of seagrasses, interactions of the seagrasses and the benthic invertebrate community, and the seasonal and spatial variations of the seagrass and invertebrate populations.

The east side of the Indian River is separated from the Atlantic Ocean by an extensive barrier beach. Cape Canaveral, a portion of this barrier beach, has been recognized by several authors as a biogeographic boundary and transition zone between Caribbean and warm temperate Atlantic provinces. (Parr, 1933; Johnson, 1934; Ekman, 1953; Briggs, 1974). Parr (1933) suggested that Cape Canaveral acts as a barrier to northerly flow of warm winter water, hence limits winter movements of warm-water species. Biogeographic ranges are generally controlled directly or indirectly by temperature (Gunther, 1957). Since the shallow basin of the Indian River is subject to wider and more rapid temperature variation than the Atlantic Ocean, and as the river straddles this transition zone, study of seasonal changes of Indian River benthic populations should greatly clarify the specific mechanisms which control the distributions of these transitional species. Further, a taxonomic survey of this region should further define the ranges of species within this transition zone.

Both the flora and fauna of the Indian River are poorly known. Reports of the distributional limits of seagrasses and algae (Phillips, 1960, 1961) and mangroves (Graham, 1964) within the Indian River are the principle floristic references. Grizzle (1974) has surveyed the decapod Crustacea of the Indian River, while Everman and Bean (1897), Brice et al. (1898), Futch (1967), and Anderson and Gehringer (1965) have surveyed fisheries of the Indian River. Other faunistic references are primarily sporadic records within specific taxa.

## 2.1 Materials and Methods

Study Area: The Indian River has been divided into a series of basins by construction of causeways. The present study concentrated on the three northermost basins, extending from just south of Edgewater, south to the Route 528 Causeway (figure 1). Water exchanges in this area are limited. Some freshwater input occurs via Turnbull Creek at the extreme north end; very limited saline water exchange occurs through New Smyrna Inlet via Haulover Canal to the northeast and through Sebastian Inlet to the south. Lunar tides are highly damped in passage from the distant inlets, and the major tidal influence is an aeolian tide of small magnitude. Circulation within the lagoon is wind-driven. Salinity is controlled largely by the balance between evaporation and precipitation, and varies within the study area from about 20 to 33‰. Rainfall is seasonal, being concentrated from June to October.

The eastern shore of the three basins is occupied by the Kennedy Space Center; the shoreline has been extensively diked for mosquito control, but the lagoon's bottom shows little effect of damage by the impoundment activity and is essentially undisturbed. The western shore has undergone some development, including limited bulkheading and dredging; these activities have centered about the City of Titusville in the middle basin, and have affected the southern basin somewhat less; the northern basin has been least affected. Other major disturbances have been the construction of several causeways and the dredging of the Inland Waterway. Causeways (from north to south) include the Florida East Coast Railroad trestle, the Titusville Causeway, Orsino Causeway, and the Florida Route 528 Causeway. Construction of the causeways has involved large-volume dredge and fill operations, with severe

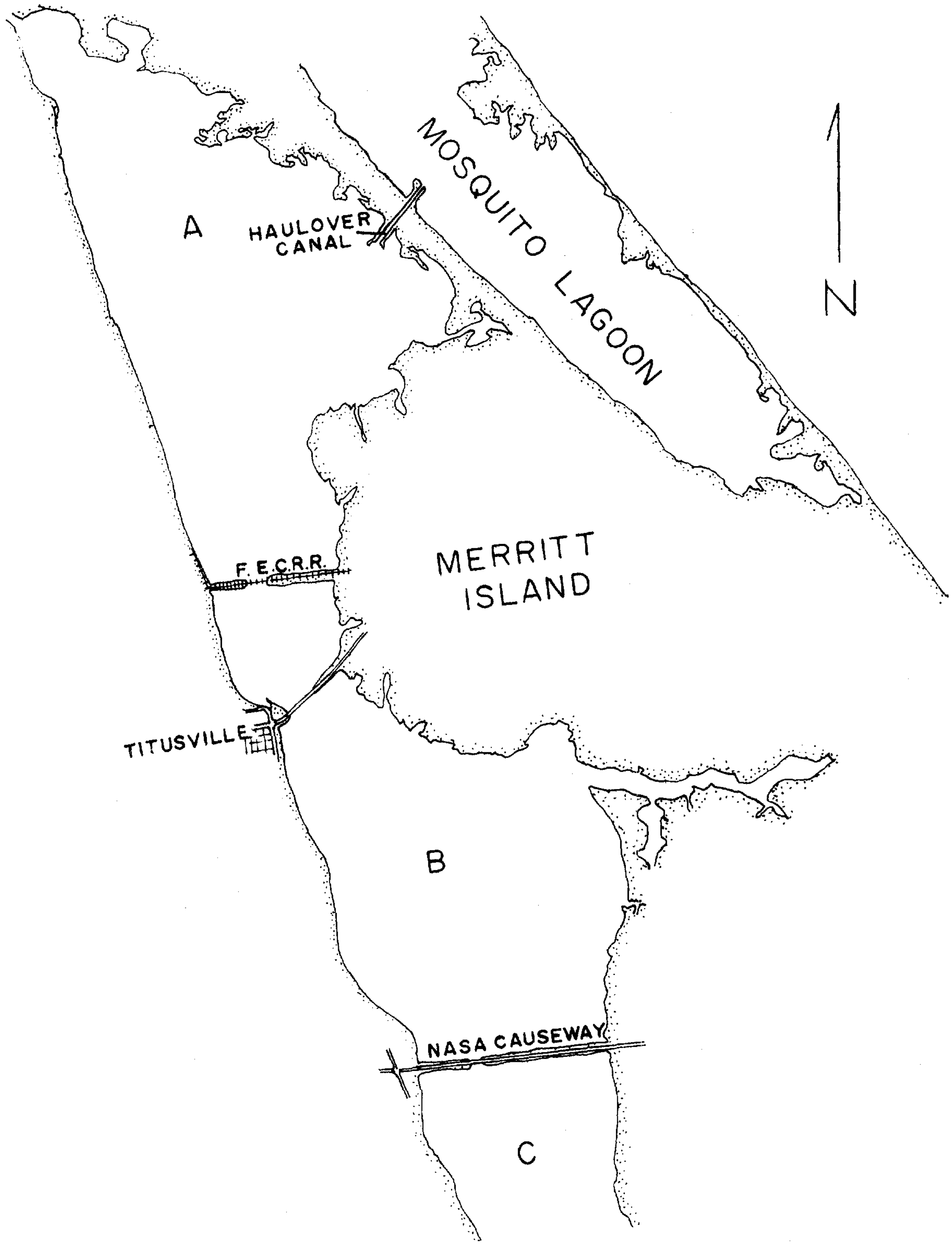


Figure 2-1. North Indian River. A: north basin. B: central basin. C: south basin.

but fairly localized disturbances of the benthic community. The Inland Waterway is maintained at a minimum width of 100 feet and depth of 12 feet; dredge spoil has been deposited as a series of islands paralleling the waterway. The effects of this dredging have not been measured but are probably considerable, as the spoil is not stabilized and has been subject to considerable erosion.

Sampling Procedure: This study extended over a period of approximately forty months. Sample areas and procedures were changed several times during this study to reflect changes in emphasis and refinements of sampling methods. A summary of sampling methods is given in Table 1.

During the summer of 1972, the principle sampling involved a large scale survey of benthic invertebrate populations. A grid of stations, based on one degree latitude and longitude squares, was sampled in the center basin. Single ponar grab samples were collected at each station, washed through 0.4 mm sieves, and sorted to major taxa.

In 1973, a longitudinal transect in the north basin was sampled to analyze the effects of depth and associated climatic variables on the benthic invertebrate community. Fifteen stations along the transect were sampled. At each station, five ponar grabs were taken, pooled, and a 20% aliquot taken. Samples were sorted to species, quantified, and diversity indices were calculated. Density and diversity were related to depth, dissolved oxygen, sediment characteristics, redox potential, temperature, and seagrass biomass. A detailed summary of sampling procedures is given by Thomas (1974).

Activities during 1974-1975 again concentrated on the center basin. During the summer of 1974, standing crop and zonation of seagrasses in this basin were studied through the use of core samples. Seventy stations were selected along a series of east-west transects. At each station, five cores were randomly sampled, using diver-operated manual corers (figure 2). Core sites were selected by randomly tossing five weighted markers from the boat; the 15 cm diameter core tubes were then pushed approximately 15 cm into the sediment at an arms's length from the marker. Cores were washed through 4 mm sieves, and all macrophytic algae and seagrasses were retained, stored in plastic bags, and frozen within 12 hours, pending later sorting. Depth,

Table 1. Sampling Methods Summary

| Parameter | Method | Ref. |
|---|---|---|
| Salinity | Optical Refractometry | |
| Temperature | Thermistor Probe | S. M. E. W. W. 1971 |
| Dissolved Oxygen | Winkler Titration | |
| Light Intensity, Penetration | Submarine Photometer | |
| Total Organic Carbon | Chromate Oxidation | Walkley & Black 1934 |
| Total Phosphates | Ascorbic Acid | S. M. E. W. W., 1971 |
| Redox Potential | Calomel/Platinum electrodes | |
| pH | Field pH meter, combination electrode | |
| Sediment Grain Size | USTM Standard Sieves, Gravimetry | Holme & McIntyre 1971 |

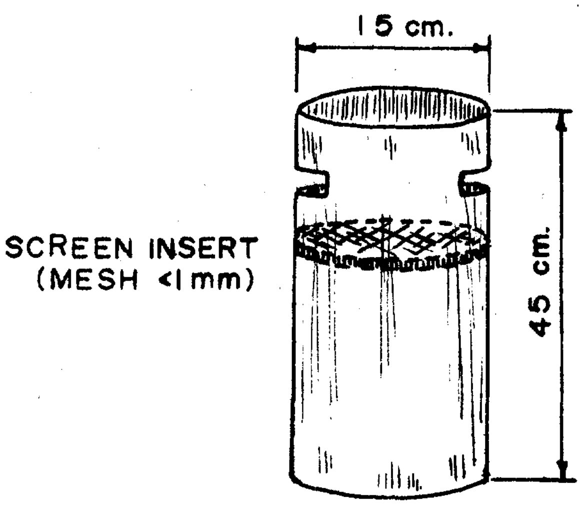


Figure 2-2. Corer constructed of PVC pipe, used in benthic sampling, 1974-1975.

water and sediment temperature, dissolved oxygen, light penetration, and redox potential were measured at the time of core sampling. Compass sightings were taken at each station, but were later found to be nearly useless for mapping, due to the great distance between the few available landmarks. A single sediment sample was taken at each site for later chemical and physical analysis, refrigerated, and quick-frozen at the end of each sampling day.

Algae and seagrasses were thawed by floating the sample in an enamelled pan and were manually sorted to species. Sorted materials were dried at $80^{o}C$ for 12 hours and weighed. Sediment samples were analyzed for total organic carbon, total phosphates, and sediment grain size.

In August, 1974, a quadrat was established near the eastern shore of the central basin for analysis of seasonal variation of invertebrate and macrophyte populations (figure 3). A grid of 5000 $m^2$ (approximately 70m by 70 m), containing 25 stations was permanently marked and sampled monthly through October, 1975. Macrophytes were processed by the coring and sorting procedure described above. Benthic invertebrate populations were sampled by additional processing of the cores taken at the four corners and center of the quadrat. These cores were washed through both 1 mm and 4 mm sieves. After removal of macrophytes, all residue was transferred to 7% $MgCl_2$ for relaxation and then fixed with neutral formalin. After 24 hours, the samples were transferred to 70% ethanol and sorted to species. Individuals of dominant species were measured by optical micrometry to measure monthly growth changes.

On the day of each monthly sample, light penetration, salinity, water and sediment temperatures, depth, dissolved oxygen, and pH were measured at the northeast corner of the quadrat.

Further resolution of the zonation of macrophytes in shallow water (0.3-1.0 m) was accomplished by means of a final transect extending from the impoundment dike on the eastern shore through the quadrat area. Ten cores at each 10 cm depth interval were taken and processed as described above.

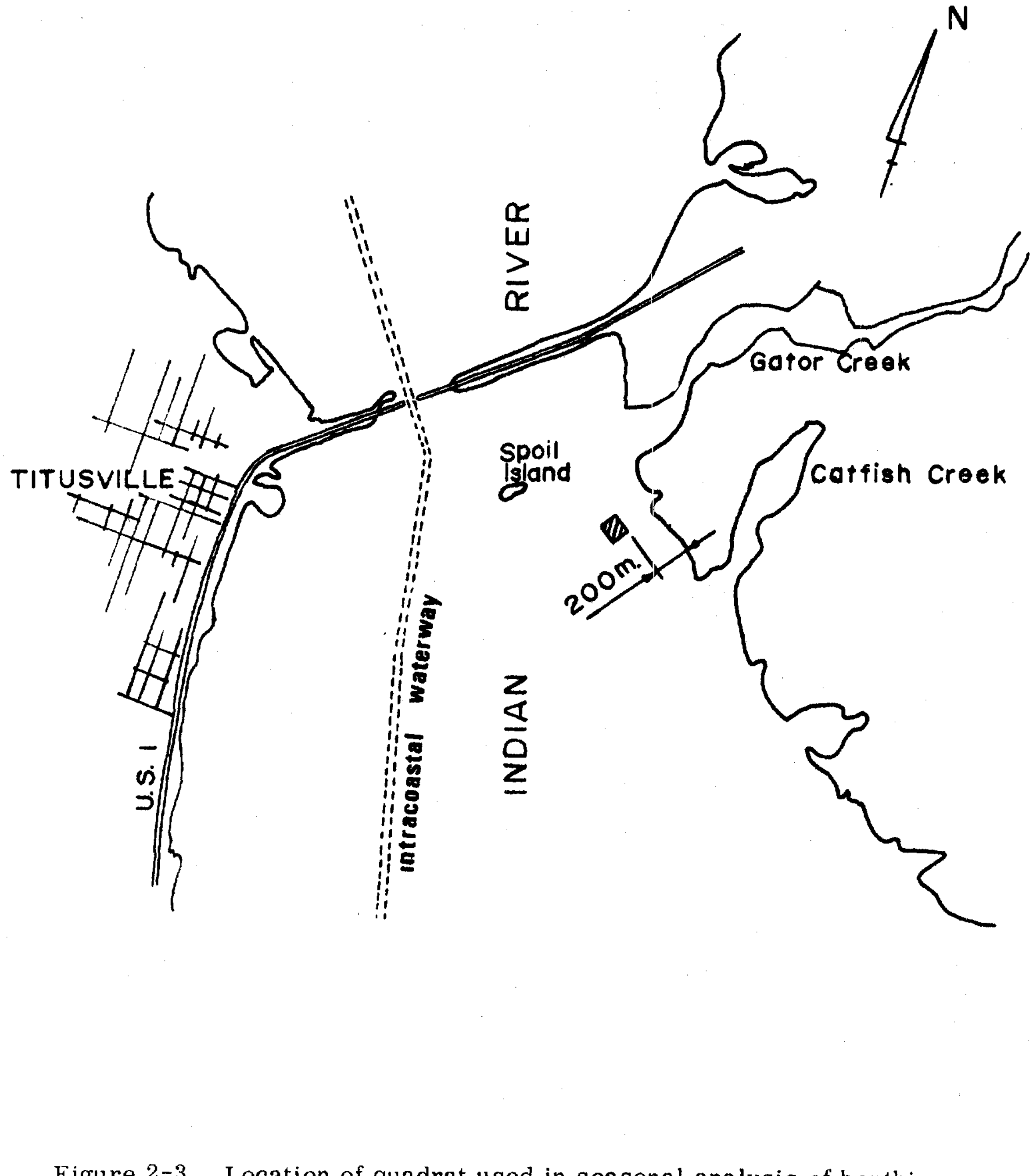


Figure 2-3. Location of quadrat used in seasonal analysis of benthic community of North Indian River, 1974-1975.

Plankton samples were collected at monthly intervals at four stations in the south basin from April 1974 to March 1975. (Figure 2-4). Volumes of ten liters were collected at 0.5 m intervals, pumped through a 55 um plankton net and bucket, reduced to 100 ml volume, and preserved by addition of neutral formalin. These samples were further reduced by decantation and the entire sample was counted.

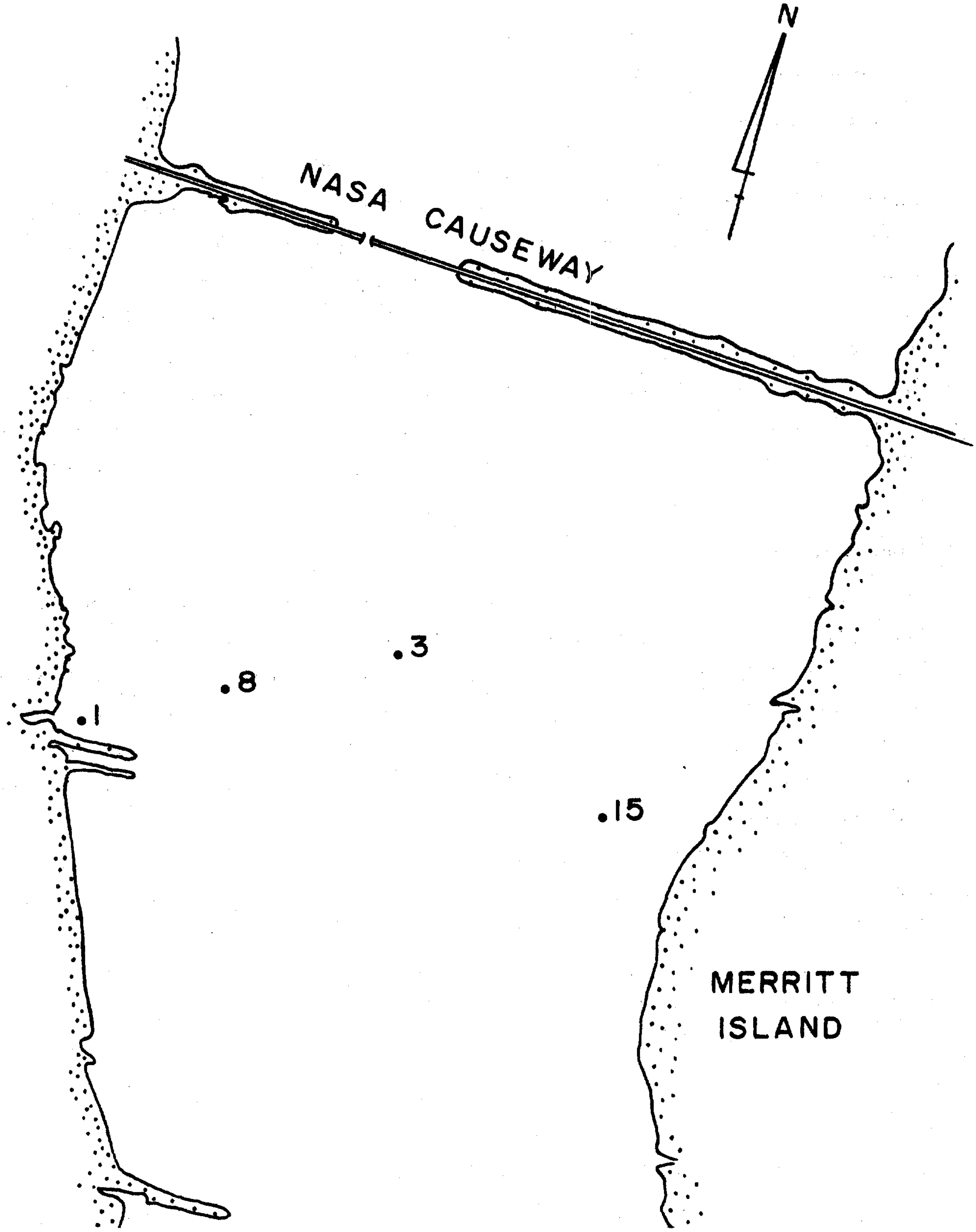


Figure 2 - 4. Location of plankton sampling stations in the South basin, 1974-1975.

## 2.3 Results

Density Patterns:

The results of the summer 1972 sampling period have been summarized in figure 2-5 & Appendix I. Organism densities within the central basin are highly variable, ranging from a low of 2000 animals /$m^2$ to a high of nearly 60,000/$m^2$. The highest densities are associated with inputs of detrital material, especially near Banana Creek, Gator Creek, and Catfish Creek along the northeast edge of the basin. Stations adjacent to the Intracoastal Waterway show a slightly decreased density (10-20,000/$m^2$), while those near the developed western edge and near the causeways have substantially lower densities (2-10,000/$m^2$). Dominant taxa include Ostracoda, Amphipoda, Polychaeta, and Nematoda, which are all primarily detritivorous.

Depth Transect:

A detailed analysis of the depth transect sampled during 1973 in the northern basin (figure 2 -6) has been given by Thomas (1974). Diversity values (Brillouin's diversity index, 1962) ranged from a high of 5.44 near the northern shore in shallow grass flats to a low of 0.90 within the channel of the Intracoastal Waterway. Diversity values showed significant relationships with depth and redox potential of the sediments, indicating a probable limitation of species richness by oxygen stress. Additional information derived from this study showed that the presence or absence of seagrasses is the major determinant of community structure, and confirmed the earlier finding that the benthic community is detritus-based, as indicated by dominance of deposit feeders (Thomas, 1974). A revised list of species collected from benthic samples is presented in order of dominance in table 2. The benthic invertebrate community is dominated by five species, including two ostracods, one polychaete, a gastropod, and a sipunculid. Of these, only one (Fabricia) is a suspension feeder; the remaining four dominants (> 5% of total), comprising about 60% of the total species, are all deposit feeders.

Benthic Macrophyte Zonation:

Results of the benthic macrophyte zonation study are presented in figures 7-10. The dominant macrophytes are: Syringodium filiforme, Acanthophora spicifera and Gracilaria verrucosa. The permanently attached macrophytes (Syringodium and Diplanthera) show a sharp zonation with depth. Shoal grass (Diplanthera) completely dominates from 0.3 to 0.5 m, but is displaced at greater depths by

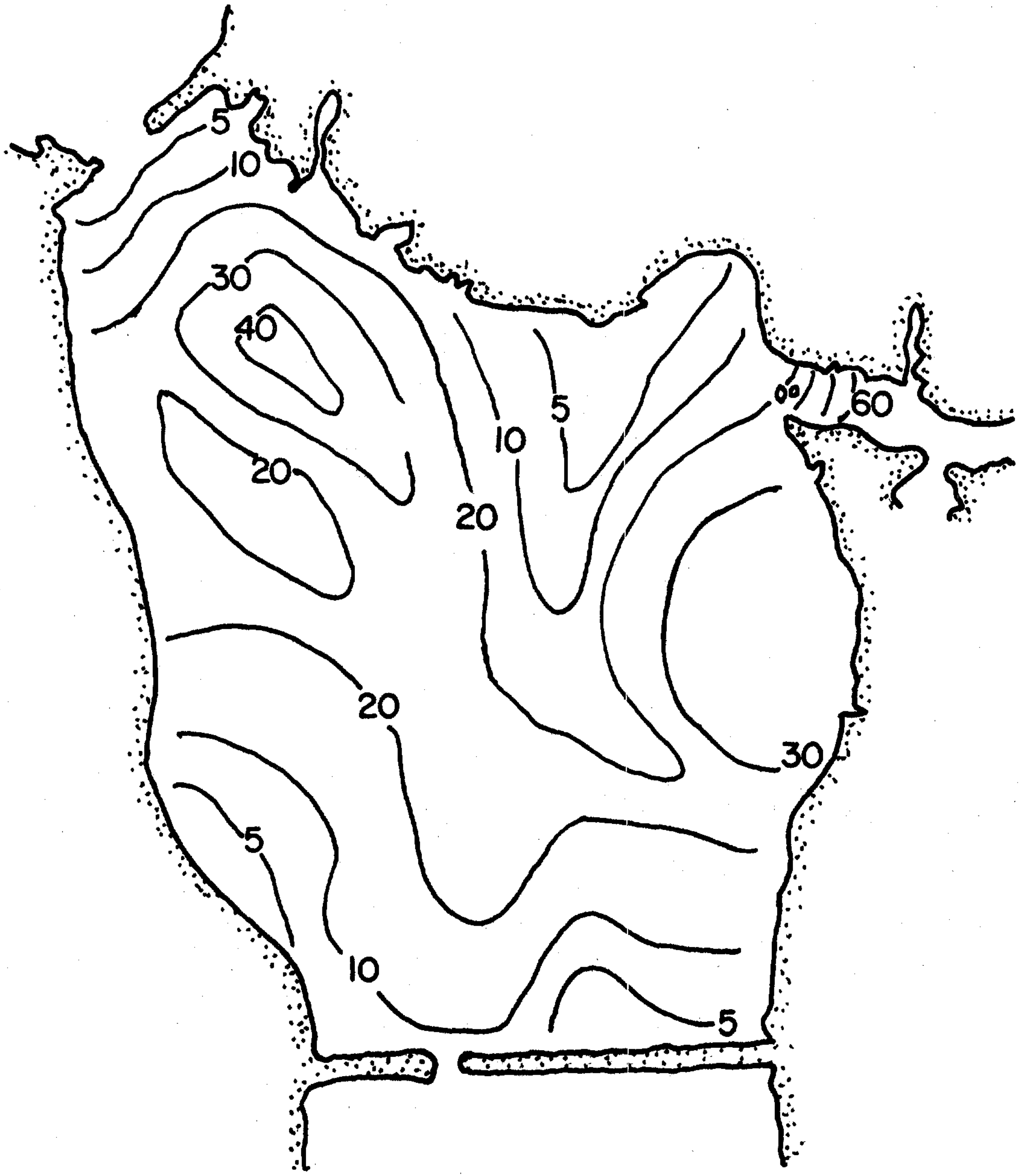


Figure 2-5. Invertebrate population densities in the central basin during 1972, in thousands of organisms per square meter.

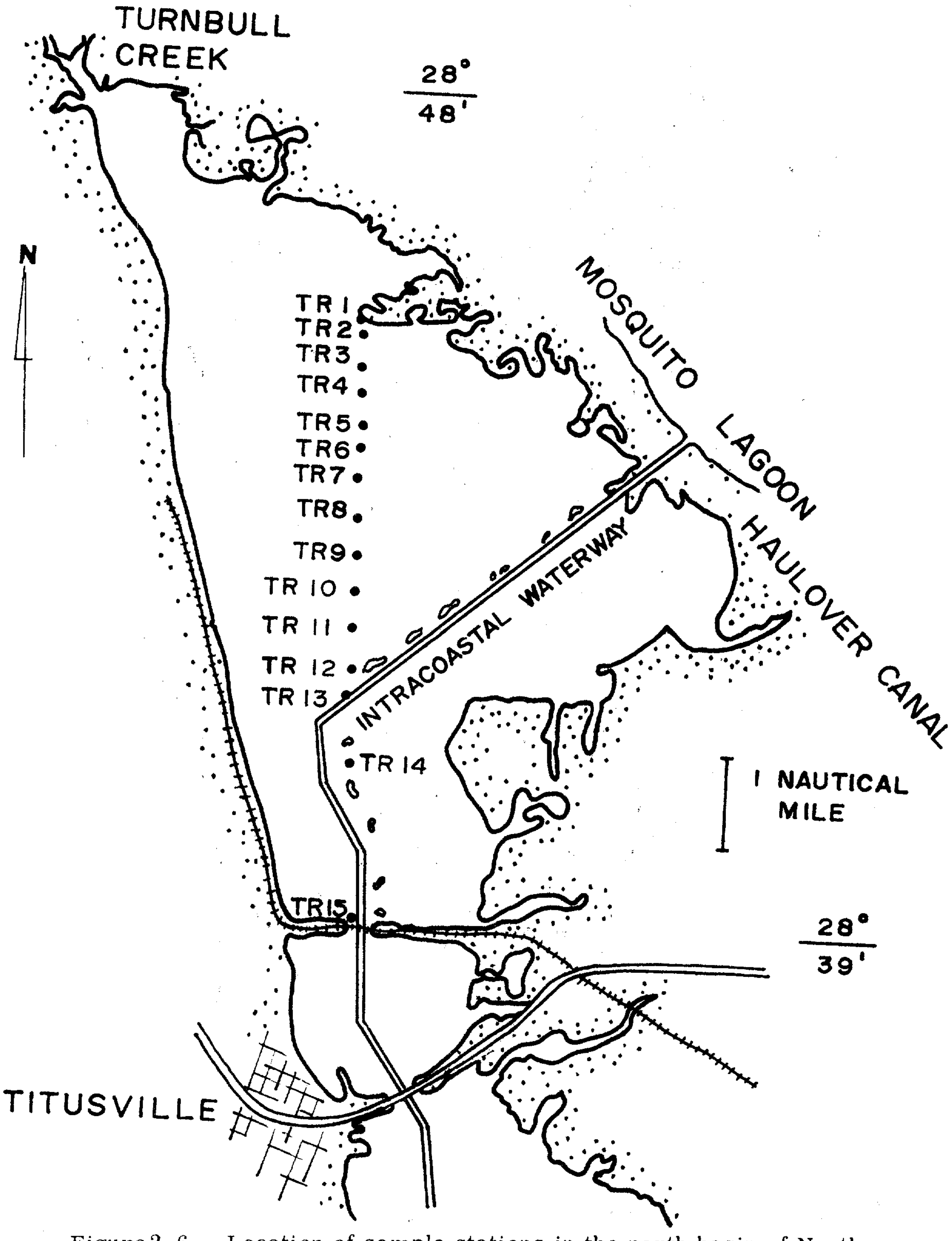


Figure 2-6. Location of sample stations in the north basin of North Indian River, summer, 1973.

Table 2.

Species Occuring in Benthic Samples in Order of Numerical Dominance

| | | No. | % | Feeding Type |
|---|---|---|---|---|
| 1. | Cylindroleberis mariae | 4011 | 38.6 | NSDF |
| 2. | Sarsiella americana | 1061 | 10.2 | NSDF |
| 3. | Fabricia sabella | 608 | 5.85 | SF |
| 4. | Caecum pulchellum | 580 | 5.58 | DF |
| 5. | Phascolion strombi | 528 | 5.08 | DF |
| 6. | Melita fresnelii | 338 | 3.25 | DF |
| 7. | Leiochone dispar | 297 | 2.86 | DF |
| 8. | Exogone hebes | 263 | 2.53 | C/S |
| 9. | Brachidantes exustus | 241 | 2.31 | SF |
| 10. | Mulinia lateralis | 174 | 1.67 | SF |
| 11. | Aricidea jeffreysi | 166 | 1.59 | DF |
| 12. | Corophiid amphipod | 146 | 1.41 | DF |
| 13. | Acteocina canaliculata | 138 | 1.33 | DF |
| 14. | Marginella apicina | 135 | 1.30 | C/S |
| 15. | Cyathura polita | 132 | 1.27 | H/S |
| 16. | Ophiophragmus filograneus | 130 | 1.25 | NSDF |
| 17 | Sphaerodorid polychaete | 103 | 0.99 | DF |
| 18. | Prionospio sp. | 96 | 0.92 | C/S |
| 19. | Erichsonella attenuata | 79 | 0.76 | H/S |
| 20. | Tanais sp. | 75 | 0.72 | DF |
| 21. | Hypaniola grayi | 69 | 0.66 | DF |
| 22. | Sphaeroma quadridentata | 63 | 0.60 | SDF |
| 23 | Scolecolepsis sp. | 52 | 0.50 | C/S |
| 24. | Sabella microphthalma | 50 | 0.50 | SF |
| 25. | Ampelisca sp. | 49 | 0.47 | DF |
| 26. | Cythereis sp. | 48 | 0.46 | NSDF |
| 27. | Branchiomma nigromaculata | 43 | 0.41 | SF |
| 28. | Eunice filamentosa | 39 | 0.38 | C/S |
| 29. | Platynereis dumerilii | 37 | 0.36 | C/S |

Table 2 (continued)

| | | No. | % | Feeding Type |
|---|---|---|---|---|
| 30. | Odontosyllis fulgurans | 36 | 0.35 | SF |
| 31. | Tharyx sp. | 33 | 0.32 | DF |
| 32. | Actinothoe gracillima | 30 | 0.29 | SF |
| 33. | Pista palmata | 28 | 0.27 | DF |
| 34. | Lysianopsis alba | 28 | 0.27 | DF |
| 35. | Synapta inhaerens | 28 | 0.27 | NSDF |
| 36. | Polydora ligni | 27 | 0.26 | C/S |
| 37. | Lyonsia hyalina | 27 | 0.26 | SF |
| 38. | Crepidula convexa | 27 | 0.26 | SF |
| 39. | Pectinaria gouldii | 24 | 0.23 | SDF |
| 40. | Oxyurostylis smithi | 24 | 0.23 | SF |
| 41. | Turbonilla interrupta | 21 | 0.20 | P |
| 42. | Aglaophamus verrili | 20 | 0.19 | C/S |
| 43. | Callipallene brevirostris | 20 | 0.19 | C |
| 44. | Diopatra cuprea | 17 | 0.16 | C/S |
| 45. | Glycera americana | 16 | 0.15 | NSDF |
| 46. | Eteone heteropoda | 16 | 0.15 | NSDF |
| 47. | Scoloplos rubra | 15 | 0.14 | NSDF |
| 48. | Syllis gracilis | 15 | 0.14 | C/S |
| 49. | Cerithium muscarum | 14 | 0.13 | DF |
| 50. | Lepidonotus sp. | 14 | 0.13 | C/S |
| 51. | Podarke obscura | 13 | 0.13 | C/S |
| 52. | Exogone hebes | 13 | 0.13 | C/S |
| 53. | Maldane sarsi | 12 | 0.12 | SDF |
| 54. | Odostomia sp. 2 | 11 | 0.11 | PQ |
| 55. | Armandia agilis | 11 | 0.11 | DF |
| 56. | Odostomia sp. 1 | 10 | 0.10 | PQ |
| 57. | Tellina sp. | 10 | 0.10 | SF |
| 58. | Scoloplos sp | 10 | 0.10 | NSDF |
| 59. | Laevicardium mortoni | 7 | 0.07 | SF |
| 60. | Cystisomid amphipod | 7 | 0.07 | DF |
| 61. | Chione cancellata | 6 | 0.06 | SF |
| 62. | Haminoea antillarum | 6 | 0.06 | C |
| 63. | Glycinde solitaria | 6 | 0.06 | NSDF |
| 64. | Nassarius vibex | 4 | 0.04 | NSDF |

Table 2 (continued)

| | | No. | % | Feeding Type |
|---|---|---|---|---|
| 65. | Caprella equilibra | 4 | 0.04 | C |
| 66. | Potamilla sp. | 4 | 0.04 | SF |
| 67. | Mitrella lunata | 4 | 0.04 | S |
| 68. | Gemma gemma | 4 | 0.04 | SF |
| 69. | Cerithiopsis emersonii | 3 | 0.03 | C |
| 70. | Anomalocardia cuneimeris | 3 | 0.03 | SF |
| 71. | Nucula proxima | 3 | 0.03 | DF |
| 72. | Amygdalum papyri | 3 | 0.03 | SF |
| 73. | Tagelus divisus | 2 | 0.02 | SF |
| 74. | Panopeus herbstii | 1 | 0.01 | C/S |
| 75. | Mysid | 1 | 0.01 | NSDF |
| 76. | Stauronereis rudolphi | 1 | 0.01 | DF |
| | Total | 10,390 | | |

DF = deposit feeder

SF = suspension feeder

C = carnivore

H = herbivore

S = scavenger

P = ectoparasite

NS = non-specific

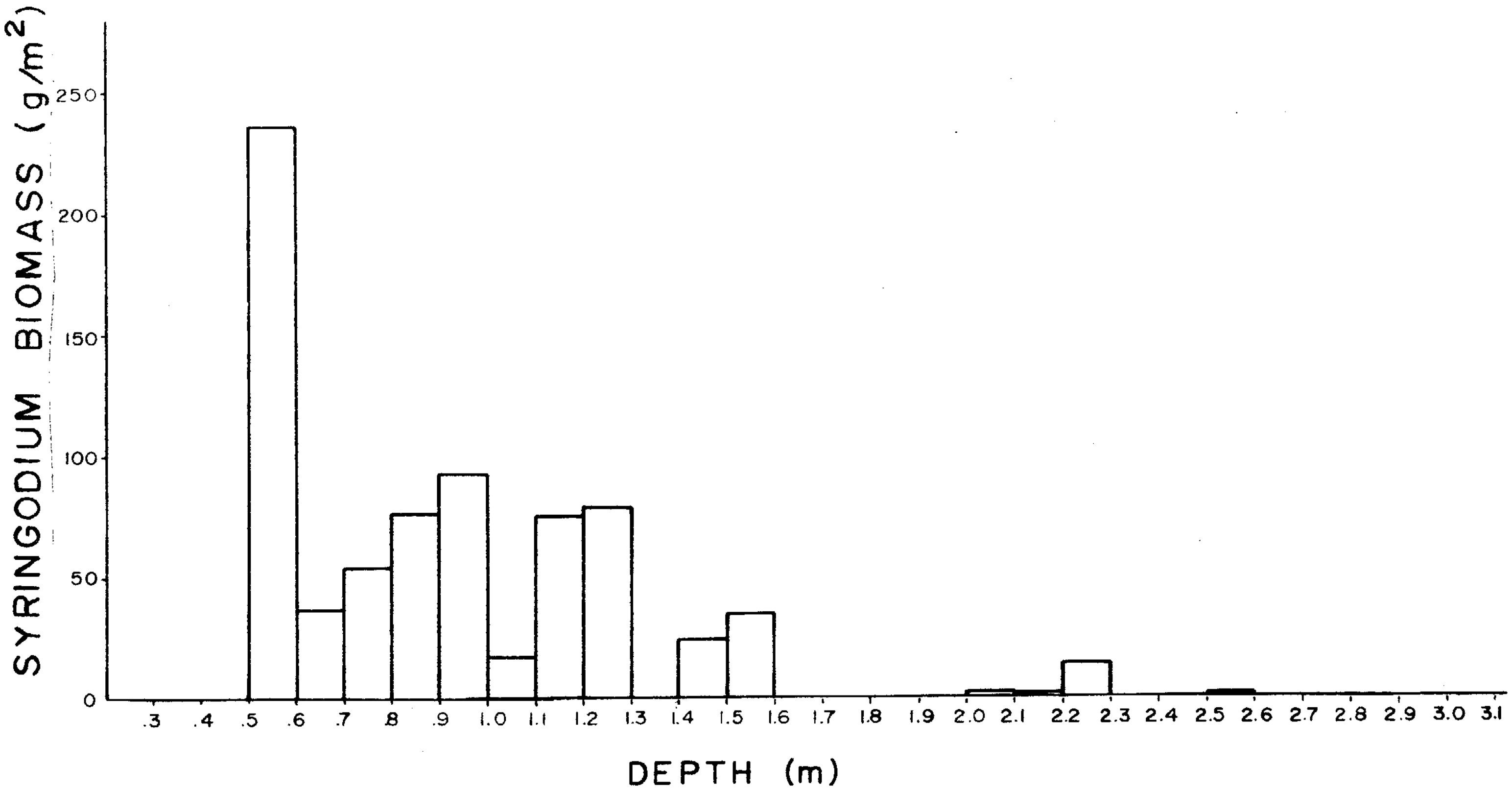


Figure 2-7. Vertical zonation of *Syringodium*, July, 1974.

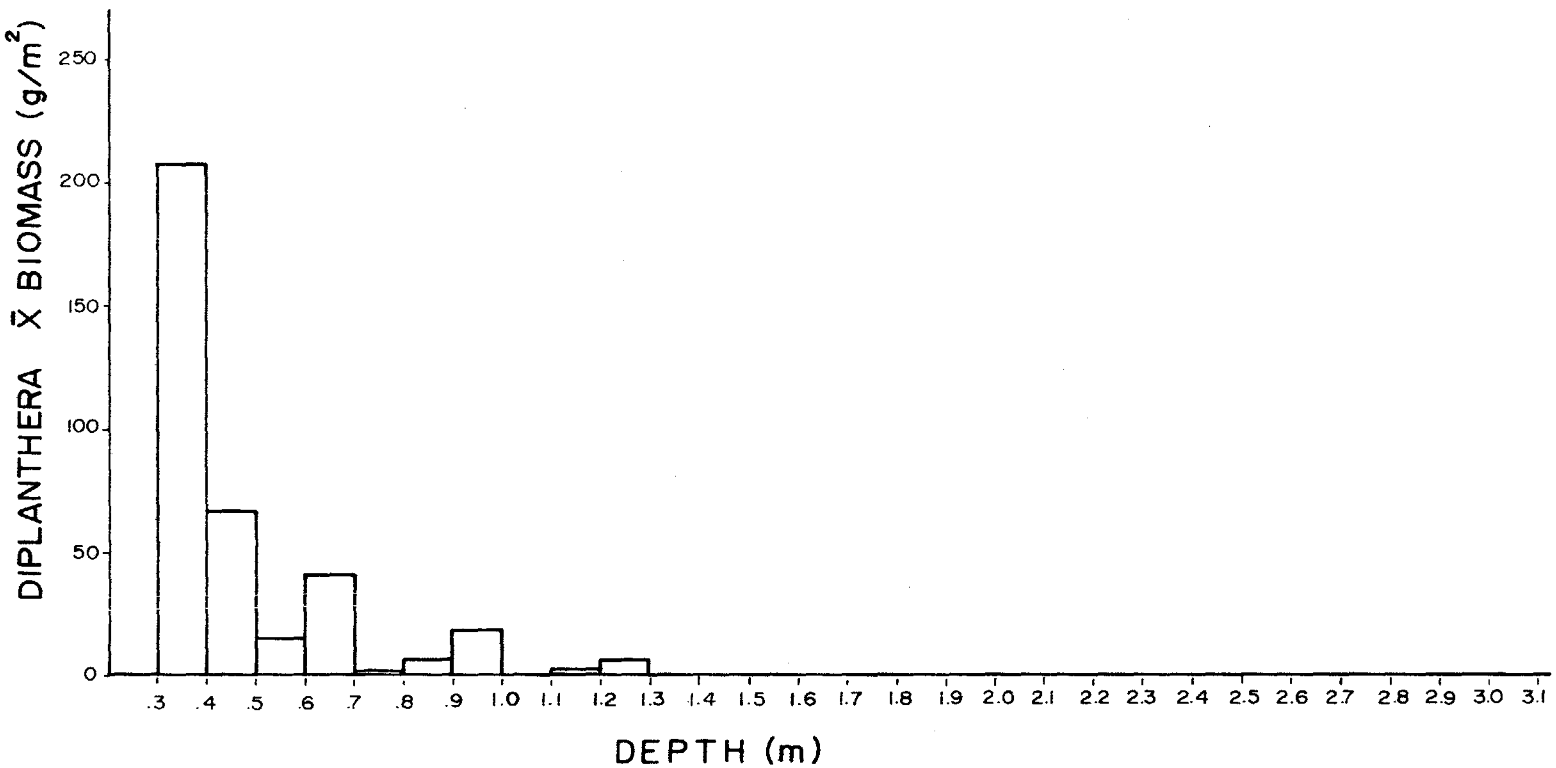


Figure 2-8. Vertical zonation of Diplanthera wrightii, July, 1974.

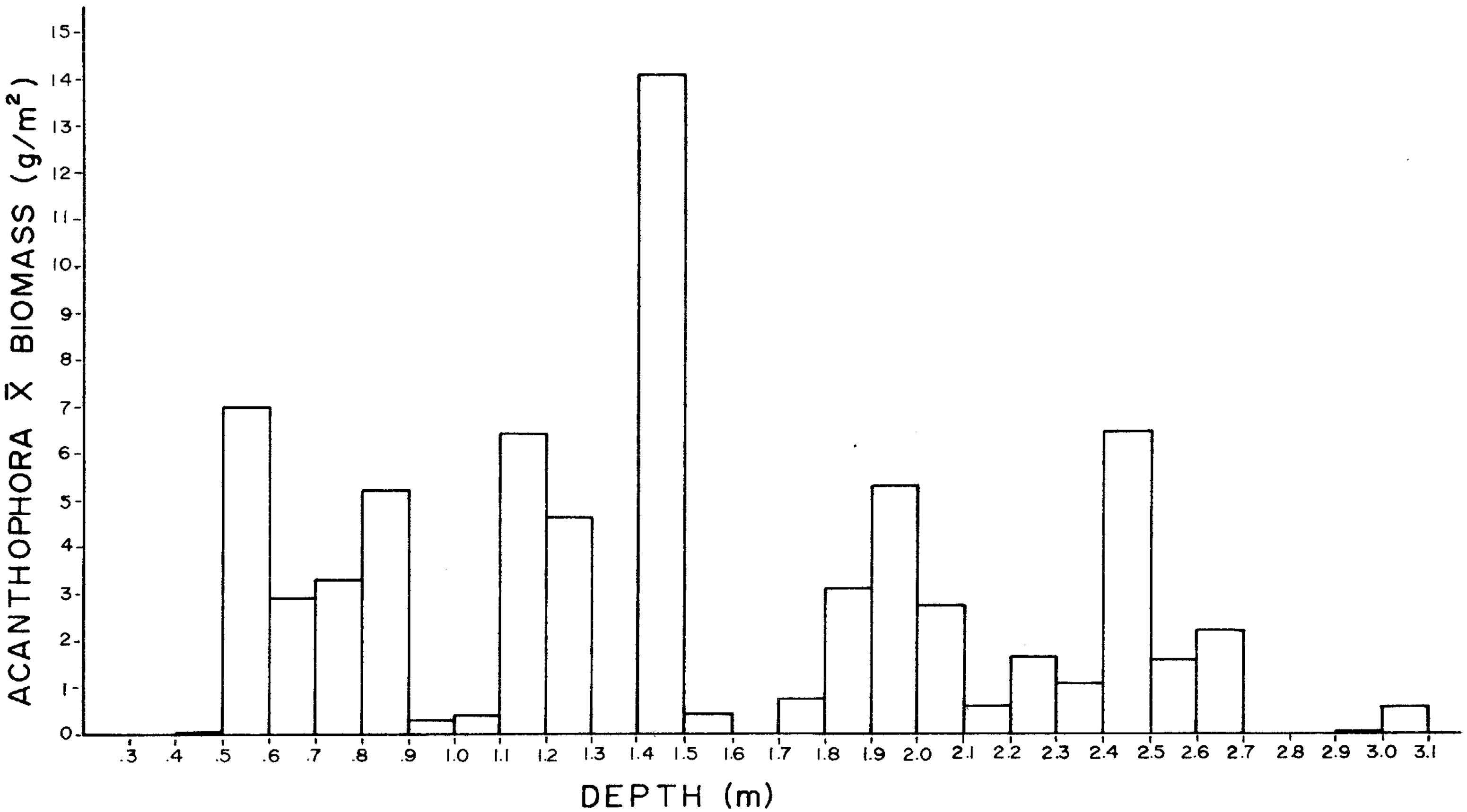


Figure 2-9. Vertical zonation of <u>Acanthophora</u>, July, 1974.

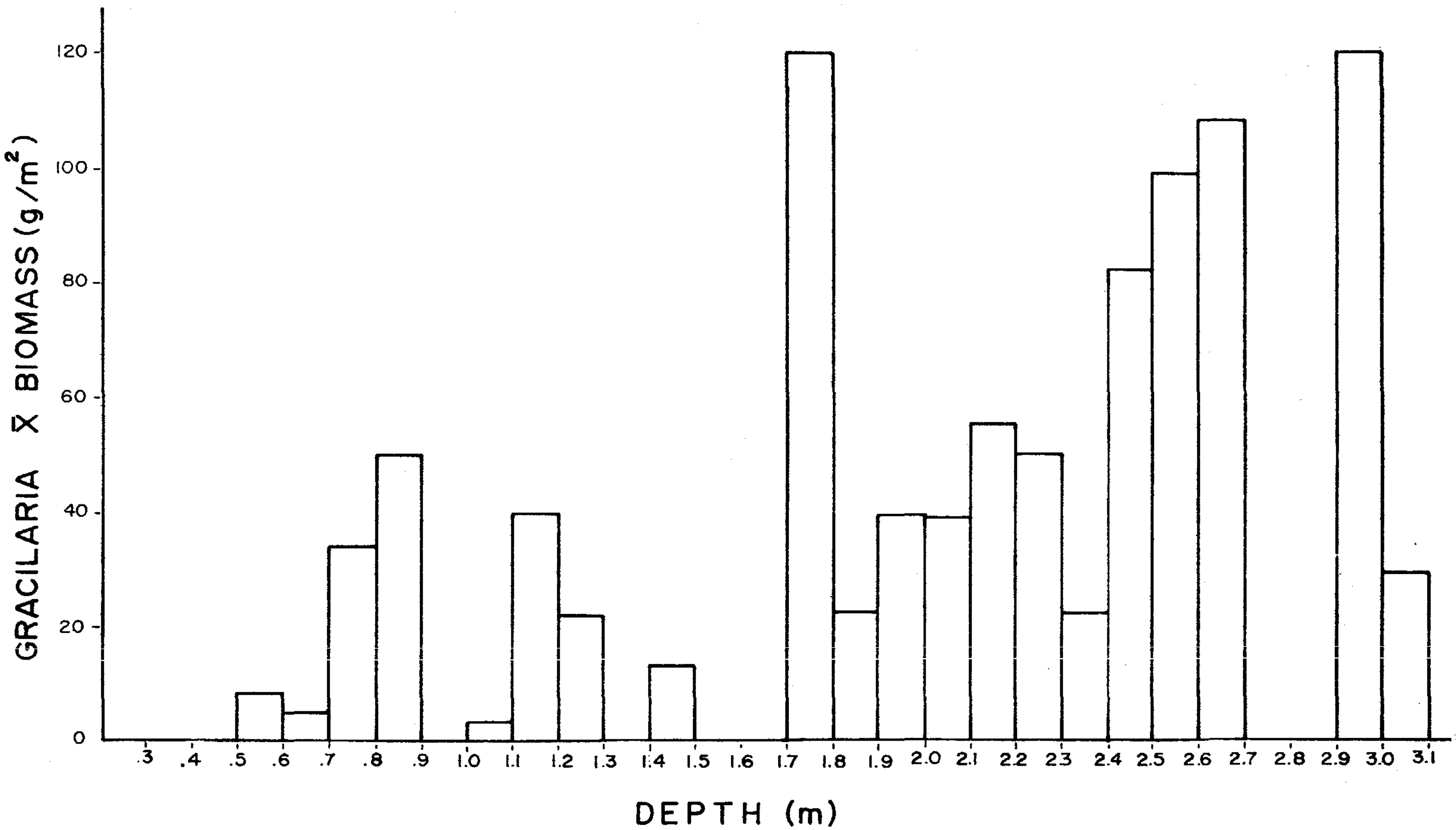


Figure 2-10. Vertical zonation of <u>Gracilaria</u>, July, 1974.

Syringodium, and does not grow deeper than 1.3 m. Syringodium has its greatest density between 0.5 and 0.6 m, but has a fairly uniform density between 0.6 and 1.3 m, gradually declining to a depth of 2.6 m.

In contrast, the Rhodophyta Gracilaria and Acanthophora, which are not permanently attached, tend to drift randomly with currents in the river and hence show less evidence of zonation. The distribution of Acanthophora is essentially random, though apparently excluded from the dense beds of Diplanthera and Syringodium in depths less than 0.5 m. Gracilaria appears to show a slight skew toward increased depths, and is also excluded from depths less than 0.5 m.

Seasonal Changes in the Benthic Community:

Temperature and salinity cycles within the quadrat (figure 3) for the period of August 1974 to October 1975 are shown in figure 11; pH and dissolved oxygen cycles are given in figure 12, and the seasonal changes in organic carbon of the sediments are shown in figure 13.

Salinity, temperature, and probably pH are strongly influenced by local climatic patterns, largely as the result of the shallowness of the Indian River; the high surface/volume ratio increases the rates of exchange between the river and its environs. The temperature cycle reflects rapid fluctuations effected by changes in air temperature and solar heating. Peak temperatures are reached in July and August, and minimum temperatures occur from December through March. Bottom temperatures are slightly less variable, indicating that the sediments may function as a thermal buffering system. Salinity varies nearly inversely with temperature, reflecting dilution by rainfall and runoff during peak summer rainfall periods.

The general decline in dissolved oxygen values appears to be an artifact of sampling technique; as sampling efficiency increased, sampling occurred somewhat earlier during the day, and the diurnal cycle has been impressed on the seasonal cycle. The pH seems to show no definite trend, though minimum values occur in summer, possible reflecting decreased buffering capacity of the water when diluted by rainwater and acid terrestrial runoff.

Organic carbon levels in sediments show a clear cycle effect, with a sudden increase in November, followed by a progressive and gradual decline through October. (figure 13).

Seasonal changes in macrophyte standing crop (biomass) within the quadrat

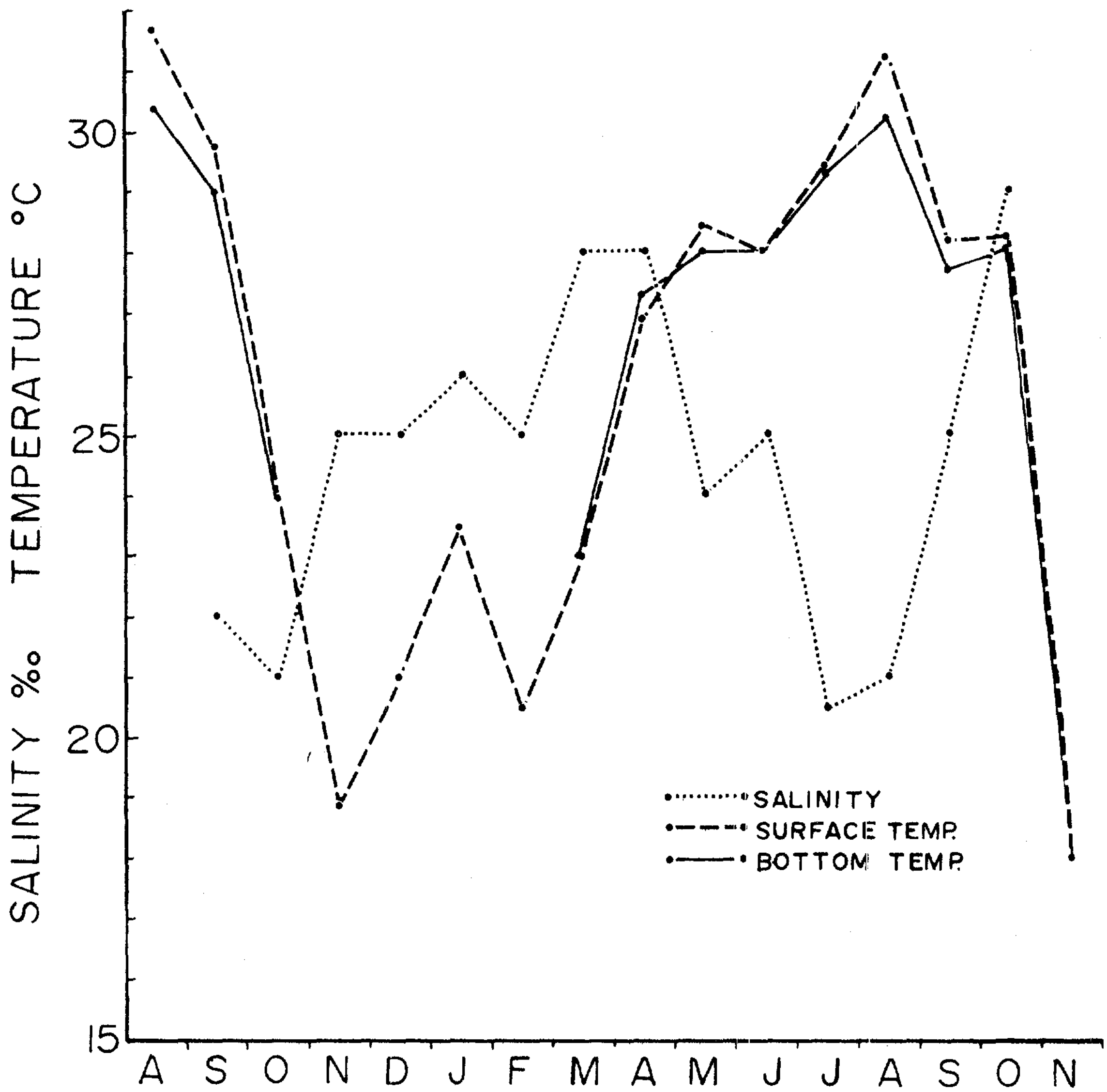


Figure 2-11. Variation in temperature and salinity of seasonal quadrat study area, 1974-1975.

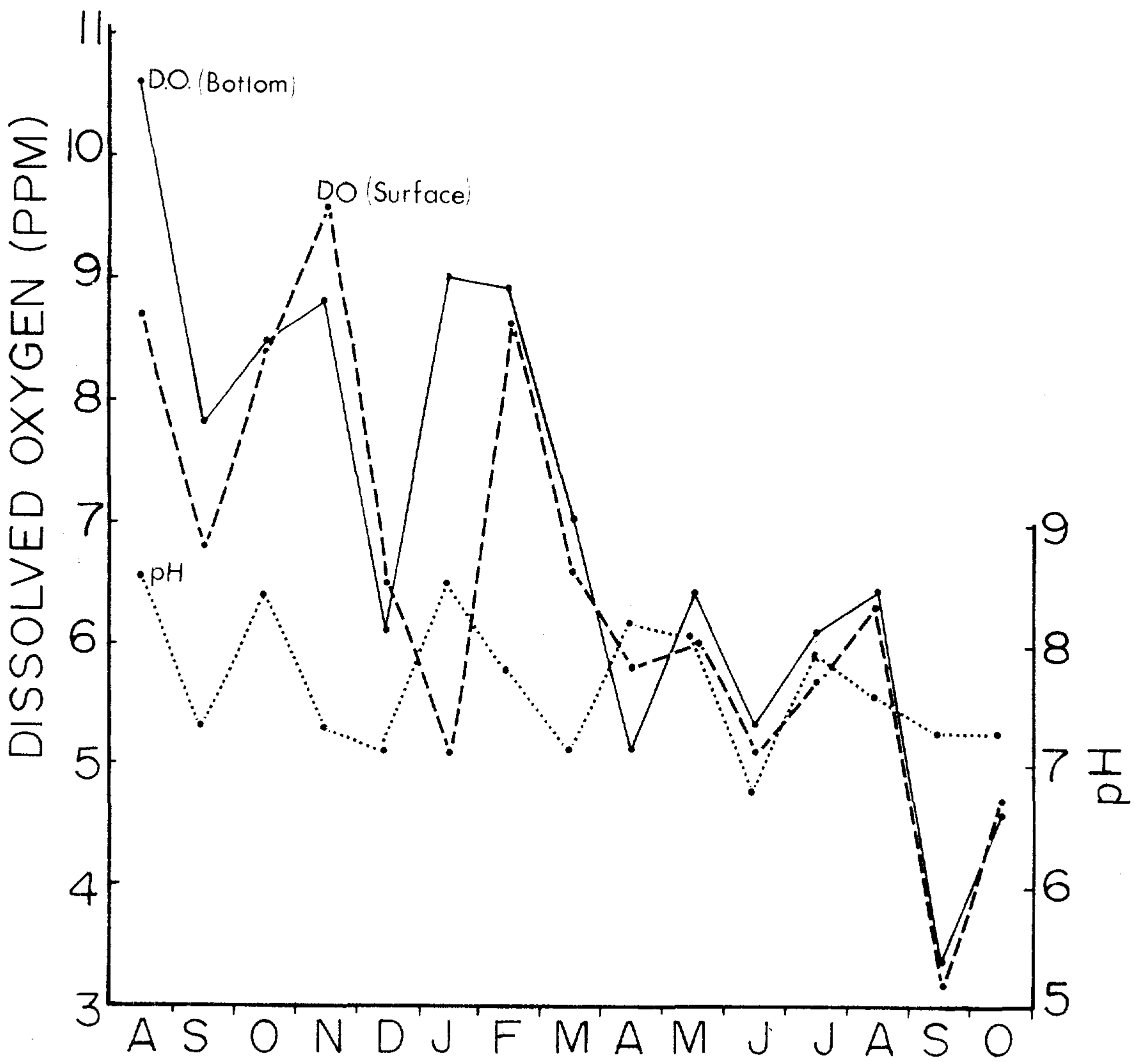


Figure 2-12. Variation in pH and dissolved oxygen, 1974-1975.

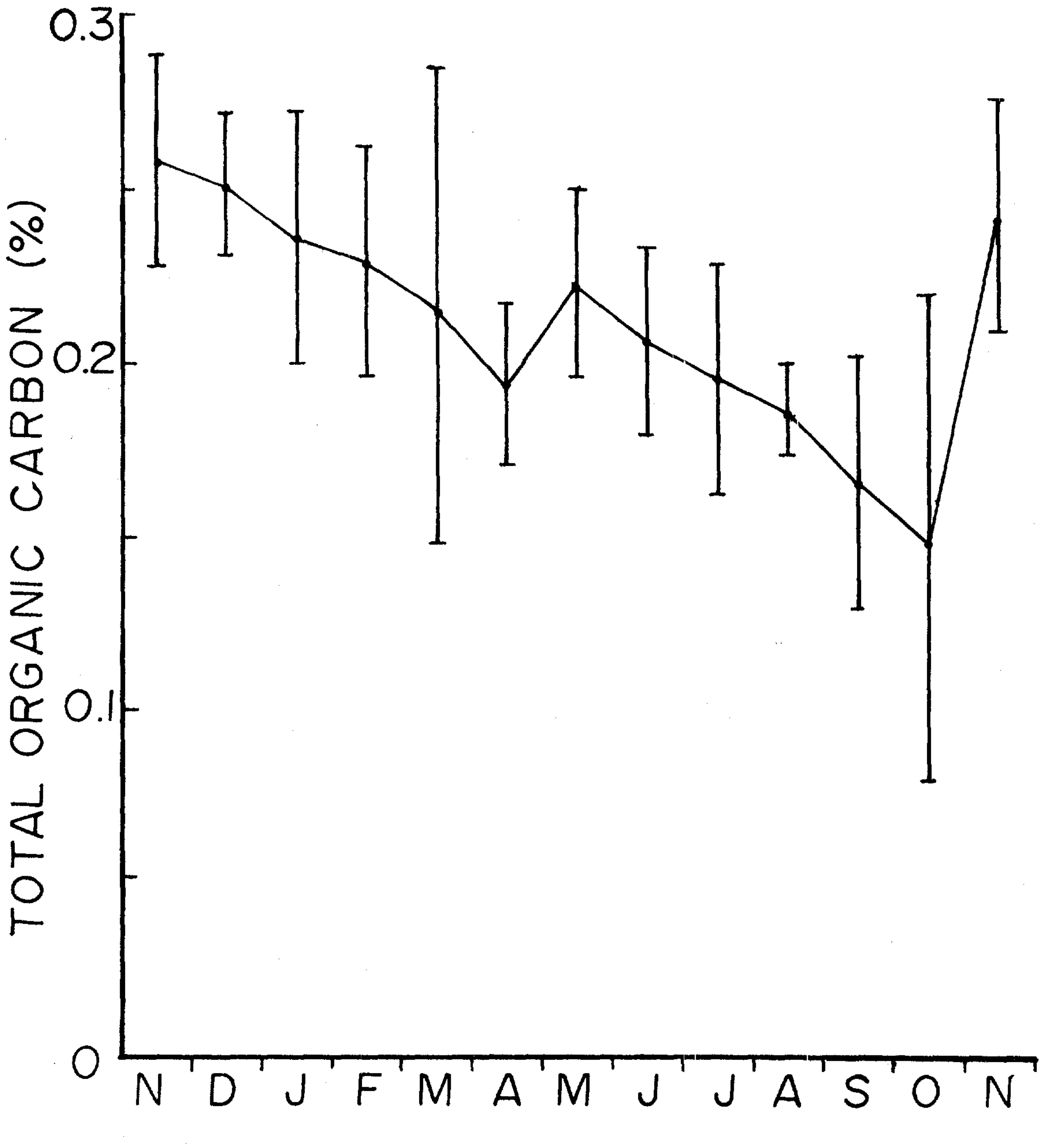


Figure 2-13. Monthly variation of total organic carbon in sediments of five stations in seasonal quadrat study area; means and standard deviations are shown.

are shown in figures 14 and 15. Six species (table 3) of algae and seagrasses occur within the quadrat; the different species have different peak biomass periods, but the total biomass is dominated by the peak of Syringodium in October. Changes in individual stations within the quadrat have been plotted in figure 16 to show the cycle of extension and dieback by vegetative growth from rhizomes. These patterns can be seen as progressive changes in the number of blank areas and as increases in density of occupied cells.

Changes in population densities of the dominant species of benthic invertebrates are shown in figures 17-32, and the combined densities of major deposit feeders, major suspension feeders, and total species are shown in figure 33. Peak densities have been summarized in table 4, together with estimated reproductive periods. The following criteria have been used to define the periods of reproduction: where sharp increases of populations occur following the minimum population densities (i.e. minimum to maximum within a few weeks), reproduction is assumed to be synchronous, limited in duration, and to occur several weeks prior to the beginning of the peak. Species showing slower changes in density, without pronounced peaks or minima, are assumed to have continuous production and recruitment of juveniles.

Shallow Depth Zonation:

A summary for the shallow-water transect (0-1 m) is shown in figure 34. This figure confirms the validity of the large-scale transect summarized in figures 7-10, but presents additional data describing the zonation of the third species of seagrass, Halophila engelmannii.

Productivity Estimation:

Net production can be estimated by the change from minimum to maximum biomass, and has been summarized in table 5. When related to temperature (figure 35), production appears to be confined to periods with temperatures in excess of $24^{o}C$.

Plankton:

Monthly variations in densities of the three major components of the plankton of the North Indian River (Diatoms, dinoflagellates, and copepods) are shown in figure 36. Densities of producers (diatoms and dinoflagellates) are low (less than 5000 cells/liter) and correlate with periods of rainfall. Consumer densities (copepods) are relatively constant.

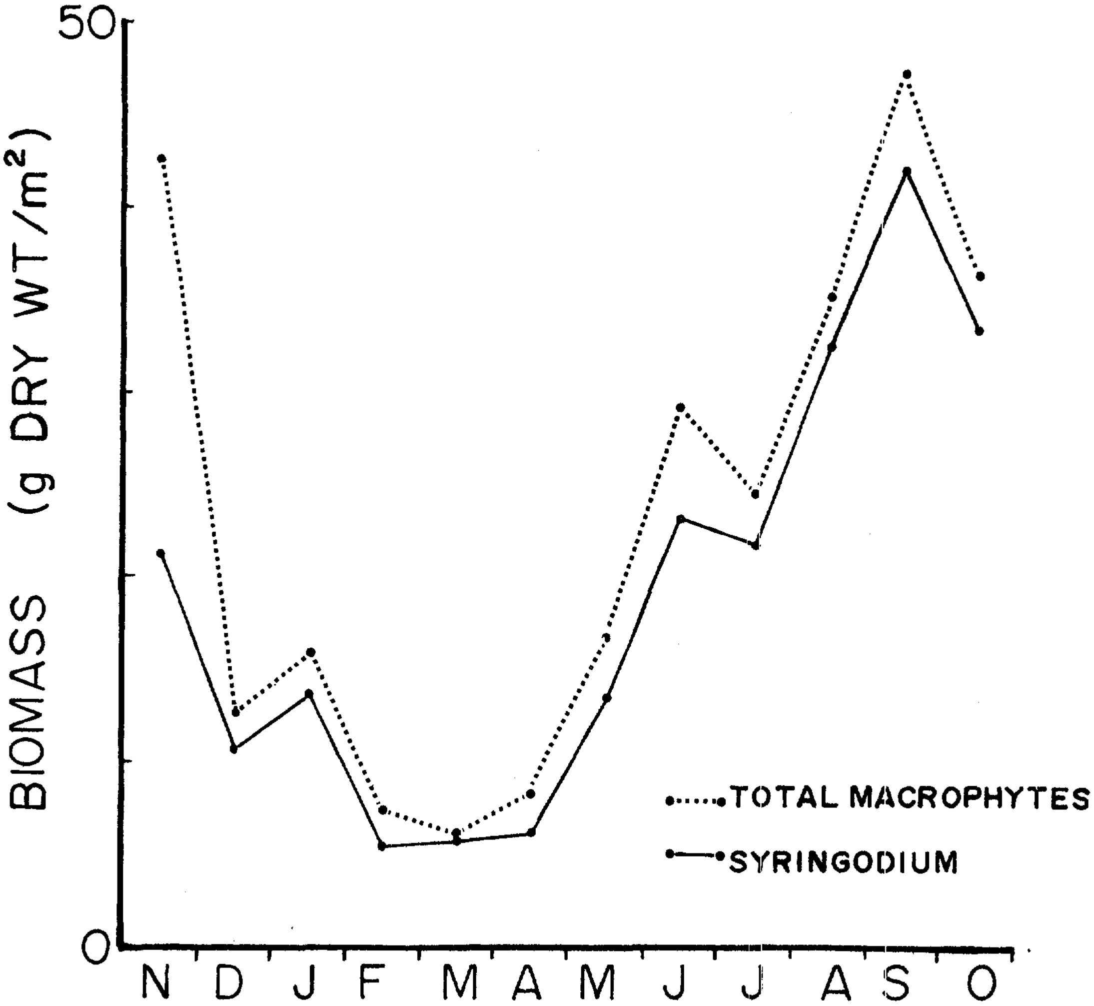


Figure 2-14. Seasonal variation of biomass of *Syringodium* and total macrophytes, 1974-75.

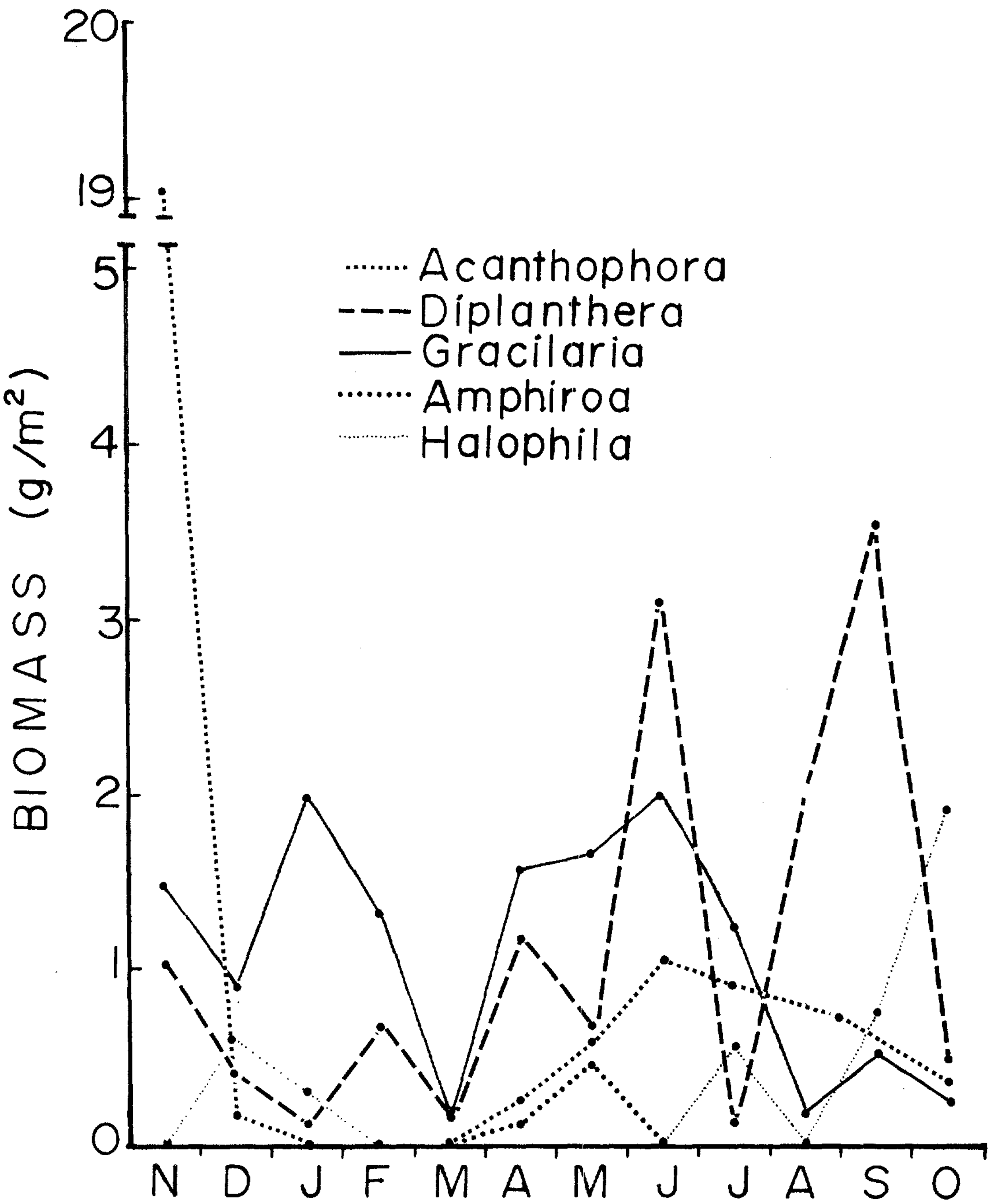


Figure 2-15. Growth cycle of minor macrophytes in the seasonal quadrat, 1974-75.

Table 3.

Maximum standing crop of macrophytes from seasonal quadrat in North Indian River

| Species | Date | Temp. | Peak Mean Biomass |
|---|---|---|---|
| *Syringodium filiforme* | October | $30^{o}C$ | 40 $g/m^2$ |
| *Acanthophora spicifera* | November | $22^{o}$ | 19 |
| *Diplanthera wrightii* | September | $31^{o}$ | 3.5 |
| *Gracilaria verrucosa* | June, Jan. | $20^{o}$ | 2.0 |
| *Halophila engelmannii* | October | $30^{o}$ | 2.0 |
| *Amphiroa brasiliana* | May | $25^{o}$ | 0.5 |

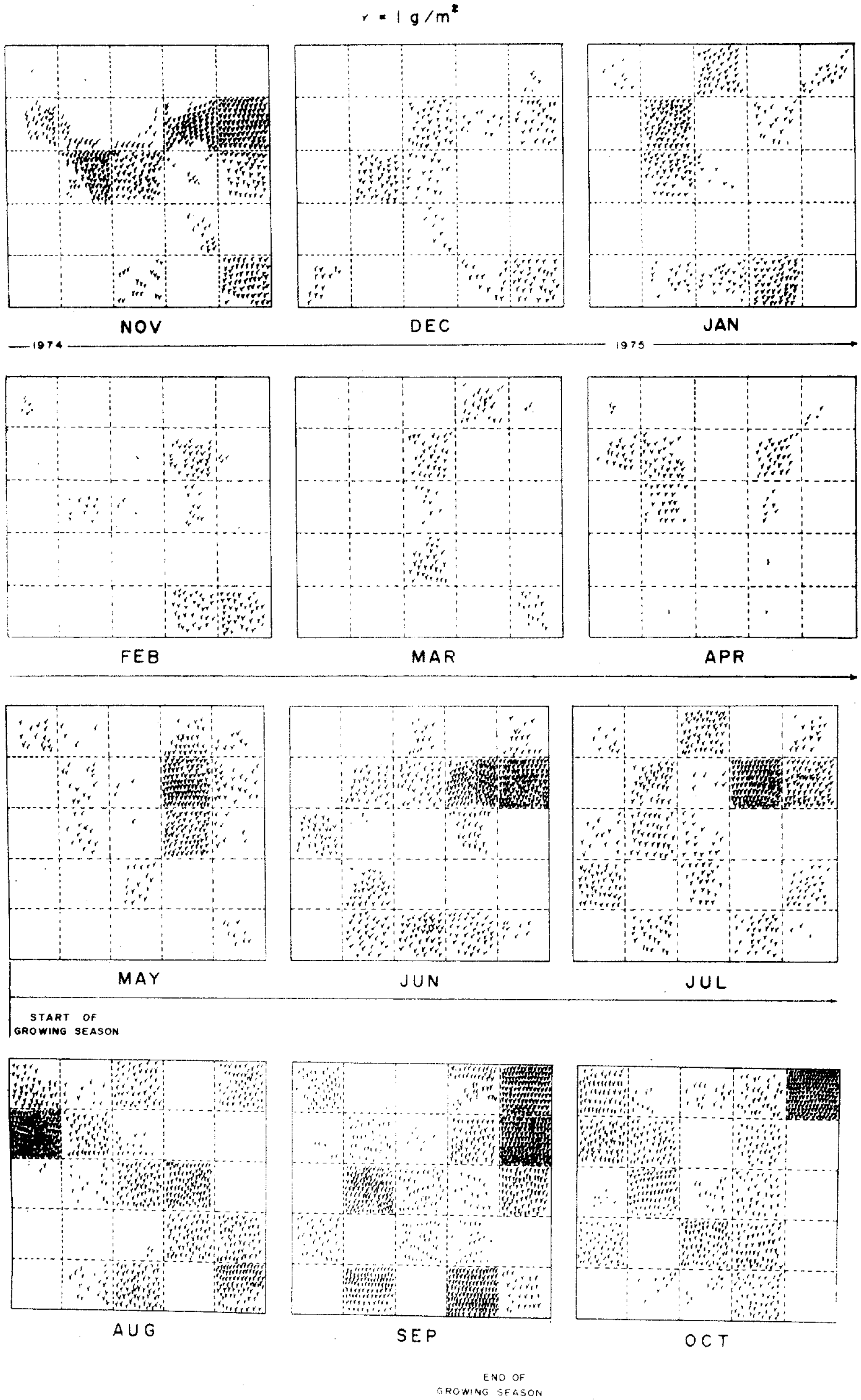


Figure 2-16. Biomass changes of Syringodium (Cymodocea) at individual stations in seasonal quadrat study area, 1974-75.

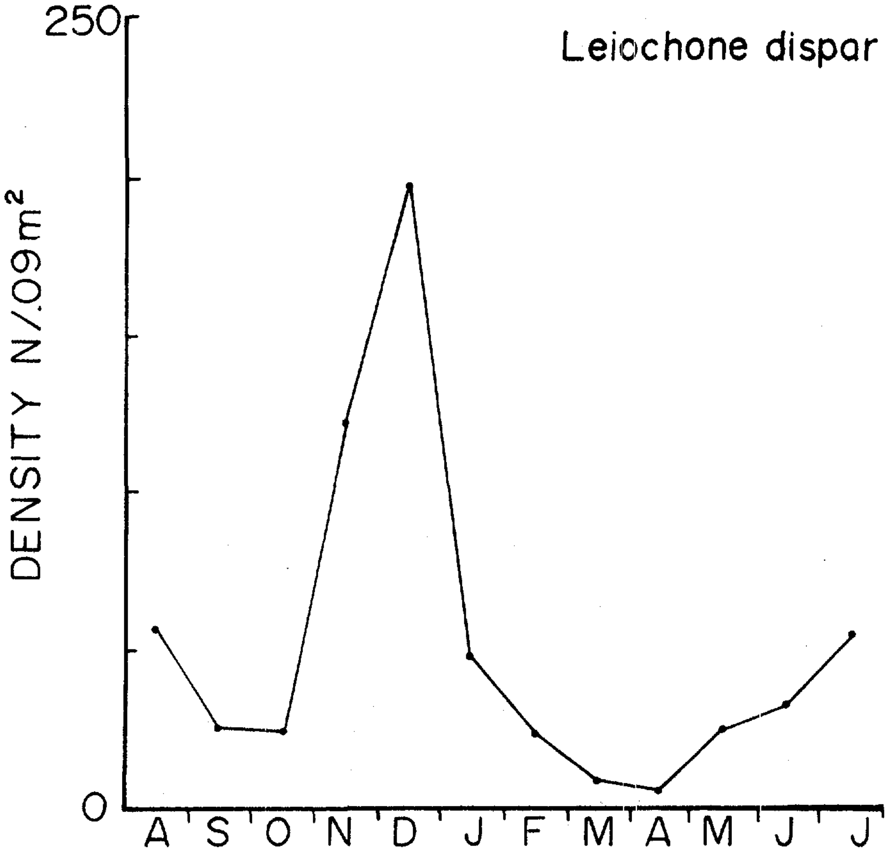


Figure 2-17. Population changes of Leiochone dispar, 1974-75.

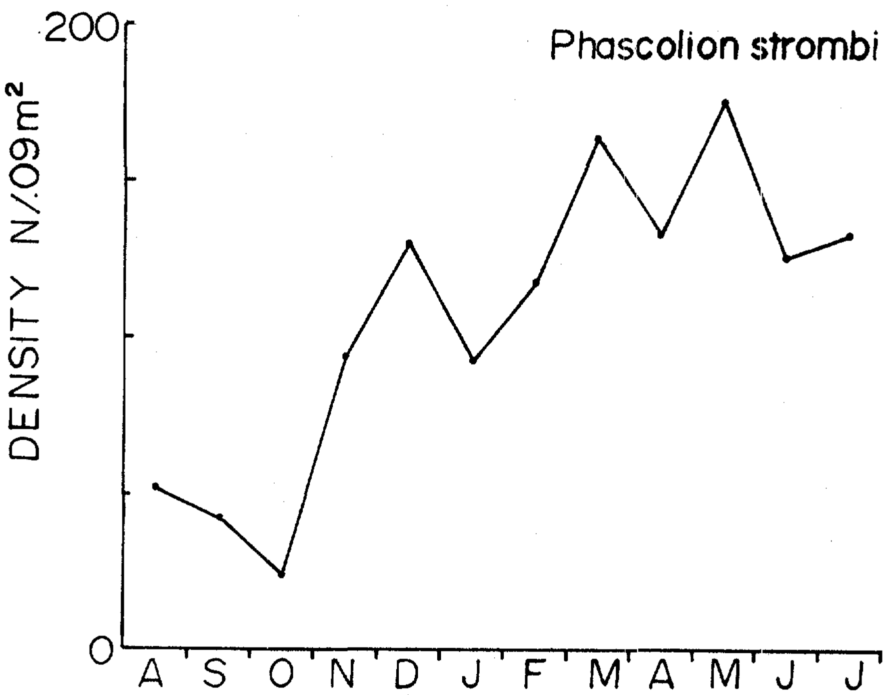


Figure 2-18. Population changes of Phascolion strombi, 1974-75.

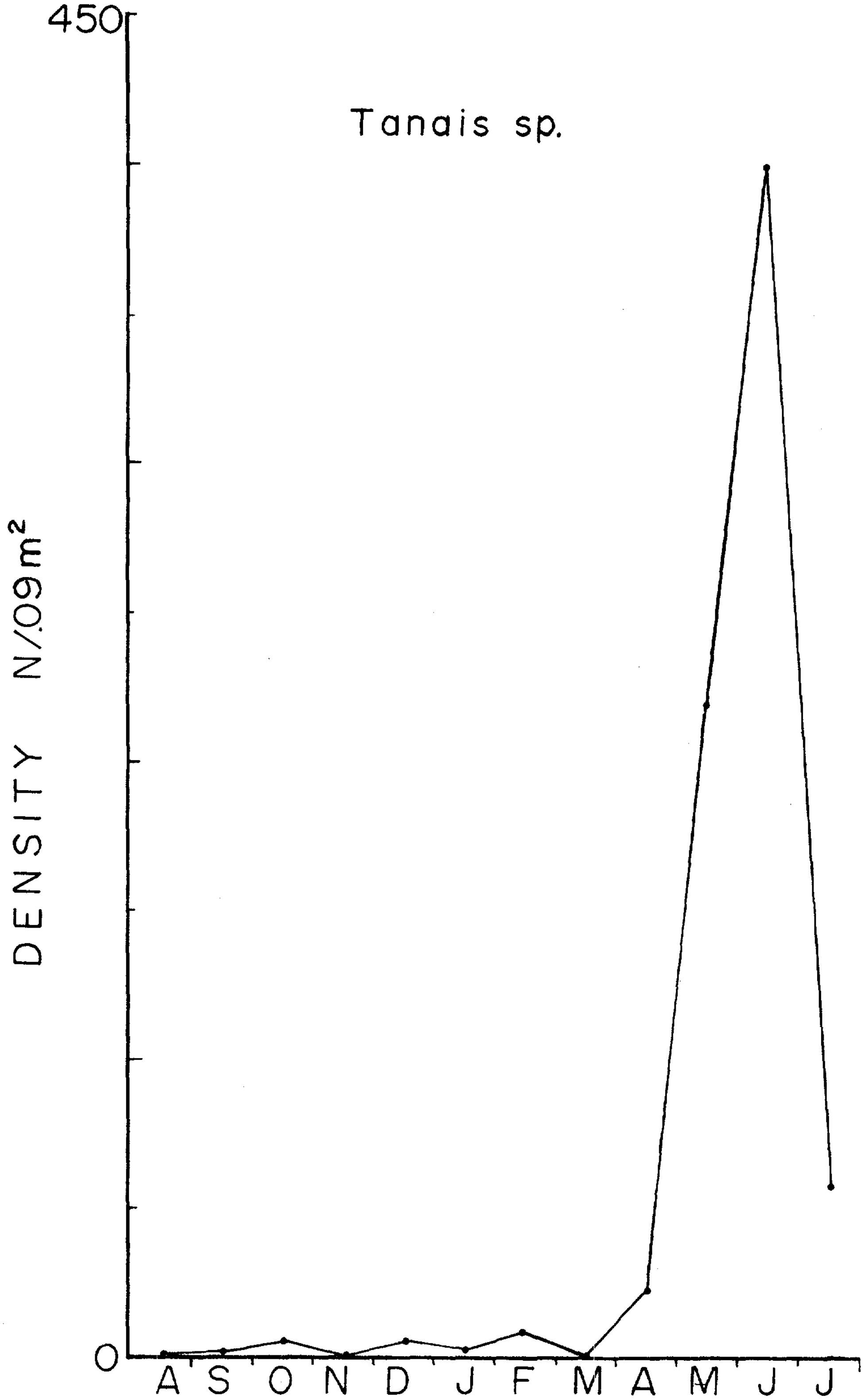

Figure 2-19. Population cycle of Tanais sp., 1974-75.

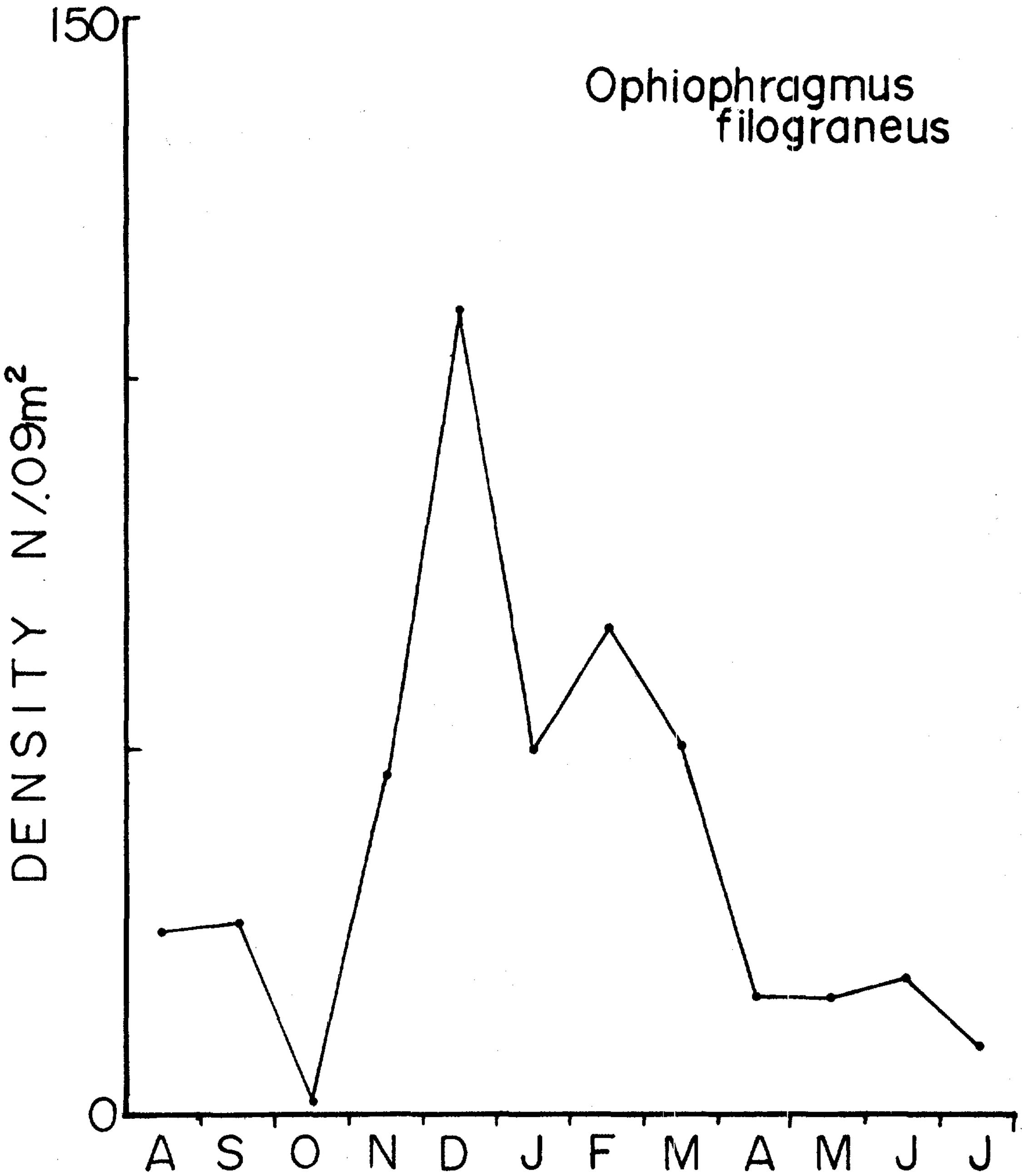


Figure 2-20. Population cycle of Ophiophragmus filograneus, 1974-75.

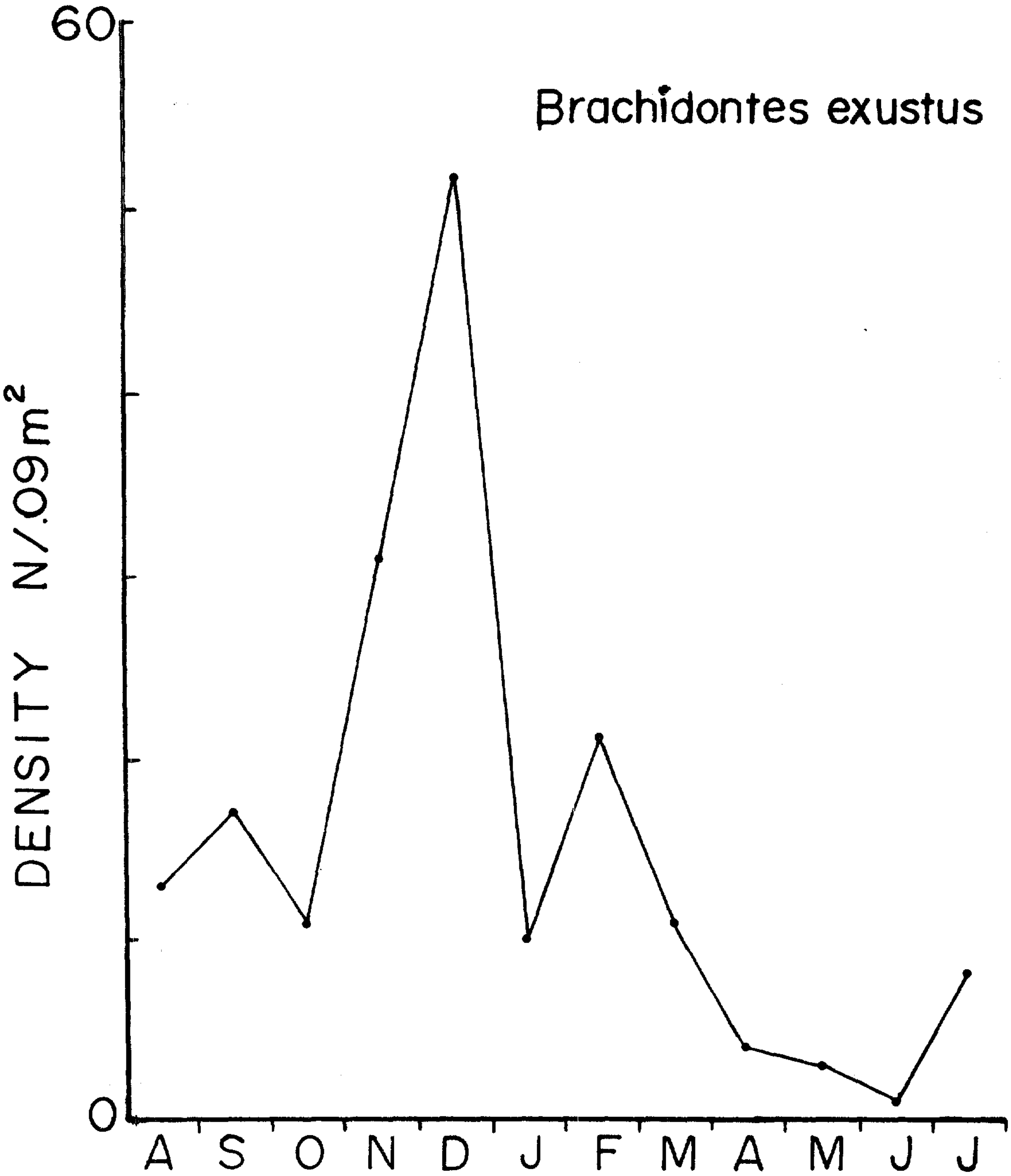


Figure 2-21. Population cycle of Brachidontes exustus, 1974-75.

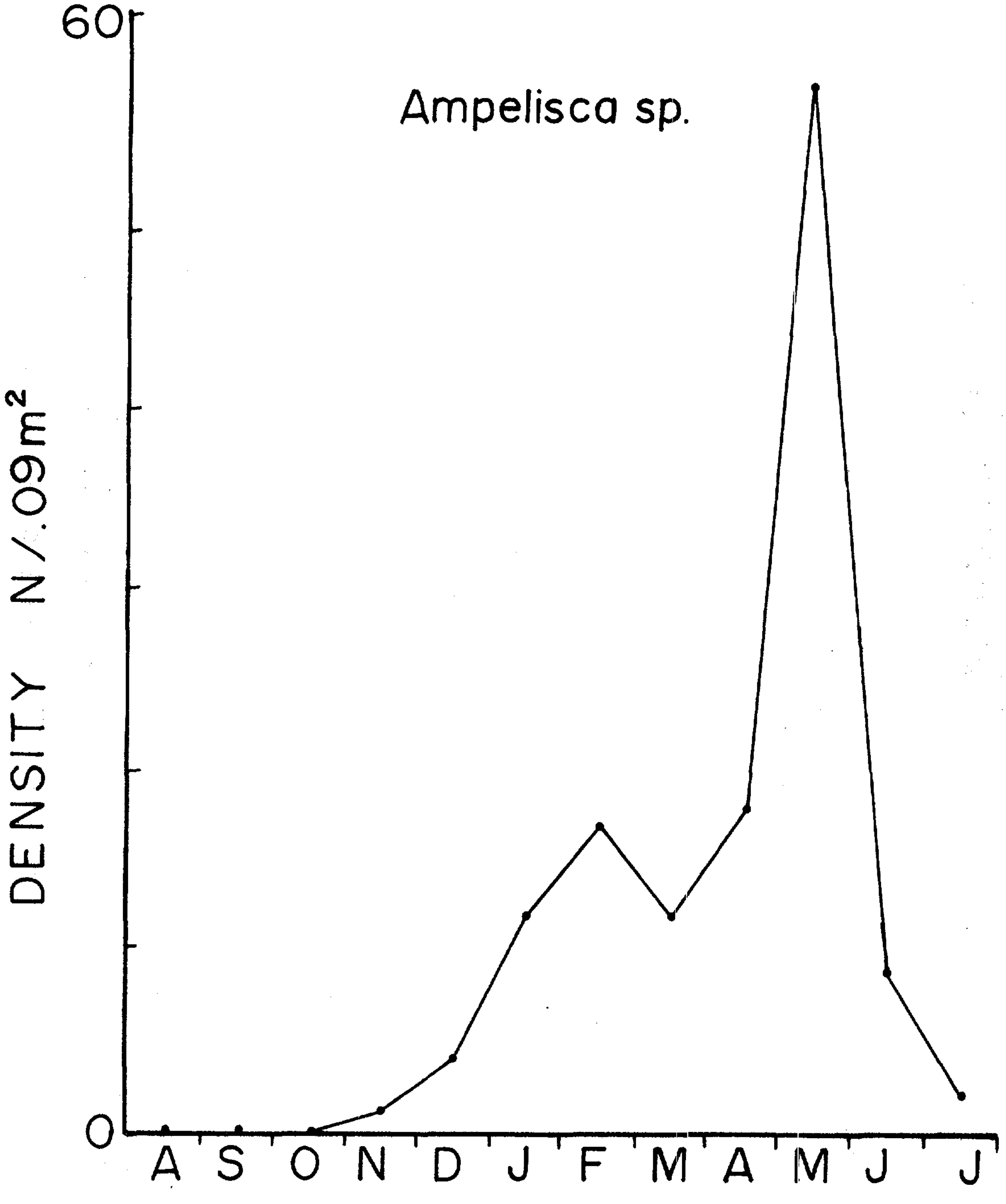


Figure 2-22. Population cycle of Ampelisca sp., 1974-75.

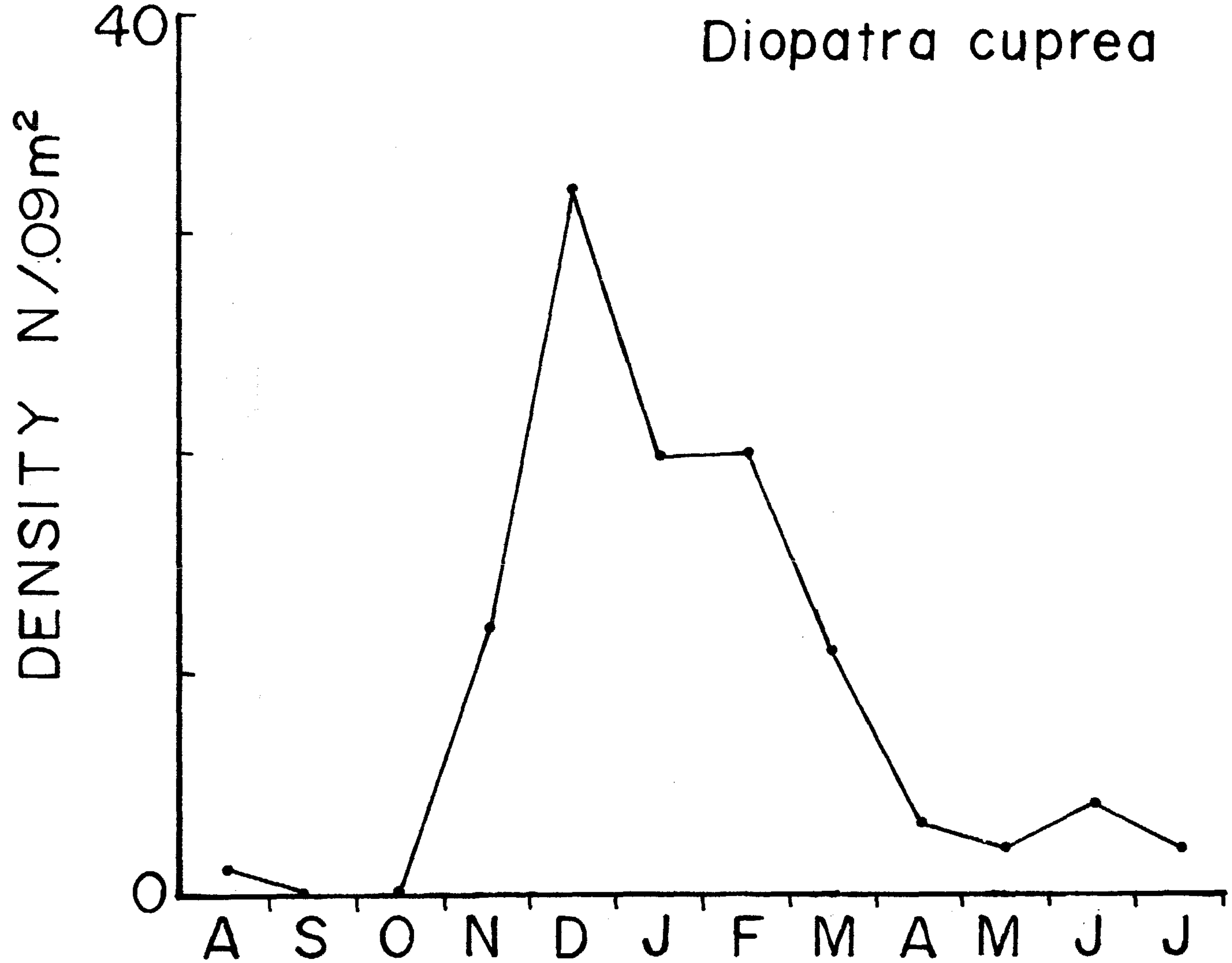


Figure 2-23. Population cycle of <u>Diopatra</u> <u>cuprea</u>, 1974-1975.

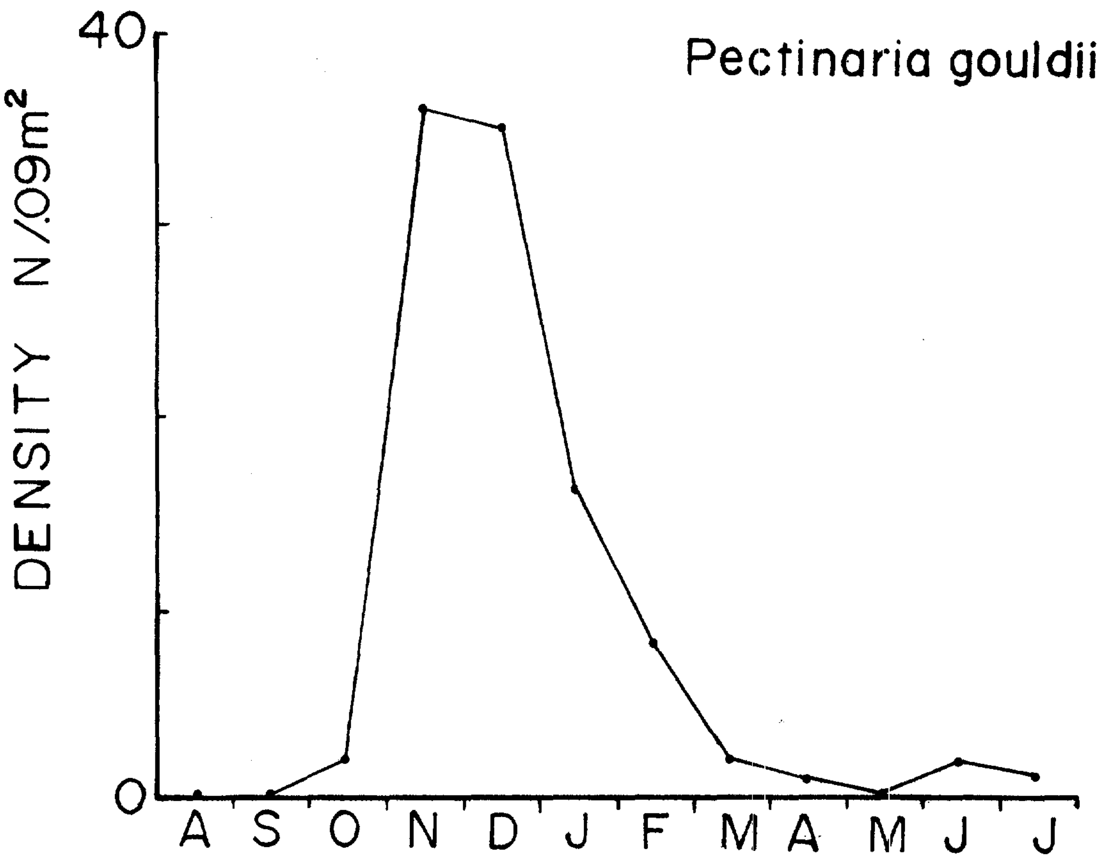


Figure 2-24. Population cycle of Pectinaria gouldii, 1974-75.

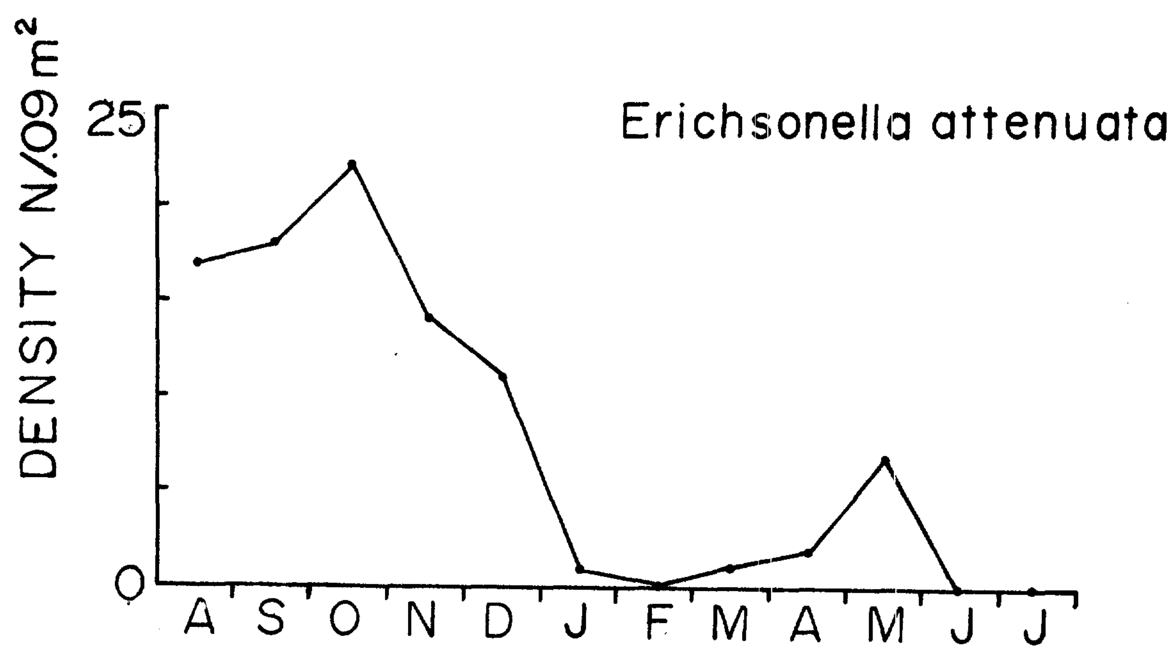


Figure 2-25. Population cycle of Erichsonella attenuata, 1974-75.

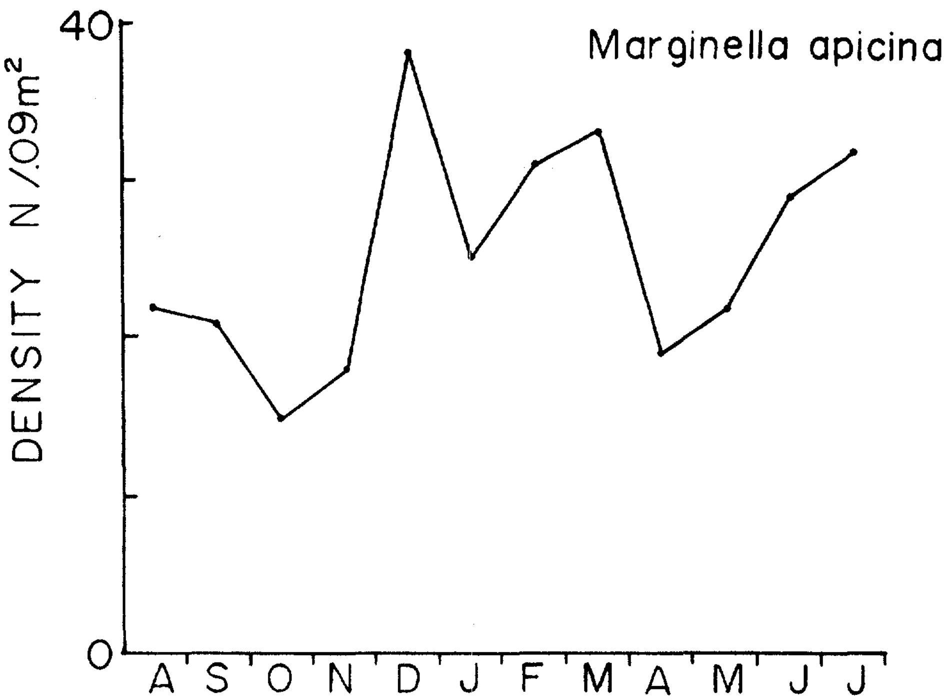


Figure 2-26. Population cycle of Marginella apicina, 1974-75.

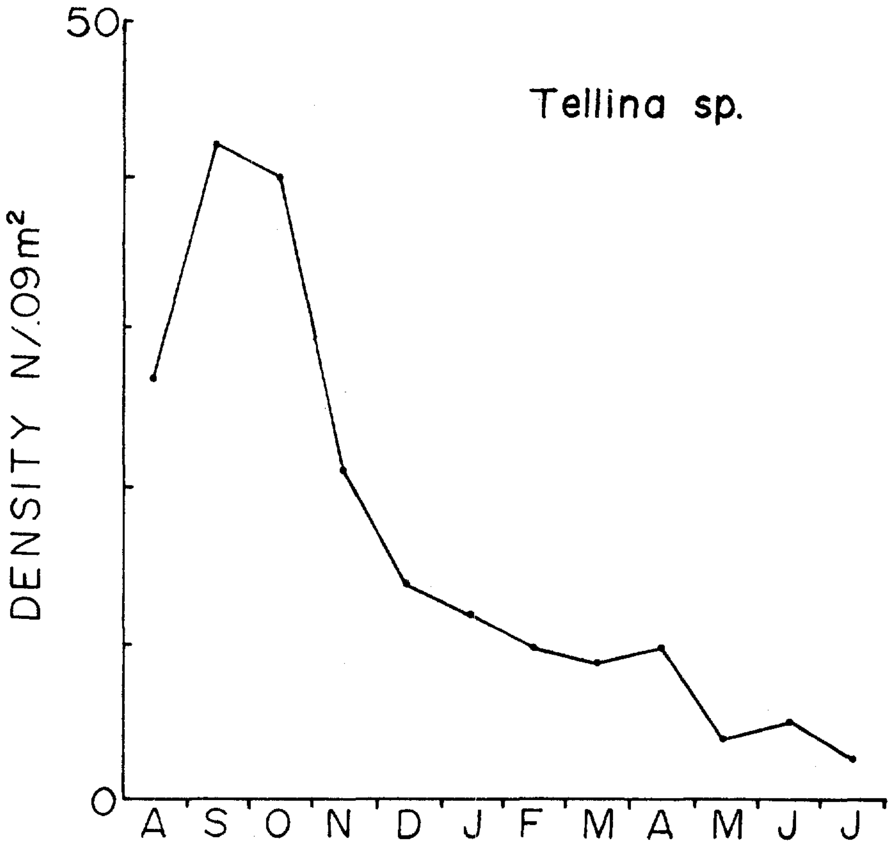


Figure 2-27. Population cycle of Tellina sp., 1974-75.

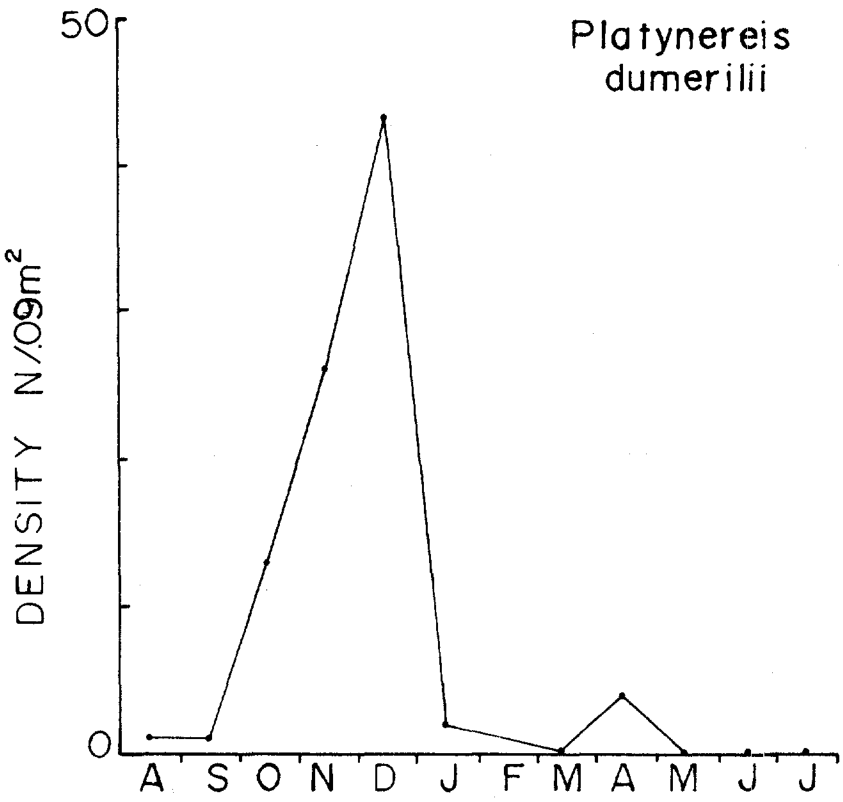


Figure 2-28. Population cycle of Platynereis dumerilii, 1974-75.

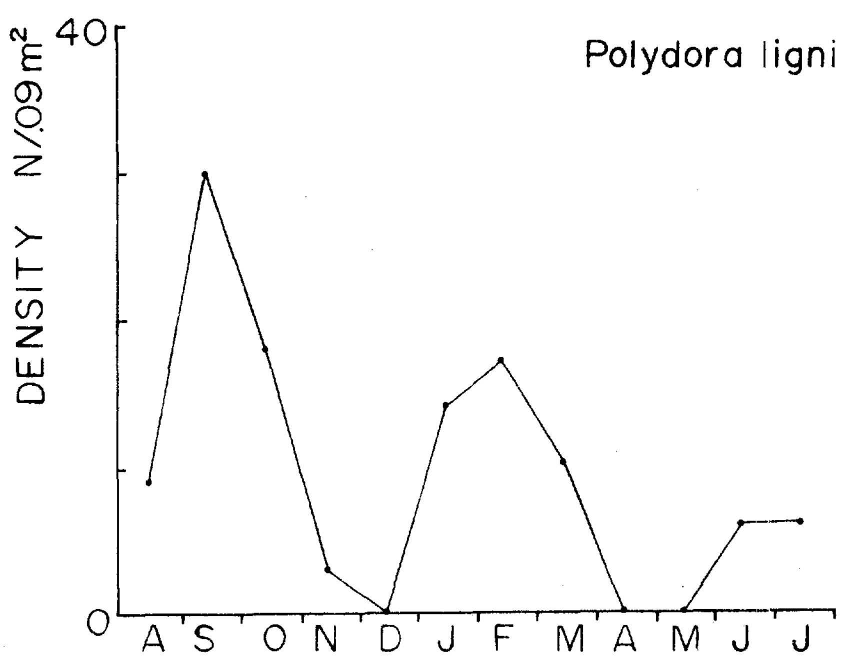


Figure 2-29. Population cycle of Polydora ligni, 1974-1975.

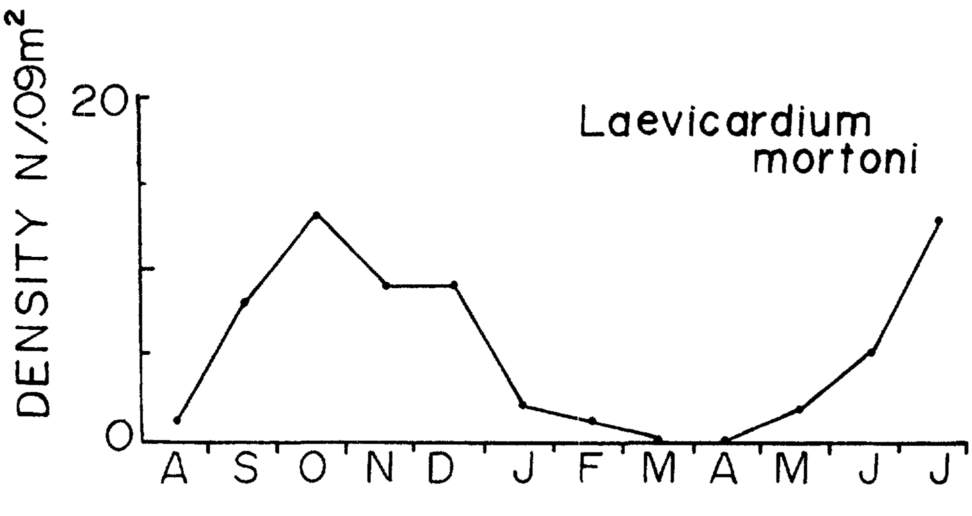


Figure 2-30. Population cycle of Laevicardium mortoni, 1974-1975.

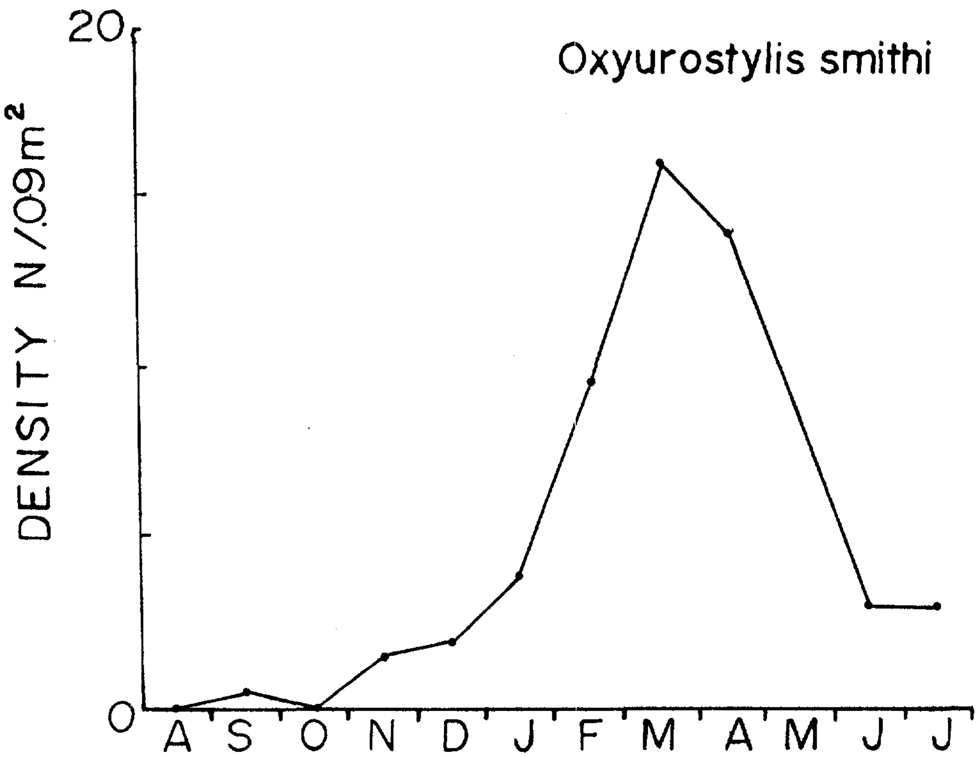


Figure 2-31. Population cycle of Oxyurostylis smithi, 1974-1975.

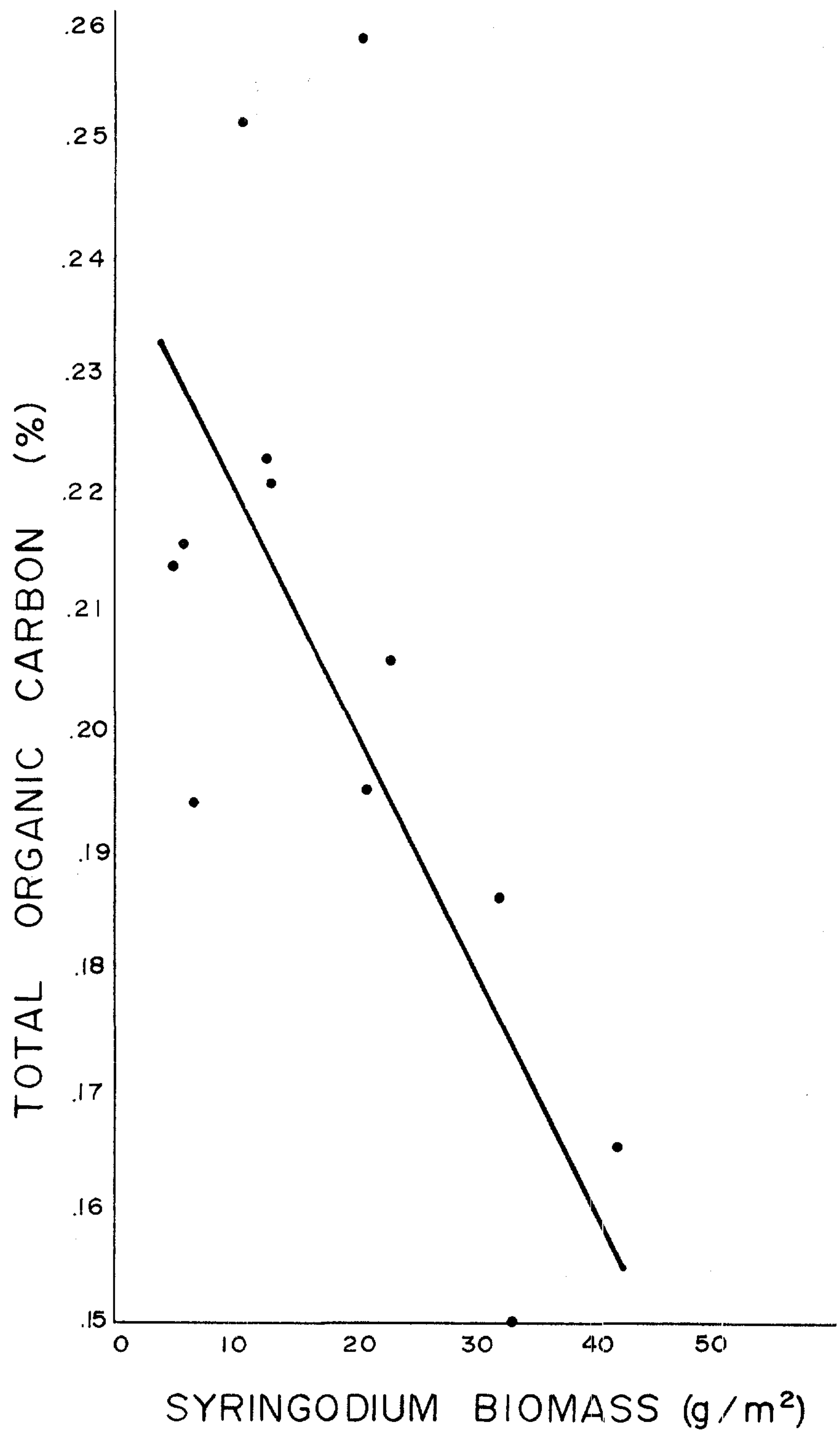


Figure 2-32. Relationship of total organic carbon to Syringodium biomass of previous month, 1974-1975.

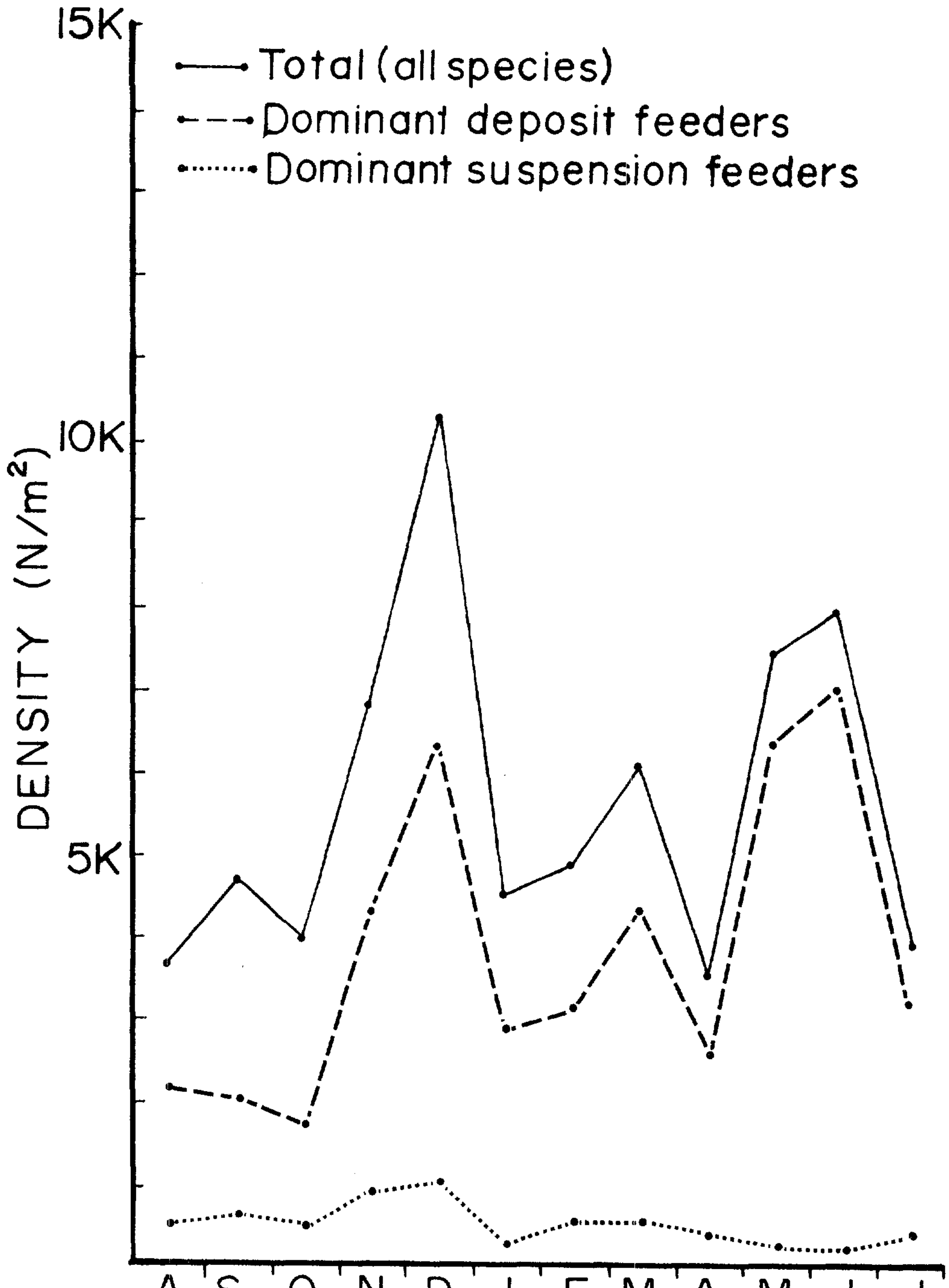


Figure 2-33. Seasonal variation of populations of major trophic groups and combined total of all species.

Table 4.

Peak populations and estimated reproductive periods of dominant benthic invertebrates.

| Organism | Feeding Type | Peak Population | Estimated Reproduction |
|---|---|---|---|
| Tanais | DF | June | February, March |
| Leiochone | DF | December | October |
| Ophiophragmus | NSDF | December | October |
| Phascolion | DF | None | Continuous |
| Tellina | SF | September | June |
| Brachidontes | SF | December | October |
| Ampelisca | DF | May | October to April |
| Platynereis | C/S | December | August |
| Polydora | C/S | Sept. Feb. | May, Dec. |
| Diopatra | C/S | December | October |
| Pectinaria | DF | November | August |
| Erichsonella | H/S | October, May | June, January |
| Marginella | C/S | None | Continuous |
| Laevicardium | SF | October | March |
| Oxyurostylis | SF | March | September |

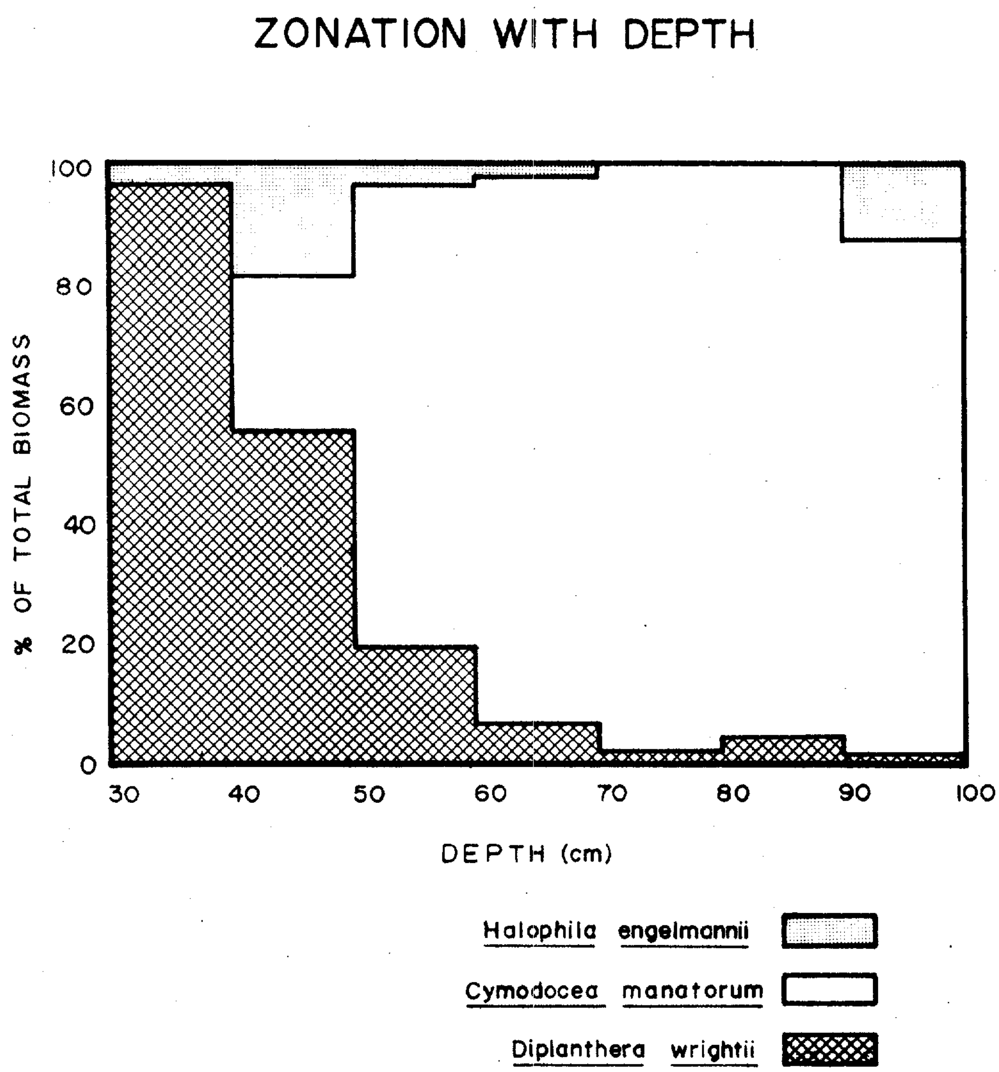


Figure 2-34. Depth zonation of seagrasses from 0.3 to 1 m, July 1975.

Table 5.

Net Primary Production of <u>Syringodium</u>
estimated by growth increment.

| | $g/m^2$ | day |
|---|---|---|
| Period | dry wt. | carbon |
| Nov. 30 - Dec. 26 | - .40 | -.16 |
| Dec. 26 - Jan. 28 | + .09 | .04 |
| Jan. 28 - Feb. 27 | - .27 | -.11 |
| Feb. 27 - Mar. 19 | .01 | .004 |
| Mar. 19 - Apr. 29 | .01 | .004 |
| Apr. 29 - May 29 | .24 | .10 |
| May 29 - June 24 | .38 | .15 |
| June 24 - July 17 | .07 | .03 |
| July 17 - Aug. 11 | .43 | .17 |
| Aug. 11 - Sept. 3 | .42 | .17 |
| Sept. 3 - Oct. 9 | -.24 | -.10 |

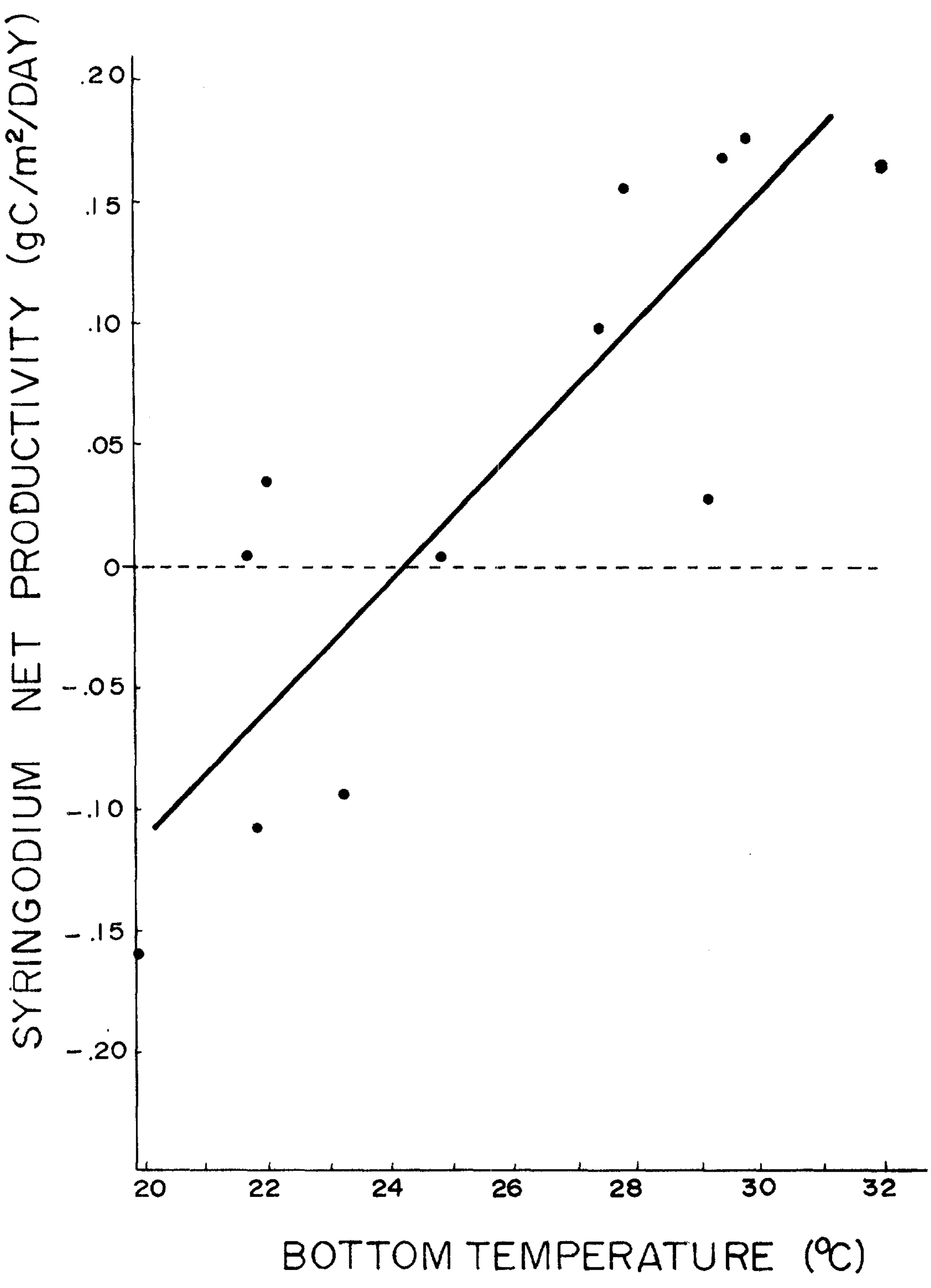


Figure 2-35. Relationship of growth increment (net production) and temperature.

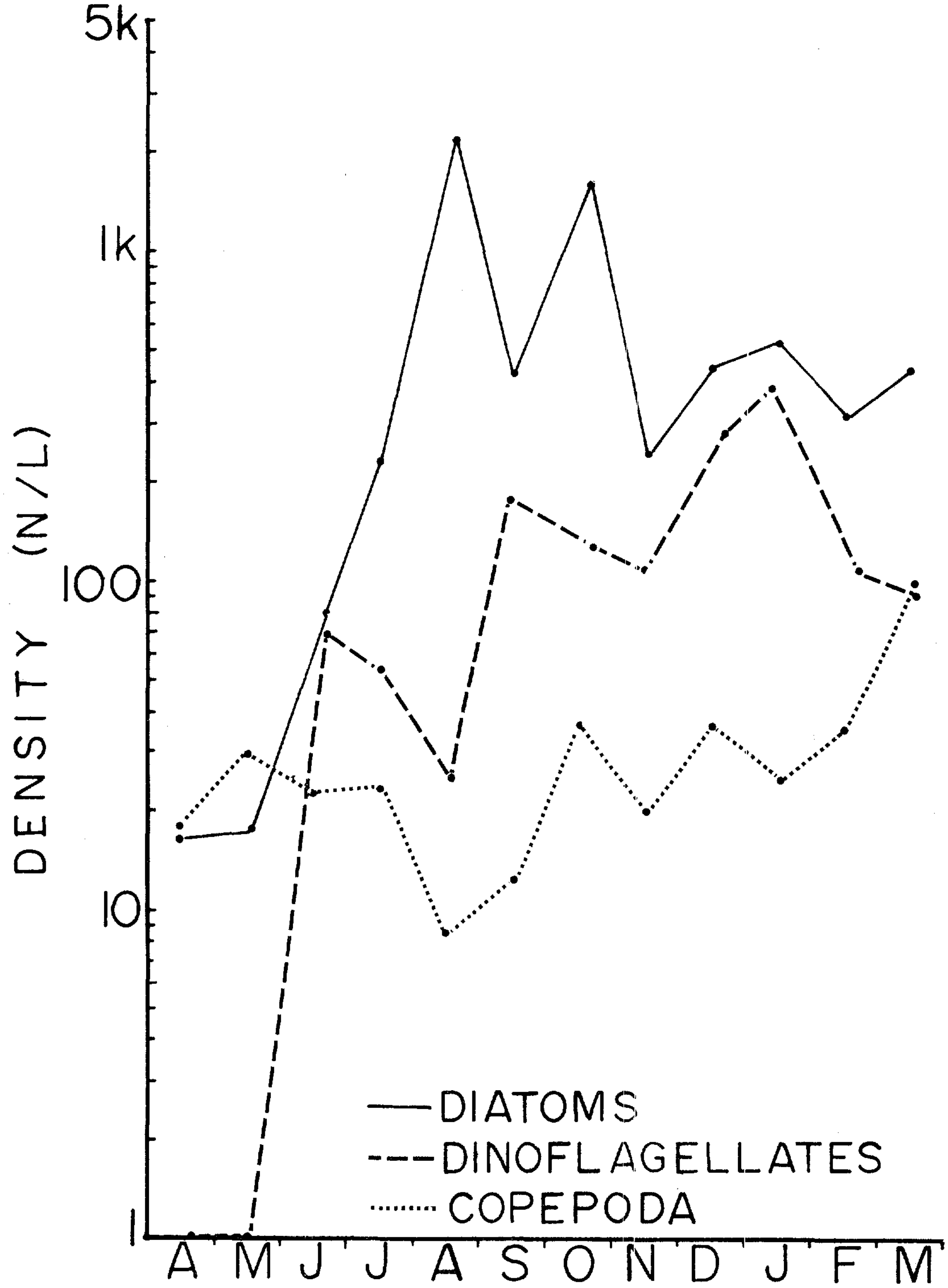


Figure 2-36. Seasonal changes of plankton density (logarithmic means) in south basin.

## 2.4 Discussion

The ecology of the Indian River is clearly dominated by seagrasses, with biomass of up to 250 $g/m^2$ for the major species (Syringodium filiforme) and 200 $g/m^2$ for Diplanthera wrightii. The high production rates, together with the physical effects generated by presence of the seagrasses, exert major influences on physical, chemical and biological processes within the Indian River. The growth cycle of the seagrasses and other macrophytes in the Indian River is highly seasonal (figures 14 and 15), leading to a surge in availability of energy or "pulse", for consumer organisms in the ecosystem. This pulse effect, together with rapid fluctuations in temperature and salinity, imposes a pronounced seasonality on the populations of benthic organisms in the community, as reproduction and growth of most inshore organisms are dependent upon the supply of detrital material produced by decomposition of seagrasses. The seasonal pulse effect is a general characteristic of seagrass-based ecosystems and has been noted in subtropical, tropical, and temperate marine ecosystems, as Laguna Madre, Texas (Odum, 1967), Puget Sound (Phillips, 1974), and Tampa Bay (Phillips, 1960). The seasonal variation in productivity is controlled by either temperature or solar input, though these usually vary concomittantly, hence are difficult to separate (Phillips, 1974). The insolation maximum (June) and thermal maximum (August) are separated by several weeks in the Indian River, but this is insufficient to conclusively separate the two effects.

Biomass of the seagrasses approximately doubles from July to the maximum in September; hence, the greatest observed density, that of Syringodium from 0.5 - 0.6 m, would be equivalent to about 500 g dry weight/$m^2$ in September. This is about one-sixth of the dry biomass of 3 $kg/m^2$ reported for Thalassia from Bear Cut, Florida (Jones, 1968); hence, the peak biomass can be considered an approximate indication of primary production rates. This suggests that benthic production of the Indian River is lower than other seagrass systems. This is supported by the rates calculated from growth increments (table 5, figure 35) measured for Syringodium, which reach a maximum of about 200 mg carbon/$m^2$/day (Net). An annual estimate derived from the difference between annual minimum and maximum biomass, is of the same magnitude, from 200 (mean) to 400 (maximum) mg C/$m^2$/day. These figures do not compensate for grazing or weathering during the growth period, and so are somewhat conservative, but are substantially less than the 830 $mgC/m^2$/day reported for Zostera in Denmark (Grontved, 1958), 1600 mg $C/m^2$ /day for Zostera in Puget Sound (Phillips, 1974), 930 mg $C/m^2$ day for Zostera in North Carolina, (Dillon, 1971), and up to 8000 $mgC/m^2$/day for Thalassia in the Caribbean (Thayer et al., 1975).

Explanations for this lowered productivity must, at this time, be speculative. One likely possibility is that the absence of appreciable currents in this portion of the river leads to localized depletion of nutrients. This effect could be large scale, involving the bulk of water colonized by the seagrasses, or could be limited to the immediate leaf boundary water layer; in either case, growth of the seagrasses could be limited by removal of some critical nutrient. Odum (1971) has indicated the important contribution of tidal currents to the high productivity of estauries; these currents act as an energy subsidy, in part by facilitating exchanges of nutrients and wastes. The observed low concentrations of plankton indicate that nutrient levels in the water mass are low and probably limiting.

Nutrient limitation might also be related to sediment characteristics. In general, fine sediments support much higher microbial populations than do coarse sediments (Jannson, 1971); the regeneration of nutrients should also increase in fine sediments as a result. The relatively coarse sediment of the Indian River, with a median grain size of about 0.1mm (fine sand) could therefore contribute to the nutrient limitation of the seagrasses, especially as much nutrient uptake may occur via the roots. Phillips (1960) has indicated that lack of fine sediments in the Indian River may be one reason for the absence of Thalassia. Bound nitrogen may also be a limiting factor, as nitrate nitrogen is below measurable levels in Indian River sediments. However, high rates of nitrogen fixation have been reported in the seagrass rhizosphere (Patriquin, 1970 a,b).

Another possibility is that Syringodium, growing here near the northern limit of its range, is inhibited by low temperatures. Phillips (1960) has indicated that Syringodium is subject to leaf-kill below 20°C, in close agreement with the temperature-growth dependence shown in figure 35. However, this does not explain why peak production values in summer are not substantially higher, though it may partially explain the low annual average values.

Carbonate is generally considered not to be a limiting factor for growth of marine plants (Phillips, 1968) though there is some circumstantial evidence implicating carbonate availability as a factor limiting seagrass productivity in the Indian River. The slightly acid pH occasionally encountered indicates a greatly reduced buffering capacity, implying a decrease in the soluble carbonate-bicarbonate reservoir. Carbonate deposition on tropical seagrasses is a normal result of photosynthetic activity at high temperatures, yet Indian River seagrasses do not precipitate carbonates, despite temperature regimes similar to those of Biscayne Bay (Roessler and Beardsley, 1974). Further, sediments of the Indian River are low in carbonates, though high carbonate sediments are characteristic of other Florida seagrass beds (Phillips, 1960). As diffusion rate is proportional to the difference between external and internal concentrations, decreased carbonates in solution may be potentially limiting to the photosynthetic process.

Regrowth of seagrasses in summer and extension into denuded areas seem to be almost entirely by vegetative growth. Flowering of Syringodium has not been observed at any time during the three year study, nor have seeds been found in benthic samples. The presence of germinating seedlings of Diplanthera at Sebastian Inlet in Spring of 1975 suggests that this species may reproduce by seeds in the Indian River, and flowering of this species easily may have been missed, as most observation was concentrated in the Syringodium beds.

The presence of large, grassless areas during peak biomass periods is a conspicuous feature of the North Indian River grass flats. As shown in figure 16 these patches appear to be temporary in nature and show evidence of recolonization. Other than manatees, which occur in low density in the Indian River, no animals seem to graze on the grass beds. Formation of these bare areas is due to two mechanisms. Horseshoe crabs (Limulus polyphemus) occur in very high densities within the grass beds (the investigators frequently, and painfully, stepped on these while sampling). These burrow at a depth slightly below the rhizosphere (10 cm), loosening the sediment and dislodging considerable quantities of Syringodium. The loosened plants are apparently pulled completely free during storms, which are concentrated in the Autumn. Large floating masses of Syringodium following the storms are a conspicuous feature of the water surface in August, September, and October.

Zonation:

The zonation of Syringodium and Diplanthera is consistent with the patterns observed by other authors (Phillips, 1960; Hutton et al., 1956; Humm, 1956). Diplanthera is tolerant of higher light and temperature in shallow water, but is competitively displaced by other seagrasses in deeper water (Phillips, 1960). One exception to the pattern is the absence of Diplanthera in deeper waters, as this seagrass normally exceeds the depth limits of Syringodium (Phillips, 1960). The zonation of Halophila has not been previously defined; the present study suggests that optimum growth for Halophila is in the transition zone between Syringodium and Diplanthera, between 40 and 50 cm.

Lower depth limits of all three grasses are apparently determined by light penetration. Turbidity of Indian River water is relatively high (refer to section on water quality), and probably accounts for the unusually shallow growth limits of these species. Interviews with Brevard County residents indicate that the Indian River waters were highly transparent until about 1960-1965, when turbidity levels began to increase. The probable cause of this increase is the periodic redredging required for maintenance of the Inland Waterway. Transparency is generally greater within the grass beds, however, and lateral visibility of up to 10 m occurs during the peak biomass period.

Zonation of the invertebrate community coincides with the presence or absence of seagrasses. Thomas (1974) has indicated Cylindroleberis-Sarsiella-Melita-Phascolion community of high diversity occurs in both Diplanthera and Syringodium, and is replaced in deeper water, where seagrasses are absent, by a Cylindroleberis-Caecum-Leiochone community. The presence of seagrasses may have several effects which control community structure. Slowing of water currents stabilizes sediments, as indicated by higher transparency, and selects in favor of suspension feeders. The high biomass of seagrasses, epiphytes, and associated aufwuchs accentuates oxygen and temperature changes, frequently leading to nocturnal anaerobicity (Broekhuysen, 1935). Occurrence of blackened areas of the bottom, colonized by fungal mycelia, indicates that this condition does occur with dense patches of seagrasses in the Indian River. These climatic extremes select for species able to tolerate oxygen deficiencies for several hours, or mobile species able to migrate above the anoxic zone. Further, the large surface area of leaves and epiphytes greatly increases habitat diversity, generating additional niches and increasing species diversity.

The species diversity of shallow stations is quite high, approaching and even exceeding the values reported for tropical estuaries by Sanders (1968). The rapid decrease in deeper waters, especially near the Intracoastal Waterway, emphasizes the importance of the seagrasses to maintenance of a diverse, stable community, and indicates the possibly severe effects of dredging.

Seasonal Patterns:

The rapid decline in biomass of seagrasses in October is paralleled by an increase in organic carbon content of sediments in November, followed by a gradual decrease in organic carbon, which reaches its minimum level at about the beginning of the seagrass dieback. This suggests that a surge of detrital material is rapidly incorporated into the sediments, followed by gradual metabolization during the remainder of the year. This hypothesis is further supported by Chen (1974), who found that breakdown of Syringodium leaves was nearly completed in about six weeks. While this surge is undoubtedly supplemented by algal macrophytic and micropelic production throughout the year, this impulse of food energy has a major effect on the ecology of the benthic invertebrates. Detritivorous species overwhelmingly dominate the benthic community, and many of these exhibit reproductive cycles synthronized to utilize this detrital pulse. Density curves of deposit feeders, suspension feeders, and total species reflect a clear peak in November and December as the detrital material becomes available. A secondary peak in May is less easily explained, but is largely due to a high density of a single species, Tanais sp. Other contributions to the May peak may reflect a general tendence of temperate species to reproduce in periods of increasing vernal temperatures, together with a possible increase in food availability due to increased breakdown of refractory detritus which was not decomposable at lower winter temperatures.

Biogeographic Considerations:

Population curves of dominant species, with the exception of Tanais, show gradual declines, rather than sudden decreases, indicating that mass mortality due to thermal death is not a general phenomenon of the North Indian River benthic community. Thus, range limitations in this general area must generally be ascribed to indirect temperature effects, such as competitive exclusion.

The effect of temperature on the seagrasses, as indicated by the dependence of growth on temperature, certainly is an important factor in controlling range of Syringodium and Halophila. North of Cape Canaveral, winter temperatures rapidly become cooler, and could readily limit ability of these species to maintain permanent populations. Absence of flowering by these two seagrasses is one possible indication of the temperature effect.

## 2.5 Recommendations

The importance of the seagrasses in the North Indian River ecosystem cannot be overemphasized. The lowered production of the seagrasses, together with loss of non-vegetative reproductive ability and restriction to shallow depths, and the relative scarcity of suspension feeders, indicate a system already under stress. Development of areas in proximity to this system should be extremely cautious in order to avoid further stress which might drastically affect the function of this system. Decreased density of benthic populations near the urbanized shore, adjacent to causeways, and in the vicinity of the Intracoastal Waterway serve as warnings of possible damage. Release of dredge spoil appears to be the most pernicious of present disturbances, probably as it affects the seagrasses through increased turbidity. Certainly, further study of these disturbances is justified.

## ACKNOWLEDGEMENTS

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Appendix 1. Densities ($N/m^2$) of major taxa in ponar grab samples from central basin, North Indian River, 1972

| | SITE NUMBER / TAXA | 1-2 | 1-3 | 1-4 | 1-5 | 1-6 | 1-7 | 1-8 | 1-9 | 1-10 | 1-12 | 1-13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | RHYNCHOCOELA | 57 | 170 | | 302 | | | 245 | | | | |
| 2. | NEMATODA | 491 | 3,321 | 7,056 | 3,566 | 4,075 | 1,340 | 16,528 | 868 | 3,094 | 19,585 | 1,189 |
| 3. | OPHIUROIDEA | 19 | 94 | | 38 | 19 | 75 | 94 | 38 | | | |
| 4. | HOLOTHUROIDEA | 94 | | | | | 19 | 19 | 19 | | | |
| 5. | CHAETOGNATHA | | | | | | | | | | | |
| 6. | PHORONIDA | | 943 | 321 | 283 | | 19 | 623 | 208 | 340 | 151 | 849 |
| 7. | POLYCHAETA | 226 | 1,075 | 1,660 | 1,962 | 472 | 302 | 736 | 830 | 547 | 113 | 906 |
| 8. | SIPUNCULIDA | 435 | 491 | 321 | 547 | 340 | 94 | 1,132 | 189 | 925 | 189 | 245 |
| 9. | GASTROPODA | 38 | 170 | 1,792 | 151 | 113 | 358 | 4,151 | 1,245 | 321 | 1,004 | 302 |
| 10. | PELECYPODA | 132 | 491 | 1,170 | 245 | 472 | 94 | 75 | 566 | 415 | 113 | 340 |
| 11. | PYCHOGONIDA | | | | | | | | | | | |
| 12. | OSTRACODA | 1,491 | 10,605 | 1,321 | 13,113 | 38 | 3,698 | 14,453 | 4,094 | 19,981 | 6,245 | 906 |
| 13. | COPEPODA | | | | 113 | 15,264 | | | | | | |
| 14. | MYSIDA | | | | 38 | | | | | | | |
| 15. | STOMATOPODA | | | | | 19 | | | | | | |
| 16. | CUMACEA | | | 75 | 38 | | 113 | 75 | | | 94 | |
| 17. | TANAIDACEA | | | 151 | | | | 113 | | | 38 | |
| 18. | ISOPODA | | 132 | 5,811 | 19 | 132 | | | | 38 | | |
| 19. | AMPHIPODA | 94 | 849 | 3,774 | 75 | | 2,208 | 604 | 4,075 | 811 | 151 | 245 |
| 20. | DECAPODA | | 57 | 19 | | 868 | | | 38 | 19 | | 19 |
| 21. | PLATYHELMINTHES | 19 | 19 | | 19 | | | | | 38 | | |
| 22. | PISCES | | | | | | | | | | | |
| 23. | OTHER | | | | | | | | 94 | 38 | | 38 |
| 24. | TOTAL/$M^2$ | 3,096 | 18,415 | 23,472 | 20,547 | 21,811 | 8,340 | 38,868 | 13,264 | 28,868 | 27,683 | 5,039 |
| | ALGAE-GRASS GMS/$M^2$ | 4.6 | 9.1 | 106.9 | 0.6 | 6.1 | 0.0 | 0.0 | 8.4 | 4.6 | 0.0 | 0.8 |

## Appendix 1. (Continued)

| SITE NUMBER | 1-14 | 1-15 | 1-16 | 1-17 | 1-18 | 1-19 | 1-20 | 1-21 | 1-22 | 1-23 | 1-25 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| TAXA | | | | | | | | | | | |
| RHYNCHOCOELA | | | 38 | | 151 | 283 | | | 75 | | |
| NEMATODA | 6,415 | 2,057 | 151 | 113 | 113 | 1,792 | 5,283 | 660 | 1,632 | | 151 |
| OPHIUROIDEA | | | 75 | 38 | | 906 | 151 | 132 | 38 | 38 | 151 |
| HOLOTHUROIDEA | | 151 | | 453 | 509 | 2,849 | 57 | | 245 | | 717 |
| CHAETOGNATHA | | | | | | | | | | | 38 |
| PHORONIDA | 283 | | 19 | 170 | 75 | | | 226 | 453 | 75 | |
| POLYCHAETA | 906 | 453 | 1,151 | 208 | 9,604 | 4,679 | 2,547 | 2,075 | 6,019 | 38 | 7,434 |
| SIPUNCULIDA | 623 | 38 | 434 | 19 | 830 | 283 | 849 | 453 | 585 | 57 | 1,453 |
| GASTROPODA | 1,019 | 94 | 75 | 264 | 925 | 2,245 | 1,698 | 132 | 2,811 | | 5,623 |
| PELECYPODA | 132 | 38 | 113 | 2,321 | 377 | 2,000 | 1,094 | 943 | 226 | | 189 |
| PYCHOGONIDA | | | | | | 283 | | | 19 | | |
| OSTRACODA | 21,472 | 1,547 | 24,189 | 528 | 1,792 | 5,811 | 25,887 | 16,377 | 1,868 | 1,774 | 1,075 |
| COPEPODA | | 151 | | | | 151 | 19 | | | | |
| MYSIDA | | 19 | 75 | | | | | | | | |
| STOMATOPODA | | | | | | | | | | | |
| CUMACEA | 94 | 132 | 358 | 1,415 | | | 57 | 38 | 19 | 245 | |
| TANAIDACEA | | | | 472 | | | 208 | | | | 19 |
| ISOPODA | 38 | 94 | | 94 | 528 | 755 | 151 | | 585 | | 472 |
| AMPHIPODA | 566 | 2,000 | 226 | | 151 | 434 | 9,038 | 1,415 | 1,434 | | 887 |
| DECAPODA | 19 | 57 | | 528 | 19 | 57 | 113 | | | | 57 |
| PLATYHELMINTHES | | | | | | 19 | 75 | | | | |
| PISCES | | | | | 19 | | 19 | | 38 | | |
| OTHER | 75 | | | | 38 | | | | | | 57 |
| TOTAL/$M^2$ | 31,642 | 6,831 | 26,887 | 6,623 | 15,131 | 22,547 | 47,412 | 22,679 | 15,604 | 2,150 | 18,320 |
| ALGAE-GRASS GMS/$M^2$ | 9.6 | 9.6 | 0.0 | 0.8 | | | 76.9 | 17.2 | 2.1 | 0.0 | |

Chapter 3

# LAGOONAL CIRCULATION

P.S. Dubbelday

## SUMMARY

Measurement of the circulation in a lagoonal area is needed to understand the interaction of the biological and chemical systems in space and time. The major driving force of the circulation is the wind. Although the wind does exhibit some regular patterns as a function of the seasons, there is still so much variability that it is difficult to obtain a near synoptic overview with limited instrumentation.

The problem is aggravated by the fact that currents in the lagoon are generally very small and below the threshold of most conventional impeller type current meters.

The first approach therefore was to measure surface currents by quasi-Eulerian observation of the drift of current crosses, combined with the locally measured wind. Sufficient correlation exists to support the notion that only the wind is responsible for the circulation.

The interaction of slope and drift currents, even with neglect of density currents and Coriolis effect, is complicated, and determined by the history of the wind field. Therefore the correlation of the surface currents with the wind does not appear obvious in all cases. An added effect, little explored in these shallow waters, is seiching and other possible wave solutions to the governing equations.

The major part of the literature on wind driven circulation concentrates on the aspect of wind setup and storm surge prediction. The circulation as such is only an intermediate step and appears without much experimental verification.

In establishing the biological health and chemical cycles of a lagoon, the circulation is of prime importance and wind setup takes the role of indicator rather than final purpose of the study.

To determine the dispersive properties of the water bodies the vertical profile was a necessary experimental item, in order to remove the ambiguity which is inherent in a pure dye dispersion study as was performed in these waters about a decade ago.

Thus vertical profiles were measured with a deflection type current meter. Special attention was given to the search for a current reversal with depth (circulation cell) as should be present in a combination of wind-drift and slope current.

The existence of such a current reversal was found, more by visual observation than by record of the current meter, since the currents turned out to be very weak.

This outcome concurred remarkably well with the projections from a modified model of the vertical profile, inspired by the shape of an observed, allegedly pure wind-drift current.

The assumption of a constant eddy viscosity coefficient, usually introduced for mathematical convenience, gives a faulty shape of the profile. A simple linear coefficient leading to the molecular value at the bottom gives a much more satisfactory fit with experiment.

In addition to this, this simple model predicts a circulation cell with currents an order of magnitude less than pure drift currents under the same wind field. This was confirmed by the weakness of such a cell in the few cases found in the lagoons. Moreover the model predicts a ratio of top and bottom stress which concurs much better with the one assumed as a rule of thumb in technical literature, than the one following from a constant viscosity coefficient.

The practical application of this conclusion is that dispersion in the lagoons is a very slow process indeed. Normally wind driven currents are small already, but a long sustained wind does not aid the transport, since the counter current produced by the slope combines with the drift current to result in a surface and bottom current which are an order of magnitude less than the original drift current.

As an order of magnitude one might state that a wind of 20 knots would give a surface current of 20 cm/s, (720 m/hr. or 2400 ft./hr.), for a just developing drift current, down to 2 cm/s, or 240 ft./hr. for a long duration wind. Winds of less strength would produce lesser currents, obviously, more so since the surface stress is roughly proportional to the square of the wind speed.

These current speeds concur in a qualitative way with those found in the older dye study. The latter effectively measures a combination of advective transport and dispersion by velocity shear and turbulence. Purely turbulent viscosity coefficients cannot be derived from it. A complete model of dispersion in the lagoon is not possible without the latter as necessary ingredients.

The conclusion is warranted that mixing and spreading of dissolved and suspended substances in the lagoons is a slow process, from several days upward.

Interaction between the various lagoons is even slower; the causeways prevent the free exchange, and measurements at Haulover Canal and the northern entrance to Mosquito Lagoon show that the estimate in the dye study mentioned of a residence time of 150 days, although little founded, appears to be in the right order of magnitude.

It was found in this study that the time constant for establishment of the drift profile is about 10 minutes. Other time constants, for establishment and decay of the circulation cell connected with drift plus slope current are harder to establish, but appear to be several hours at least.

Such questions of development in time of the circulation are under continuing investigations by analysis of historic waterlevel records of a large number of stations around the lagoonal area, and of the data produced by tide gauges at either side of Haulover Canal.

## Study of Lagoonal Processes in the area of Kennedy Space Center

### 3.1.0 Introduction

The physical parameters in a baseline study of a lagoonal system tend to play a secondary role in a first approach to the problem. Biological, chemical, and geological parameters are the ones by which the health and quality of such a system is judged. Sudden, periodic, or slow secular changes are indicators of natural or man made, beneficial or deleterious processes which may be open to corrective measures. Toxic or nutrient chemical compounds may be monitored, and danger levels established above or below which the normal operational cycle of the waterbody might be disturbed.

A next step in the understanding of such cycles is the local modeling of the relationships between the chemical and biological, and to some extent, geological parameters. (See e.g. Patten 1971). A deeper understanding of the processes, and a strengthening of the predictive capability can only be acquired through measurement and modeling of the physical parameters. Amongst the latter it is especially the current field and corresponding surface height distribution which have a direct bearing on the transport of the various substances, and therefore on the relationships of these between each other and the outside world. To place the following discussions in proper perspective, it is in order to analyze the word dispersion in the context of spreading of dissolved or suspended substances in a water body. In the technical sense the word covers the diffusion both by molecular processes as well as by actual transport through fluid motion; the latter is generally described as "advection". The decision whether a given advection process is considered part of dispersion, or as advection proper is very much a matter of scale, specifically, it is the decision of the observer at what scale measurement and analysis will take place. Since averages will be taken in accordance with this scale, the fluctuations about an average introduce cross-correlations into the advective term. Such cross correlation are then traditionally expressed as a diffusion term with an effective dispersion coefficient. An example is the longitudinal dispersion coefficient, introduced by Taylor (1954),for the one-dimensional modeling of a (tidal) estuary.

Our experience and measurements show that a longitudinal dispersion coefficient is even less established in wind-driven lagoons than in the tidal regime, since the vertical current profile is strongly non-monotonic, and dependent upon the history of the wind driving the circulation. Therefore, in this study considerable attention is devoted to the elucidation of this vertical profile, to avoid the need of a longitudinal dispersion coefficient.

Under the grant, a comprehensive study was made of the surface currents in the lagoons, in connection with the locally measured wind. The results are contained in a master's thesis by Dill (1974). In this thesis a review of literature on wind drift currents is presented. All through the study it was realized that monitoring capability should be one of the final products. Along this line of thought, a detailed investigation was undertaken into the transport through Haulover Canal, centrally located in the area, where currents and levels are of sufficient magnitude to warrant routine measurement. The ensuing master's thesis by Browne (1974) showed that the difference of water height at both ends of the Canal provides a reliable measure of transport through the canal. It was suggested to NASA-KSC that height gauges would be permanently installed for future monitoring and this was performed under the terms of the third year part of the grant.

From theoretical considerations it follows that the vertical profile of a drift current combined with a slope current will exhibit a variety of forms, depending on the time history of the wind. The existence of a current which changes direction with depth was shown by Schneider et al. (1974). Such a vertical structure obviously has a bearing on dispersion of substances, and thus it was fortunate that under the provisions of the third year renewal two deflection type current meters could be deployed. Some preliminary profiles were taken by Motschman, (1975) as a senior project. A number of vertical profiles throughout the area were obtained and new theoretical ideas developed which appear to fit some of the features.

The scarcity of literature on shallow wind-driven lagoons prompted a critical survey by Nenart (1975). This will be continued and extended into a master's thesis.

A synoptic collection of water level heights has been gathered by NASA-KSC in the past by means of tide gauges throughout the lagoonal system. Analysis of these data has been started by Waterhouse. It is envisaged that this will lead to increased understanding of the relation between wind field and current structure, and further usage of level gauges for monitoring of the current system.

The analysis of the data and theoretical considerations posed various questions which will lead to further investigation.

Further analysis of the vertical current structure is planned by Meyer, who conducted the profiling during the third year of the contract, to result in a master's thesis.

Undergraduate (senior) projects are started by Sandgren and Picciotti on the bottom stress in a wind-driven situation, and by Walters on the variation in surface height along the axis of a lagoon.

The organization of this chapter is as follows. The introduction is followed by a section on the relevant theory. Then the work performed with the deflection current meter is described. Because of the fact that it was done in the same locale, the dye study of Carter and Okubo is shortly discussed in a separate section, and the relevance to our work indicated. A summary is given of the theses of Browne and Dill.

3.2.0 Theory

3.2.1 Basic Assumptions

Several texts and monographs provide the basic set of equations which form the starting point for any theoretical study of fluid systems. We will not repeat these here, but refer to the article by Pritchard in the "TRACOR" report (1970), p. 5 ff. for an example. Typical for the state of the art is the fact that, although the wind as a driving force is mentioned in the general equations of this TRACOR report, the remainder concentrates solely on the tide as the driving force. The regime in the lagoons under study is characterized by shallow depths, relatively little fresh water inflow, and negligible tidal action (the only tidal action discernible is at the Northern narrow entrances to Mosquito lagoon). We will start here from a reduced form of the equations, whereby the following effects are neglected.

1. Coriolis effect is ignored. This is justified by consideration of the Ekman number $E = A_V/(\rho \omega \sin\varphi h^2)$ where $\rho$ is the density, $\omega$ the rotation rate of the earth, $\varphi$ the latitude (Greenspan, 1968, p.7), which can also be considered the square of ratio of the depth of frictional influence $D$, (Neumann and Pierson, 1966, p. 193) to actual depth, $h$, apart from a factor $\pi^2$. The vertical eddy viscosity coefficient $A_V$ is difficult to evaluate, but for a typical depth of 2 m it can easily be established that the condition $h \leq 0.1\, d$, leads to $A \geq 14$ g $cm^{-1} s^{-1}$, which is probably true for the lagoons under study. (Compare Neumann and Pierson p. 195)

2. The depth of frictional influence is a measure for the influence of Coriolis effect on the vertical profile. Its influence on the lateral variation in current and water level is felt rather through inertial effects than through friction and is given by the familiar factor in the Kelvin wave: $\exp(-fy/\sqrt{gh})$

Thus the relevant dimensionless number $fb/\sqrt{gh}$ is the ratio of the width b to $\sqrt{gh}/f$, the latter expression has been called the "radius of deformation" by Rossby (1936). See also Csanady (1973). Typical numbers for the lagoons, b = 1 km, h = 2 m give for this ratio .016, which is quite small indeed, thus disregarding of the Coriolis effect appears warranted.

3. Stratification is ignored by virtue of the magnitude of the inverse of the internal Froude number, $F = u^2/g'h$, where $g' = \frac{\Delta\rho}{\rho}g$. For a depth of 2 m, and a typical current of .2 m/s one finds that in order for the stratification effect to be no more than 10% of the inertial force the relative change in density in a vertical section should be below .2% . This is probably satisfied; salinity measurements seem to indicate practically perfect vertical mixing , but this question deserves further study.

The following theoretical comments are based on the assumption that wind is the sole driving force in the lagoons, leading to drift and slope currents. The discussion of the various dimensionless numbers gives some support to this assumption, but this can not be considered a proof. Especially it has not been established whether relative (density) currents play a role.

Most of the literature on wind driven circulation of very shallow water bodies concentrates on the prediction of storm surges. Characteristic for these papers are the references Ippen, 1966, Chapter 5; Silvester, 1970.

The equations presented generally have an empirical character, understandably, since the purpose is to contribute to prediction and technology rather than to a basic understanding of the circulation. The prediction of dispersion of pollutants demands deeper insight into the structure of the circulation, to avoid the reliance on a dispersion coefficient parameterizing the unknown processes, and as a consequence difficult to assess quantitatively.

Any fundamental insight into circulation is beset with the complication of turbulence. The connection between basic study of turbulence and its application to predictive description of a water body is quite long. It has become common practice to replace the turbulent field by a quasi-laminar description, where the eddy coefficient is of necessity a complicated function of external and internal circumstances. Such a description, amongst other drawbacks, does not account for the quasi-ordered structure, which in recent years has become the object of study, over the traditional study of Reynold's stresses and higher order correlations. (Laufer, 1975).

The first object of this study, though, is to reach a certain predictive capability for a given lagoonal system, and thus we will have to sacrifice on the point of universal validity. It is realized that the results may only be applicable to the given system. At the same time the effort will be guided by general principles, and maybe features discovered will have a bearing on more general systems as well.

### 3.2.2 Vertical Velocity Profile

In this section the structure of the vertical velocity profile is discussed assuming that the boundaries are far away. In a later section the closure problem will be discussed.

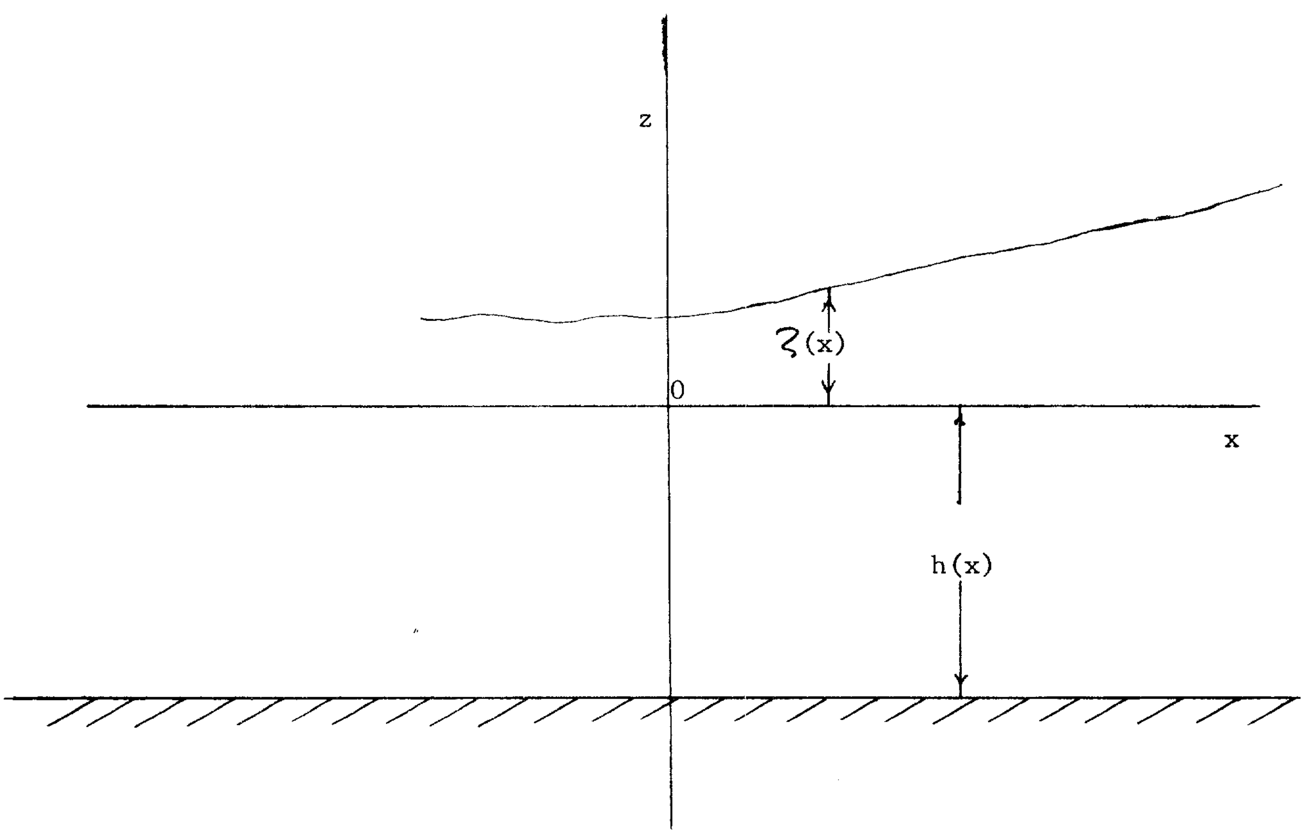


Figure 1

Geometry of Surface Height Definition

The figure (1) shows the geometry of the situation. The z-axis is positive up from the undisturbed water surface at z = 0. The depth h is thus a negative number. The surface height is given as $\zeta$ (x).

It is assumed that inertial effects can be neglected, as well as horizontal friction. Then the following equations describe the model, for the stationary case

$$\frac{\partial p}{\partial x} = \frac{d}{dz}\left(A \frac{du}{dz}\right) \qquad (1)$$

$$-\frac{\partial p}{\partial z} = \rho g \qquad (2)$$

where:

p - pressure
$\rho$ - density (constant)
u - velocity
A - vertical eddy viscosity coeff.
$\tau_s$ - wind stress

with boundary conditions

$$u(h) = 0$$
$$A \left.\frac{du}{dz}\right|_0 = \tau_s \qquad (3)$$

Some authors (e.g. Bye, 1966) replace the no slip condition by zero bottom stress. Physically there is no good reason for this, even if one considers the "bottom" to be the top of the laminar boundary layer.

The slope currents, driven by the surface height variation make their appearance through integration of the hydrostatic equation

$$p - p_{atm} + \rho g (\zeta - z) \qquad (4)$$

so that equation (1) reads

$$\rho g \frac{\partial \zeta}{\partial x} = \frac{d}{dz}\left(A \frac{du}{dz}\right) \qquad (5)$$

For a stationary equilibrium of drift and slope current we assume that the "mid-water-solution" (Bye, 1966) is subject to the condition.

$$\int_0^h u \, dz = 0 \qquad (6)$$

If we assume that the coefficient A is independent of depth, we can find simple solutions for slope current, drift current, and a combination of the two.

First we notice that in all cases the solution for the stress is given by

$$\tau_{zx} = A \frac{du}{dz} = \rho g \frac{\partial \zeta}{\partial x} + c \qquad (7)$$

For a windstress only we have $\tau_{zx} = \tau_s$ , while for surface slope only

$$\tau_{zx} = \rho g \frac{\partial \zeta}{\partial x} z \qquad (8)$$

so in neither case does one find that the bottom stress is zero, as is sometimes assumed. This is independent of the choice of A . If A is assumed constant one finds as a solution,

$$u = \frac{\rho g}{2A} \frac{\partial \zeta}{\partial x} (z^2 - h^2) + \frac{\tau_s}{A} (z - h) \qquad (9)$$

which varies according to the relative importance of slope and wind stress, by the parameter

$$s = \rho g h \frac{\partial \zeta}{\partial x} / \tau_s \qquad (10)$$

For steady state (6) one finds $s = -\frac{3}{2}$, leading to a current profile

$$-\frac{4A}{\tau_s h} u = 3 \left(\frac{z}{h}\right)^2 - 4\left(\frac{z}{h}\right) + 1 \qquad (11)$$

Notice that here the bottomstress is

$$-\tau_b = \frac{1}{2} \tau_s \qquad (12)$$

The figure 2 shows a sequence of profiles for illustration. The form should not be taken too serious in details, since other than for s = -3/2 and s = 0 the acceleration should be accounted for, apart from the unrealistic assumption of constant A.

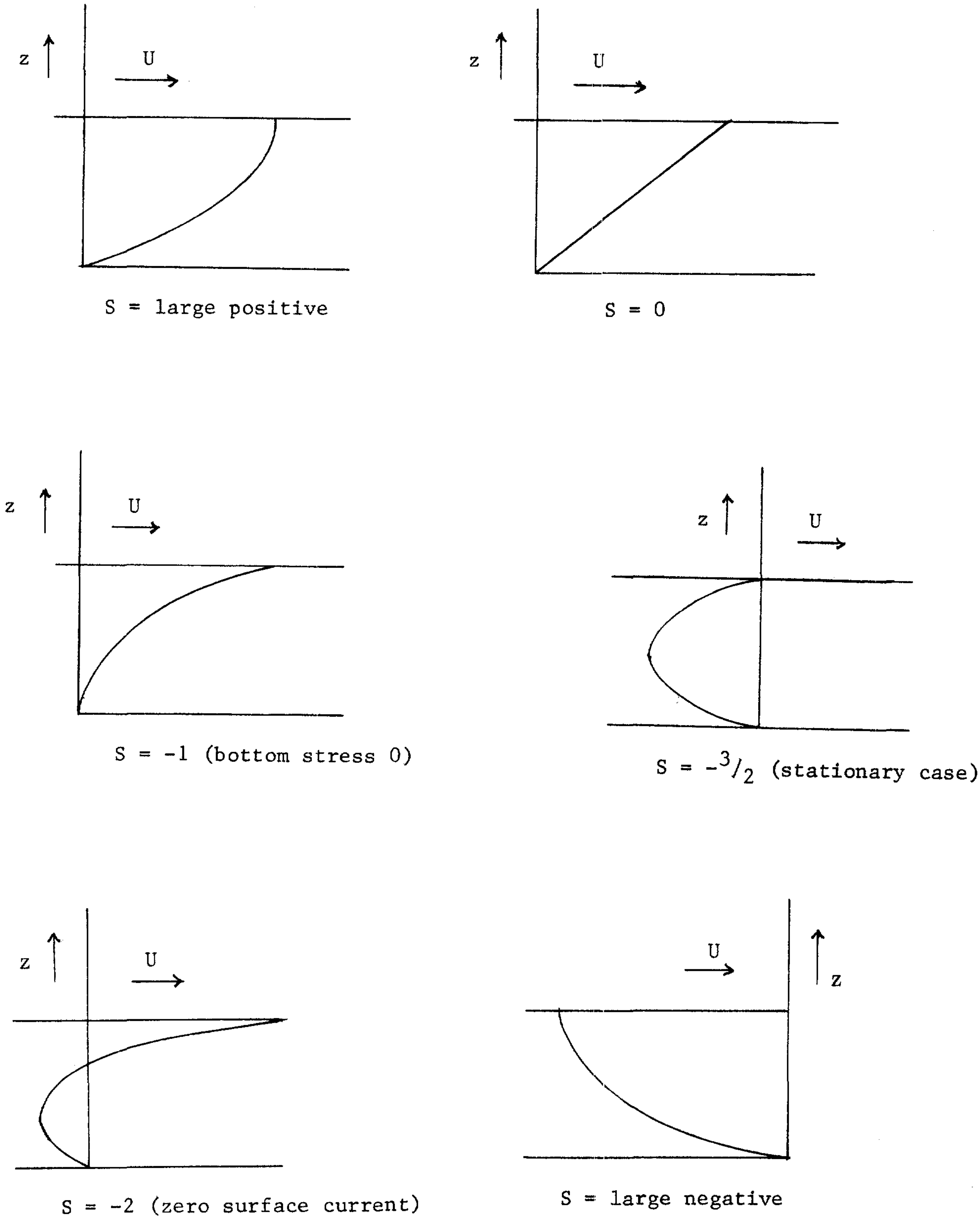


Figure 2

Sequence of Combinations of Drift and Slope Current

The unrealistic aspect of the assumption A = constant is demonstrated by the drift profile for s = o. Instead of a constantly decreasing velocity one finds experimentally a velocity almost constant up to close to the bottom. This should presumably be interpreted as a consequence of the decrease of A with depth, in accordance with the ideas of Prandtl's mixing length theory.

Various propositions for A are found on the basis of this theory. Prandtl gives plausible arguments for the expression

$$\tau = \rho \ell^2 \left| \frac{du}{dz} \right| \frac{du}{dz} \qquad (13)$$

where the mixing length $\ell$ is represented by $\ell = k(z-h)$. k is the Karman constant. This assumption produces a singularity at the bottom.

Von Karman proposes

$$\tau = \rho k^2 \frac{(du/dz)^4}{(d^2u/dz^2)^2} \qquad (14)$$

which, upon integration, has an extra integration constant, the determination of which is not physically clear.

To avoid these drawbacks, it was attempted to describe the data by a variable A according to

$$A(z) = A_o' \left[ 1 - \exp\left(\frac{h-z}{H}\right)\right] + \mu \qquad (15)$$

This expression has the desirable feature that, for a depth large compared with the "scale depth" H, A will not increase indefinitely but approaches a constant $A'_o$. Near the bottom the A approaches the molecular viscosity coefficient $\mu$. This prevents a singularity at the bottom. Since the depths under study are probably shallow compared with the hypothetical H we replace (15) by its first order approximation in (z - h)/H.

$$A(z) = A_o \left(1 - \frac{z}{h}\right) + \mu \qquad (16)$$

Assuming (16) we find the following profiles

(a) Drift current

$$u_{drift} = -\frac{h\tau_s}{A_o} \ln\left[\frac{A_o}{\mu}\left(1-\frac{z}{h}\right)+1\right] \tag{17}$$

(b) Slope current $u_{slope} =$

$$= \frac{\rho g \beta h^2}{A_o}\left[\left(1-\frac{z}{h}\right) - \frac{A_o+\mu}{A_o}\ln\left\{\frac{A_o}{\mu}\left(1-\frac{z}{h}\right)+1\right\}\right] \tag{18}$$

Applying the stationary condition where $\beta = \frac{\partial \zeta}{\partial x}$

$$\int_0^h u\, dz = 0$$

amounts to equating the negative of the integral of (17)

$$\int_0^h u_{drift}\, dz = \frac{h^2\tau_s}{A_o}\left\{1-\left(1+\frac{\mu}{A_o}\right)\ln\left(\frac{A_o}{\mu}+1\right)\right\} \tag{19}$$

and the integral of (18)

$$\int_0^h u_{slope}\, dz = \frac{\rho g \beta h^3}{A_o}\left[\frac{3}{2}+\frac{\mu}{A_o}-\left(1+\frac{\mu}{A_o}\right)^2\ln\left(\frac{A_o}{\mu}+1\right)\right] \tag{20}$$

It is important to notice that the expressions between brackets in (19) and (20) agree in terms of the first order, determined by $\ln\frac{A_o}{\mu}$ and only differ in second order terms. As a consequence the slope $\beta$ will be close to $-\tau_s/(\rho g h)$ and if we set

$$\beta = -\left(\frac{\tau_s}{\rho g h}\right)(1+\varepsilon) \tag{21}$$

then we find

$$\varepsilon \approx \frac{1}{2\ln\left(\frac{A_o}{\mu}+1\right)-3} \tag{22}$$

Inserting this value for $\beta$ into $U$ we find for stationary conditions

$$U_{total} = -\frac{h\tau_s}{A_o}\left[\frac{2\left(1-\frac{z}{h}\right)\left\{\ln\left(\frac{A_o}{\mu}\right)-1\right\}-\ln\left\{\frac{A_o}{\mu}\left(1-\frac{z}{\lambda}\right)+1\right\}}{2\ln\left(\frac{A_o}{\mu}\right)-3}\right]$$

and a surface current

$$U_{surface} = -\frac{h\tau_s}{A_o}\left[\frac{\ln\left(\frac{A_o}{\mu}\right)-2}{2\ln\left(\frac{A_o}{\mu}\right)-3}\right]$$

ignoring 1 compared with $\frac{A_o}{\mu}$ .

If we assume 40,000 for $A/\mu$ the profile is as shown in figure 3.

Although it is not claimed that a linear A is dictated by experiment, or strongly founded in theory, it is observed that such an assumption results in the following improvements over a constant A, in accordance with experimental evidence.

1. The sharp difference in profile between slope and drift current (figure 2, $s = \infty$ and 0) has disappeared (figure 4).

2. The absolute value for the surface speed for a surface current appears more realistic.
   Assuming $\tau_s$ = 2.7 dyne/cm$^2$ (corresponding to a windspeed of 900 cm/s, Neumann and Pierson, p. 197),and a depth of 330 cm, one finds for a constant A, $u_{drift}$ = 2.23 cm/s, and for a linearly variable A, $u_{drift}$ =24 cm/s. The latter appears more compatible with measurement of pure drift currents.

3. The surface current in a steady state superposition of a slope and drift current is $u_s = -\frac{h\tau_s}{4A_o}$ for a constant A, and about $-\frac{h\tau_s}{2A_o}$ for a variable A. Measurements cannot decide between these two cases , but it does indicate that for variable A the surface current is reduced down to about 1.1 cm/s, while the relative reduction for constant A is only by a factor of 4. This would

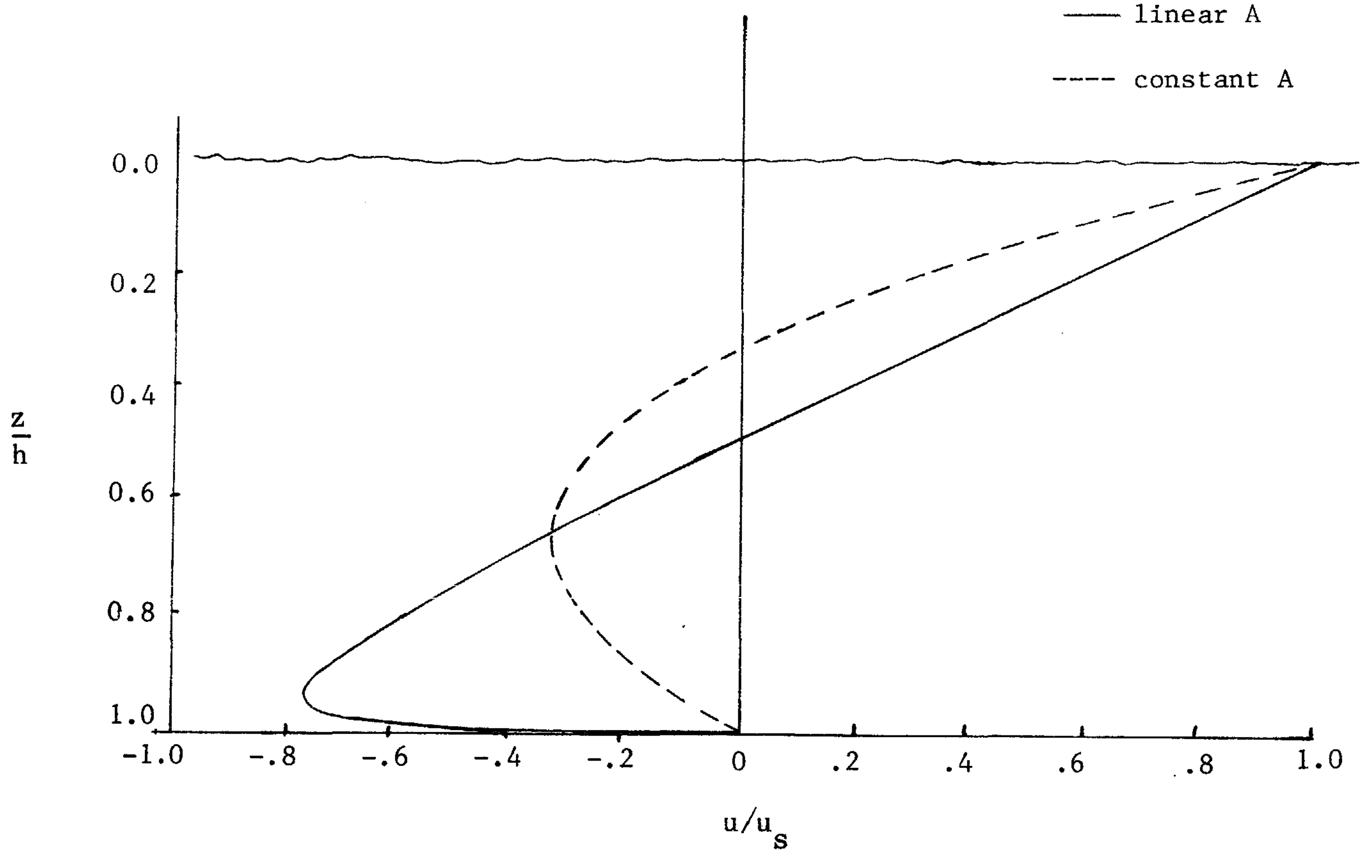


Figure 3. Comparison of stationary profile for constant A and linear A

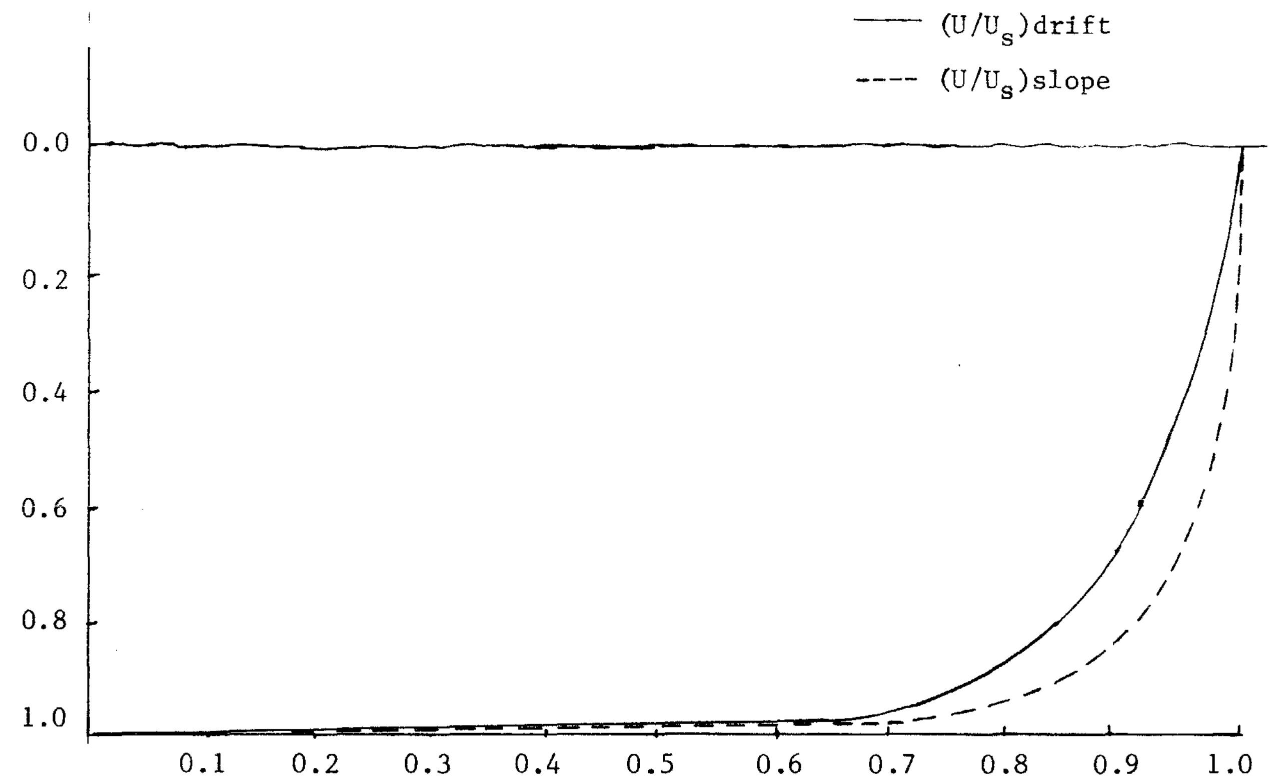


Figure 4. Comparison of drift and slope current profile for linear A

explain why it is difficult to find the assumed circulation cell which is established after a long duration wind.

4. The experiments seem to indicate that the current reversal in a slope and drift current combination appears more like the shape of figure 3, solid line, than that of figure 3, dashed line, where the positive current is limited to the upper third of the total depth.

5. The bottom stress at equilibrium for variable A is, by applying equation (7)

$$\tau_b = \rho g \beta h + \tau_s = -\varepsilon \tau_s \approx \frac{-\tau_s}{2 \ln\left(\frac{A_0}{\mu}\right) - 3}$$

As to order of magnitude (0. 05) this concurs much better with the often used approximation $|\tau_b/\tau_s| = 0.1$ (Ippen 1966) then the ratio which obtains for constant A which is (see 12) $|\tau_b/\tau_s| = 0.5$

It is clear, though, from the development that one cannot assign an invariable value to $\tau_b/\tau_s$ , since this ratio is a function of the time history of the wind field.

The measurement of bottom stress is at this time anticipated as a logical extension of the inquiry into the vertical structure of the wind driven circulation.

The above computations of current profiles for a linear A show that it is misleading to draw conclusions from constant A.

Further study is conducted of the development of current profiles in time as a function of wind duration.

### 3.2.3 Solution for Closed Basin

It is easily shown that the equations ( 1, 2) do not allow closing the solution at a lateral boundary, in other words, the given vertical profiles can only be considered an approximation to the mid-lagoonal area.

To allow for a closed circulation the non-linear terms and/or the horizontal friction has to be reinstated. The corresponding problem in oceanic circulation, where the Coriolis force is important, has an extensive literature, originally representing a controversy between non-linear (inertial) and linear (lateral friction) models (Stommel 1966); later resulting in a merger of boundary layer models of ever increasing complexity.

For shallow non-rotating basins the only work to this author's knowledge is that of Bye (1966) who proposes a model with both advective and viscous terms, which he solves through the vorticity equation.

Unusual and attractive in his approach is the fact that viscosity is represented by the molecular kinematic viscosity; as a consequence he finds at sufficiently large Reynolds numbers the occurrence of instability which conceivably corresponds to the onset of turbulence.

Within our heuristic approach which attempts to represent the turbulent situation by an eddy viscosity coefficient, it is tempting to quote Bye's solution for very small (almost zero) Reynolds number, (based on A instead of $\mu$) as an approximation to the circulation of a closed basin. The dimension crosswise to the wind is assumed to be homogeneous, thus the model describes the vertical circulation cell which physical insight dictates.

For a typical example the Reynolds number, defined by Bye as:

$Rey = \rho \tau_s h^2 / 4\mu^2$ (This is the usual definition of Rey = $\rho V L/\mu$, with $V = \tau_s h/4\mu$; replacing $\mu$ by A.)

would be: $Rey = \dfrac{(1)(2.7)(330)^2}{(4)(400)^2} = .46$ a small number

The basic equation to be solved is the biharmonic equation $\nabla^4 \psi = 0$ ( $\psi$ is the stream function) under the boundary conditions that the boundary is a streamline ($\psi = 0$) and

$$\tau_s = A \frac{\partial^2 \psi}{\partial z^2}\Big|_0$$

$$\frac{\partial \psi}{\partial z}\Big|_h = 0$$

$$\frac{\partial \psi}{\partial x}\Big|_0 = \frac{\partial \psi}{\partial x}\Big|_L = 0$$

The results pertinent to our study are given in figure 5 (fig. 10 of Bye 1966).

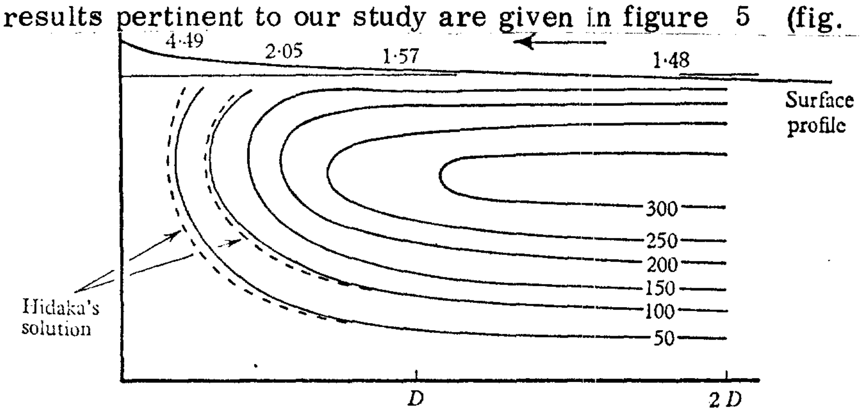


FIGURE 5. The zero-Reynolds-number end solution. The surface profile indices are coefficients of the non-dimensional slope $(\partial\xi/\partial x)/(\tau_s/\rho g D)$.

The surface numbers indicate $-\beta/\left(\frac{\tau_s}{\rho g h}\right)$ asymptotically approaching 3/2 according to ( 10 ), for constant A.

The lateral boundary layer in Bye's model is of the order h . In a turbulent situation the lateral boundary layer would rather be approximated by $(A_H/A_V)h$. It is difficult to assess the values of $A_H$ and $A_V$ in the lagoons; it is expected,though, that the boundary layer is still small compared with the lateral extent of the lagoon.

### 3.2.4 Time Dependence of Lagoonal Circulation

So far only steady situations have been considered. For the simplest cases it is not difficult to give explicit expressions for the development in time of a given profile. The general time dependent problem will not be discussed here, but a survey will be given of the time constants which play a role in the circulation.

Ignoring advective terms one can easily give the time dependent solution to the equation for the vertical profile, with constant A,

$$\frac{\partial u}{\partial t} = \frac{1}{\rho} \frac{\partial}{\partial z} \left( A \ \frac{\partial u}{\partial z} \right) \tag{23}$$

under a step wind stress of height $\tau_s$ at time t = 0.

The solution is

$$U = \frac{\tau_s (z-h)}{A} + \sum_{0}^{\infty} a_n \exp - \frac{(2n+1)^2}{2} \pi^2 \frac{t}{T} \cos\left(\frac{2n+1}{2}\right) \pi \frac{z}{h} \tag{24}$$

where $T = \frac{\rho h^2}{A}$ and $a_n = -\frac{\tau_s}{A} \left(\frac{2}{2n+1}\right)^2 \frac{2h}{\pi^2}$

By analytic and numerical methods one can find time dependent solutions for more realistic A. It would be a worthwhile investigation to assess the consequence of a time dependent A, which is probably what would happen in reality, since the turbulence is probably an increasing function of the duration of the wind.

Apart from the exact time dependent solution it is of value to estimate time constants involved in the establishment of the vertical profile and subsequent stages in the realization of a steady response to a given wind field.

Dimensional inspection of equation (23) shows that the characteristic time is $T_{drift} = \frac{\rho h^2}{A_v}$ (25). For a value of $A/\rho = 100 \text{ cm}^2/\text{s}$ and $h \doteq 1.8$ m one finds $T_{drift} \cong 5$ min.

The next time constant of interest is the seiche period, which would enter the picture in the decay of a slope-drift current system after the wind dies down suddenly. This is given by $T_{seiche} = 2L/\sqrt{gh}$. Obviously the period is strongly dependent on L, the length in the direction of the prevailing slope. Assuming again a depth of 1.8 m, a width of 2 km and a length of 22 km (true for area 3) one finds for the period in the cross axis direction about 16 min, up to about three hours in the lengthwise direction. For comparison, the fundamental seiche period in Lake Okeechobee (circular, with radius of 25 km) is about six hours.

It is difficult to find the time constant characteristic for the build-up of the stationary slope current-drift current combination, as long as there is no well established idea on the closure of the solution at the solid boundaries.

If we assume an average current $u$ over a depth h, a slope $\beta$ which is related to the wind stress by $\beta = -\frac{3\tau_s}{2\rho g h}$ then the time needed to "fill" the triangular area which is the difference between the wind induced sloping surface and the mean water level is given by

$$T_{slope} \cong \frac{3}{16}\frac{\tau_s L^2}{u \rho g h^2}$$

For $\tau_s = 2$ g/(cm s$^2$), L = 22 km, and u = 10 cm/s one finds

$$T_{slope} \cong 1\ 1/2 \text{ hrs.}$$

Notice that the height difference along the lagoon is for this case

$$\Delta h = 21 \text{ cm} \qquad \text{(wind set up)}$$

This overview of the relevant time constants points out that the detailed superposition of currents as a consequence of a shifting wind presents a complicated pattern indeed. Some experiments confirming the theoretical ideas were conducted. Schneider et al (1974) found a current vector which varied in direction with depth, under noticeable correlation with the wind field. In the present study a circulation cell has been found, albeit very weak, which confirms also the notion that the currents in the stationary case are an order of magnitude smaller than a pure drift current under the same windstress.

## 3.3.0 Measurement of Vertical Profile in Lagoons

### 3.3.1 Vertical Profiles in Indian River near Melbourne

Vertical profiles were measured near Melbourne,to become acquainted and develop techniques with the General Oceanics # 2010 deflection current meter. It is based on the principle that a positively buoyant cylinder, attached at the lower end, will be deflected in a current. The deflection is measured by recording on film the markings of a freely moving sphere inside the cylinder. A magnet on the sphere maintains the orientation, so that current direction is defined. The attractive feature of the instrument is that weak currents can be measured, down to about .2 knots. The latest type which we acquired features burst sampling, i.e. at a preset interval not just one, but a series of exposures is taken, 1.8 s apart. This prevents to a large extent the faulty readings which a passing wave might give, and which would be indistinguishable from a persistent current. To more effectively reduce this problem of aliasing, we proposed to General Oceanics to insert the possibility of either adjustable, or randomized time lapse between the exposures in a burst. The importance of this suggestion was acknowledged by General Oceanics.

Detailed description of the method and the data are found in the report on a senior project by Motschman (1975).

The data measured on 18 April 1975 are tentatively interpreted as showing the onset of a pure drift current. (See figure 6).

Profile # 1 should not be considered as taken at one given time. Rather, the bottom current ( at 2.5 m) was measured first, the mid-depth current ( 1.5 m) next, and the surface current last. Thus the three velocities presumably represent the development in time of a drift current profile.

One can make a rough estimate of the time constant by assuming that the equilibrium profile is constant, and that the wind has started at the time the measurements started. Then the time constant is found to be about 10 minutes, which is roughly compatible with theoretical ideas.

The steady state drift profile at t = 11:52 and following strongly reveals the inadequacy of a constant A, which would predict a linear profile, as in the second graph in figure 2. This is an added reason to inspire faith in the linearly structured A as proposed in the theoretical section.

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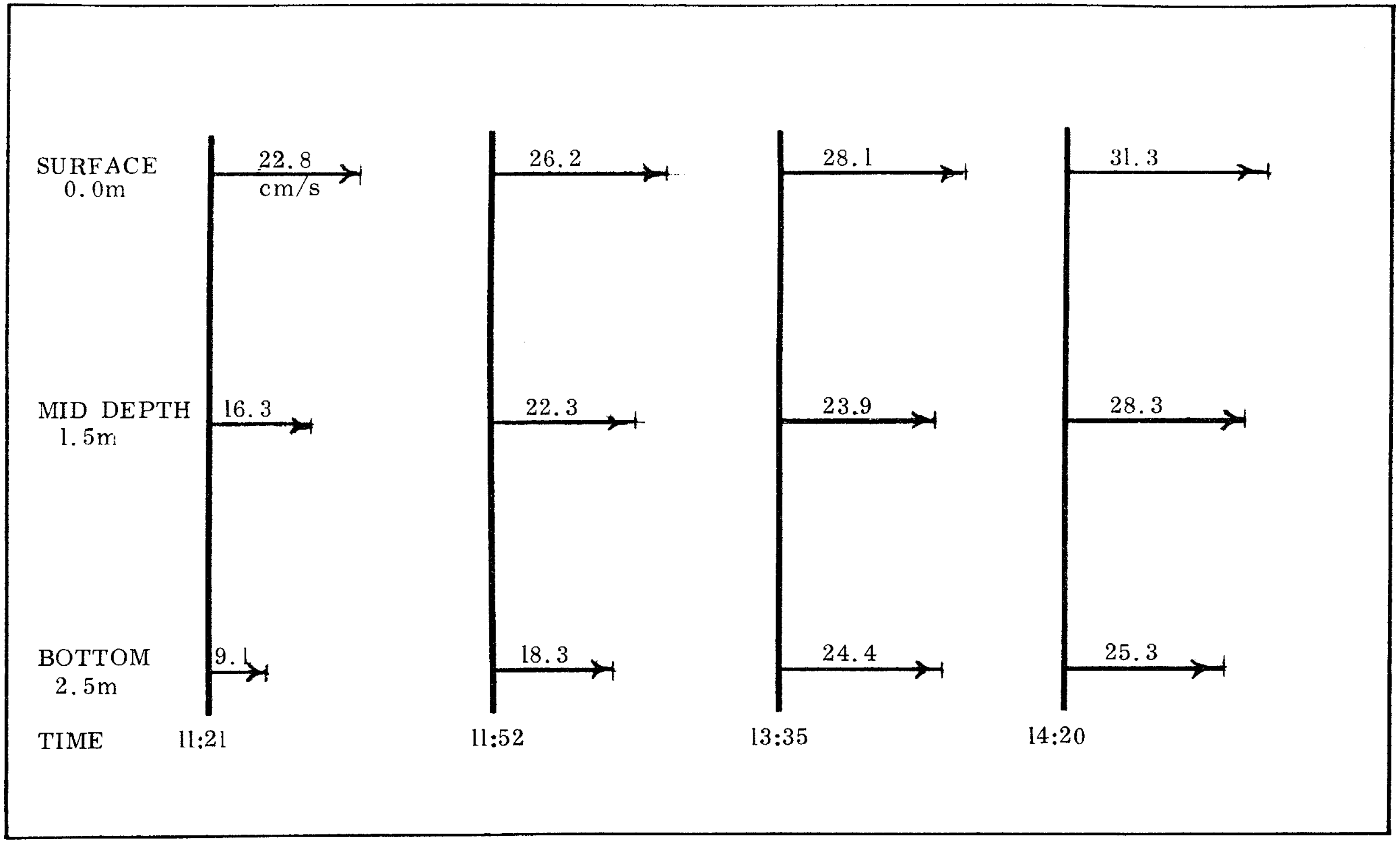



Figure 6. Sequential velocity profiles, measured near the Melbourne Causeway, 4/18/75.

To quantitatively interpret this profile, we compute the wind stress by the formula $\tau_s = (2.6)\ 10^{-3} \rho_2' w^2$, where the windspeed was 900 cm/s. It follows that $\tau_s = 2.7$ dyne/cm$^2$. According to the formula for A in the same reference (Neumann and Pierson, 1966) we find A = 400 g/cm s. The formula for the drift current, (17) then gives a surface current of 23 cm/s which is well within the measured range of 17 to 22 cm/s (figure 4). The profile according to formula (17) is shown in figure 5. By comparison, with the same numbers the formula for constant A, (9) would give a surface current of 2.2 cm/s, which is far too small. The same windstress for the steady state condition of slope plus drift current would produce a surface current of 1.0 cm/s. This might explain, why it is in general difficult to find convincing examples of the circulation cell implied by the steady state condition of drift and slope current.

### 3.3.2 Vertical Profiles in KSC area

The deflection current meter was used for synoptic measurement of the vertical velocity profiles in the lagoonal waters of Kennedy Space Center. An estimate of the wind field was made; it was not attempted to establish correlation with the wind as measured by the weather station at KSC. It appears that in order to establish such correlation it is indicated to have long time series of the water heights of gauges surrounding a given area, as was proposed for the extension of the grant into the fourth year. The measurements of the vertical profile are too widely scattered in time and space to allow a breakdown into the various factors which determine the total circulation, as discussed in the theoretical section.

The complete set of data with description of the details of deployment of the instrument is given in the Appendix. (Volume 3 of this Report)

A short description is presented in the sequel, with emphasis on special events, and generalizations where possible.

Scrutiny of the data shows the considerable, maybe exclusive, advantage of burst sampling. It enables one to reach a meaningful average when there are fluctuations, and to judge when there is no semblance of an average drift. Compare a burst series with just one random value out of the series, and one realizes the completely faulty conclusion that might have resulted from the single measurement of an instrument without burst sampling.

It is not attempted to analyze the measured fluctuations, but there is undoubtedly abundant material for such an analysis present.

A survey of the stations occupied appears in figure 7.

1. Station III-1, 11 April, 1975

This station is the center of the draw bridge in Haulover Canal. The meter is attached to a block on the bottom of the canal, depth 4.9 m. The wind is about 20 knots, from the west.

As expected, the current is all the time in the direction of the canal, about 45°, and averages at about 70 cm/s.

A remarkable feature is that the fluctuations about the average are considerable, from about 60 to 85 cm/s. It once more demonstrates the advantage of burst sampling, but the cause of the fluctuations is rather obscure. Considering the sensitivity of the instrument, which is approximately given by $d\alpha/dv = v\cos\alpha$ where $\alpha$ is the deflection angle, one sees that the sensitivity goes to zero near the 90° deflection angle. Thus small fluctuations in the deflection would read as large variations in v. Maybe these variations in the deflection are caused by small vertical currents. This point deserves further study.

It is of interest to compare the measured bottom current with the water-heights measured by the permanent tide gauge at the west end of the canal. (Section 5 ). Unfortunately the other gauge was stolen, so that no complete calibration is possible. Because of the fluctuations a detailed correlation between water height and bottom current would be misleading. One could, though, compare the average current 70 cm/s with the average water height between 9 and 12 a.m. which is about 42 cm, above an arbitrary datum. The graph of Browne, (1974) figure 10 gives a difference in water height of 6.9 cm for an average current of 70 cm/s, thus one could conclude to currents from the single station for a certain span of time.

Since the average water level of the two bodies of water connected by the canal can vary over long periods of time, it is not possible to draw a conclusion concerning the absolute level from these observations. A record much longer than available should be averaged in order to establish mean water.

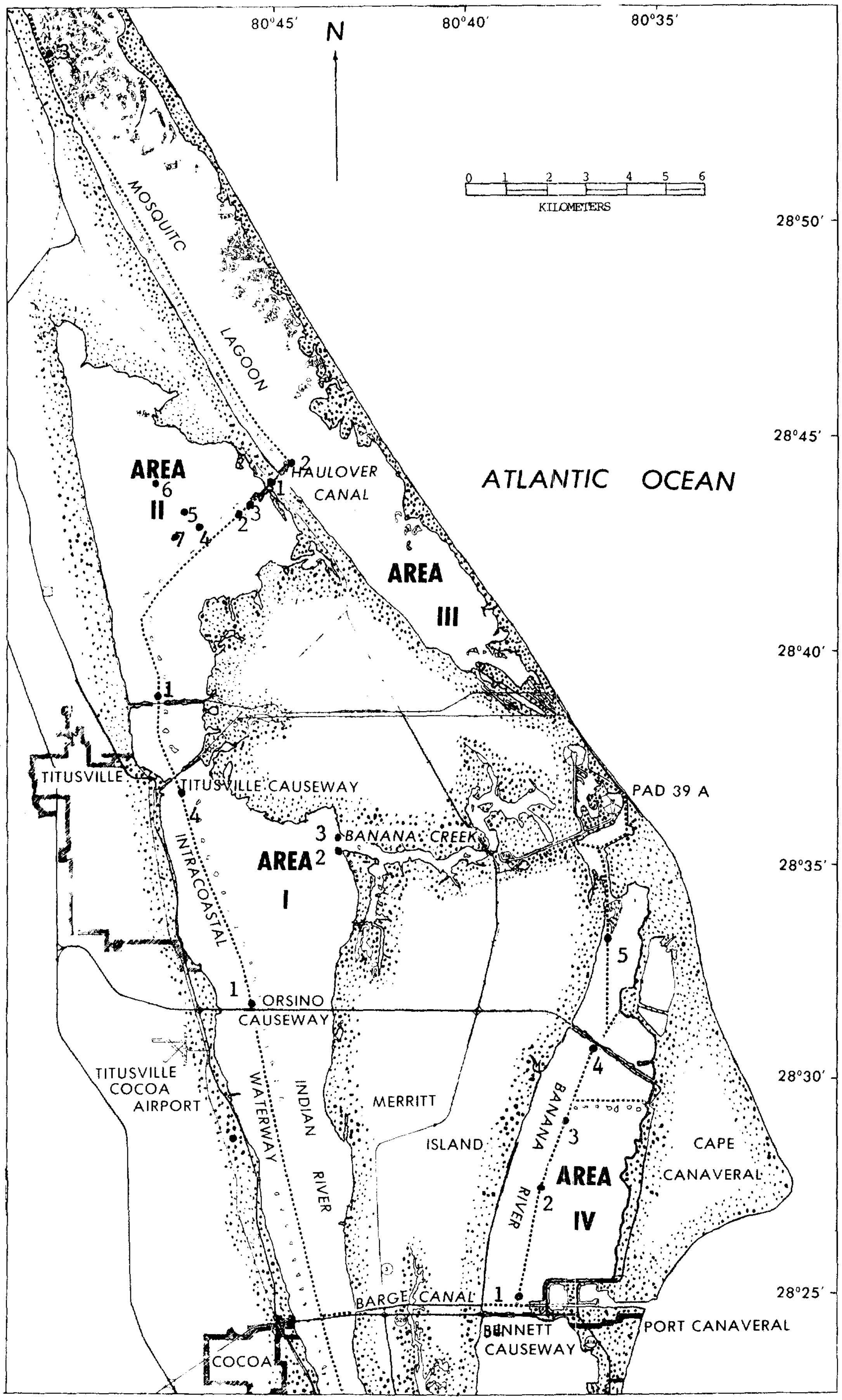



Figure 7. Location of Stations; Vertical Profiling

2. Station II-2, 6 June, 1975

This station is near the west entrance to Haulover Canal, in the Intracoastal Waterway. The wind was from the northwest, about 10 knots.

The graphs show the result of averaging the data. Overall it appears that there is a current in the direction of the wind, in the order of 10 cm/s. An unusual feature is the direction of the mid-depth current at 11:00, which is almost perpendicular to the main direction of wind and current. Also the shift of the surface current between 11:10 and 11:12 by $55^{\circ}$ to the right of the wind is difficult to explain.

3. Station II-3, 6 June, 1975

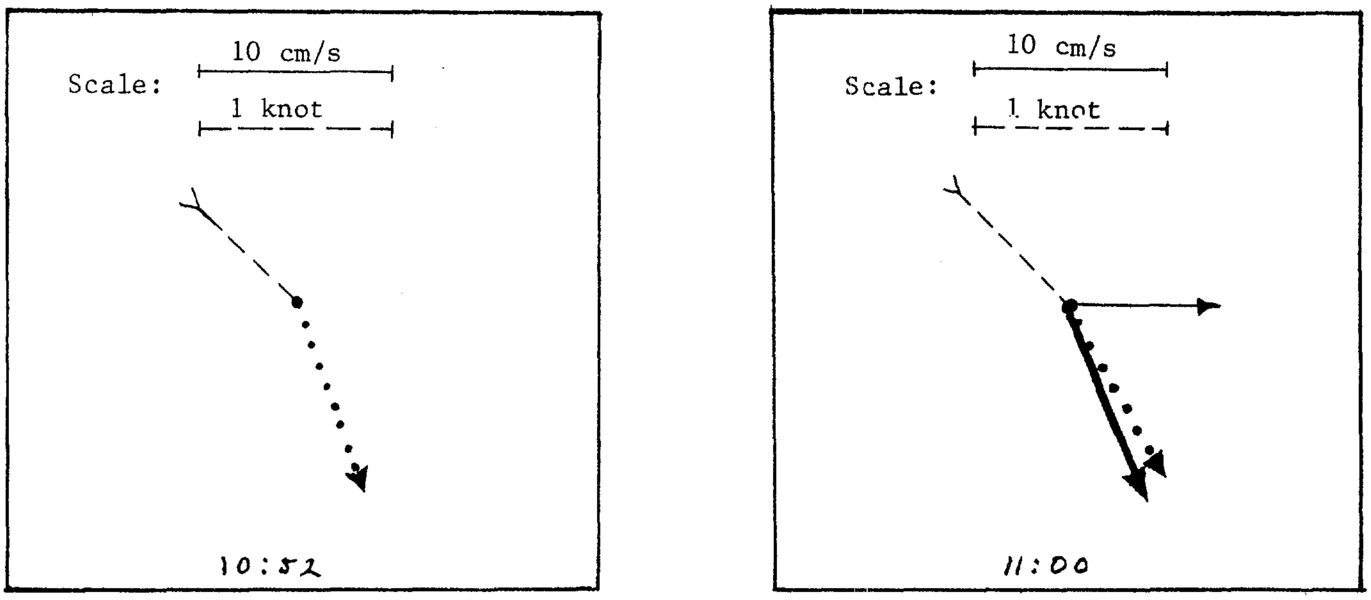
These data were taken sequentially to those under 2. The station is right at the entrance of the jetties at the west side of Haulover Canal. The currents are weaker, on the order of 6 cm/s. The graphs clearly show the striking difference in direction between surface currents versus mid-depth and bottom. This is tentatively explained by the assumption that the main profile is dictated by the outflow from Haulover Canal, which generally has a larger value, since it has the character of a hydraulic current. The surface drift current then is vectorially added to this "jet" out of Haulover Canal.

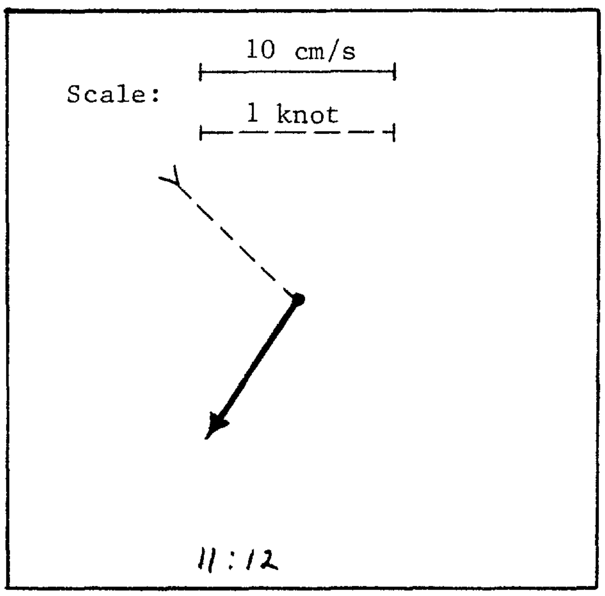
4. Station II-3, 27 June, 1975 Time 12:00 - 12:21

The location of this station is near the jetties at the western entrance to Haulover Canal. (Compare the same station at 6 June.) Now the wind is from the SW at 10 knots, thus in the direction of the canal. The data show that the current is all the time in the direction of the canal with a speed of about 30 cm/s. It appears that the current is wholly under the influence of the canal, like the entrance to a funnel. Only surface data were taken. Some fluctuations in the data seem to be from other than statistical cause and deserve further attention.

5. Station II-1, 27 June, 1975 Time 12:30 - 13:20

This station is 30 m N of the railroad bridge, in the Intracoastal Ww. The wind is from 5-10 knots from the NW, after it had been blowing from the SW prior to data taking. (See item 4). It appears that both surface and bottom current are rather persistently in the $155^{\circ}$ direction, 6.3 and 13.3 cm/s respectively.



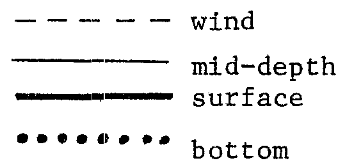




Figure 8. Station II-2.
6/6/75

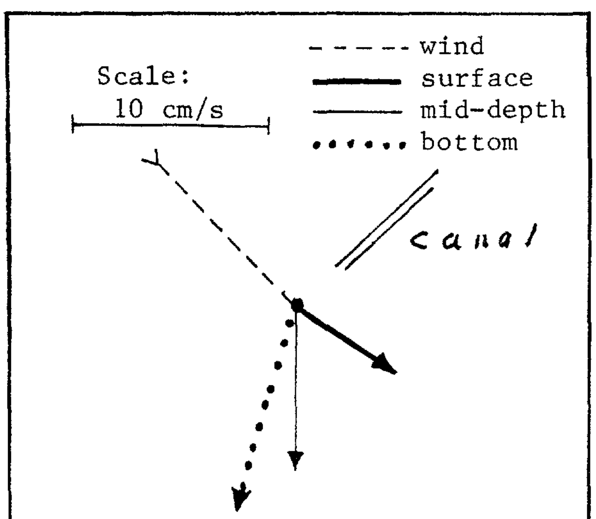



Figure 9. Station II-3 6/6/75

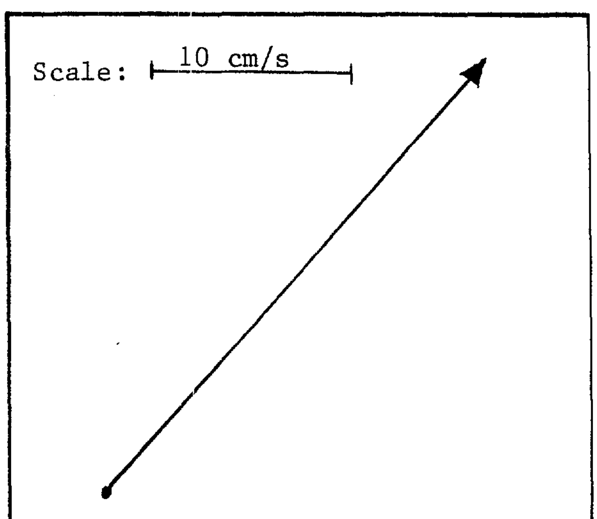



Figure 10. Station II-3 6/27/75

Considering that at station II-3 a little earlier the current was running out of the area through Haulover Canal, under influence of wind pile-up, the interpretation of this current could be that now the piled-up water is running back southward, aided by the wind, which is in the same direction. The fact that the current is not quite along the axis of the lagoon might be due to the angle of the wind with this axis.

6. Station I-4 , 27 June, 1975 Time 13:35 - 14:08

This station is near the Titusville Causeway, in the Intracoastal Ww. (depth 4.6 m). The wind is from the NW from 5-10 knots.

The record shows some strange variations from the full current to below threshold. It would appear that this is a spurious effect, and that the current is persistent at about 13 cm/s, in a direction of $160^{o}$.

7. Station I-1, 27 June, 1975 Time from 14:33 to 14:43.

This station is in the Intracoastal Ww near the NASA Causeway. The wind has shifted to SW, at about 10 knots. The current record is erratic, but seems mostly to indicate that the speed is near or below threshold. The interpretation might be that the shifting wind now opposes the slope current, and reduces the current to values below threshold.

8. Station I-2 and I-3, 27 June, 1975

These stations are in the mouth of Banana Creek, the south and north "channel", respectively. The depths are about 1.2 m. The depth is so small, that a profile cannot be resolved. The hypothesis is that the creek is very much under the influence of the water height in the main lagoon, and to a lesser extent of the wind stress on the creek itself.

Starting at 15:25 with a wind from the E, about 5 knots, the current is 10.8 cm/s. It gradually increases to 15.8 cm/s at 15:30, to decrease to 13.8 at 15:34. The direction is about $244^{O}$ all through. It looks as if this trend is continued in the north channel, where the current is fluctuating about 7 cm/s in a direction $220^{O}$ at 14:00.

Upon return to the south channel, the film record shows a steady current at $100^{o}$, about 7.4 cm/s. Thus the current is reversed, apparently under the influence of a thunderstorm, (most of this was visual observation of the surface current, and current at the depth of the meter). The current was flowing west at about 20 cm/s. With the passing of the thunderstorm the current changed at the surface, while the bottom current continued westward, slowly reducing to zero, while the surface current changed to east, increasing in strength. After the whole current profile was directed east the surface current slowed down, until it amounted to about 1.5 cm/s. The observed phenomenon probably constitutes again a case of superposition of slope current produced by pile-up at the eastern boundary of the lagoon, on the wind drift current driven by the strong winds of the storm.

9. Station IV-4, 7 July, 1975

This station is near the bridge in the NASA Causeway. The wind was from the SW at 15 knots. This was the first time that two deflection current meters were available, deployed at two depths simultaneously. Unfortunately the major part of the record of the lower current meter was not retrieved, and as a consequence only a short span of simultaneous data is available. The lower meter, depth 5.5 m shows a current of 12.0 cm/s at $190^{o}$, time 13:20. The surface current was very erratic, even for directly adjacent frames. Close to time 13:20 the current seems to have stabilized, and is around $340^{o}$, and 15 cm/s. If these data are correct, this would constitute a current reversal indicative of a drift-slope current superposition. The data sequence of the lower meter is too short and uncertain to definitively support this conclusion.

10. Station IV-5, 7 July, 1975

This station is the northern end of area IV. The wind was from the SW, 15 knots. Two current meters were deployed at 1.2 and 4.6 m depth.

The record of the upper meter is very inconclusive; for about thirteen frames the current is steady, about 30 cm/s, and $148^{o}$. Then it is variable for about 3 minutes, both in strength and in direction, until it seems to stabilize at about 6 cm/s, and roughly $100^{o}$. There is no obvious relation to anything in the wind field to cause this. Neither is there much to derive from the correlation with the record of the deep meter. This starts out with a current of 10 cm/s, at $240^o$ for 7 frames, then after some blurred frames it seems to settle down at $190^o$, 7 ft/s while the surface current is still strong.

There seems to be no satisfactory explanation for this behavior.

The mouth of Buck Creek off Area IV was explored, but there was no noticeable current there.

Since the upper current meter showed very obvious malfunctioning later, 18 July, it probably was already unreliable in the above described record. The bottom current meter record appears to be reliable.

11. Station III-3, 1-5 Aug. 1975

This station is at the northern end of Mosquito Lagoon, where connection with the lagoonal area is through a relatively narrow channel. By personal communication of local people it was learned that height variations are appreciable, and in step with astronomical tide. This is confirmed by the current record. A short portion is reproduced in figure 11. A semidiurnal variation is unmistakenly present. The crosses indicate a period of six hours starting with a crossing of zero axis, and it appears as if subsequent crossings coincide with a six hour period, indicative of a semidiurnal tide. The record should be analysed with inclusion of overtides and mixed tides. There probably is also a component due to wind pile-up.

From this record an estimate may be made of flushing of Mosquito Lagoon by tidal action.

If we assume that a volume $\Delta V$ passed into and out of the lagoon during each tidal cycle, the concentration after n cycles ($C_n$) will be approximately (assuming complete mixing)

$$\frac{c_n - c_o}{c_o} = \left\{1 - \left(\frac{\Delta V}{V}\right)\right\}^n - 1$$

assuming that the volume of Mosquito Lagoon is small compared with the volume north of the connecting channel, and $\Delta V$ small compared with $V$ .

From the record in the figure one sees that the amplitude of the velocity is about $v_o = 30$ cm/s. Combined with an estimated cross sectional area of 120 $m^2$ we find that $\Delta V = v_o AT/\pi$ , where T is the tidal period.
Thus $\Delta V \approx 2.5 \times 10^5 m^3$.

The total volume of Mosquito Lagoon is about 84 x $10^6 m^3$. Then $\frac{\Delta V}{V} \cong$ .0030. Thus the concentration drops after 3 days only by 3%, and after one week by only 8%.

This shows that flushing a conservative substance out of Mosquito Lagoon by tidal currents is an extremely slow process.

12. Station II-7, 8 Aug. 1975

This station is 1.3 nm, $314^{\circ}$, from aid # 6, which is near the center of area II, north of the Intracoastal Ww. The wind was from the NW about 5 knots.

The record of this experiment is very inconclusive; direction and velocity is variable. The main conclusion would appear to be that the current is very small, and close to threshold, about 5 cm/s. This would concur with the low wind speed, which would not be enough to create drift currents within the range of the current meter.

13. Station II-2, 23 Aug. 1975

This station is mid-channel between aids 1 and 2, west of the entrance to Haulover Canal. The wind was from the NE, about 5 knots. The current was very small, visually it was estimated at 2 cm/s to the east. This is the same location as on 6 June, when there was a noticeable current to the SE, $\approx$ 8 cm/s, with a NE wind of 10 knots.

14. Station II-4, 23 Aug. 1975

This station is .85 nm $325^{\circ}$ from aid # 4. The wind had been steady from the SE for about three days. It was expected that this location would be suitable for observation of a current reversal with depth, which is a consequence of the assumed superposition of a slope and drift current.

At 11:30 it was visually observed that the current at the surface was about 4 cm/s to the NW, and at depth 1.8 m it was 4 cm/s to the S. This does indicate a current reversal.

From 12:00 until 12:25 the bottom current (1.8 m) was quite stable, about 6.5 cm/s, at $190^{\circ}$. The mooring block was placed in a hole dug in the sand, in order to have a better average over the lower part of the profile.

The surface current at 12:32 was about 4 cm/s to the north, by visual observation.

The record of the surface current from 12:32 to 12:35 is extremely erratic. Thus, there is no direct measured evidence of the reversal, but the circumstantial evidence of visual observation, and direction of the wind, which is about opposite to the bottom current point towards the existence of the circulation cell.

15. Station II-5, 23 August, 1975

This station is 1.7 nm in direction $324^{o}$ from aid # 4. It thus is a bit farther north than II-4. It was taken up in a continued effort to establish the existence of a current reversal. Wind was to the E , at 10 knots.

Here again the film record of the events is very difficult to interpret, obviously because the current is near or below the threshold of the current meter.

Visual observation of small particles suspended in the water showed a movement of the upper 60 cm layer in the direction of the wind, and movement in opposite direction of the lower layer. Current speeds were very small. This again appears to be a weak circulation cell, similar to the one in item 14.

It is probably correct to say that the observation of a circulation cell in the act is made difficult by the fact that the currents are an order of magnitude smaller than the pure drift current under the same wind field. This is explained by the assumption of a linear eddy coefficient of viscosity instead of the usual constant one.

16. Station IV-5, 29 Aug. 1975 Time 9:23 Wind E 5-10 knots

This station is at northern end of Haulover Canal. It was also occupied on 7 July, 1975. (item 10)

At 8:55 the current (surface) was 4-8 cm/s to the south.

From 9 - 9:12, depth 3.8 m, current $\approx$ 7.5 cm/s at $\approx 200^{o}$

From 9:12 - 9:23 mid-depth, 1.8 m. Record not very stable, but it looks like mostly $270^{o}$, 5.4 cm/s.

At 9:23, meter at surface. It was visually noticed that the meter started out with fins pointing south, indicating a south current, then it swung around clockwise by $400^{\circ}$, with a period for $300^{\circ}$ of 15 minutes; it rotated in spurts.

The corresponding film record: at 9:40 it seems to have settled at $100^{\circ}$, 8.4 cm/s.

From 9:23 through 9:35 the surface current is stable at $100^{\circ}$ and 8.4 cm/s, then all of a sudden it started rotating, matching the visual observation, through $150^{\circ}$, $180^{0}$, $210^{\circ}$, $280^{\circ}$, $360^{\circ}$, $10^{\circ}$, $80^{0}$, and settles at $100^{\circ}$ 8.4 cm/s. This rotation of the current had not been observed before. One wonders if it could have been an eddy passing by.

17. Station IV-4, 29 Aug. 1975

This station is near the NASA causeway bridge, 100 m. south of the site occupied on July 7. The wind is to the east, 5-10 knots.

The current at depth 4.6 m was reasonably stable, about 7 cm/s at $170^{\circ}$.

At depth 2.1 the current was virtually the same as on the bottom, $180^{\circ}$ and 7.0 cm/s, the difference is not significant.

The surface current was very stable typically around $170^{\circ}$ and speed of 8.4 cm/s.

This time there is no indication at all of a current reversal. Possibly the east wind has established a circulation cell (weak) superimposed on a rather steady slope current directed to the south. This superimposed circulation cell may be responsible for a slight variation in direction of the current from top to bottom, but this is hard to confirm by the data.

18. Station IV-1, 29 Aug. 1975 Time 11:40 - 12:15

This station is 90 m. north of SR 528 causeway bridge, in mid-channel. At this time the wind was to the E NE, 5-10 knots. From 11:50 - 12:02 depth 3.0 m. The current at this depth is quite stable at about 7 cm/s and $225^{\circ}$. At the surface the current is slightly smaller, about 6.0 cm/s and $210^{\circ}$. It could be hypothesized that the shift toward the west is due to the influence of the nearby Barge Canal.

19. Station IV-2, 29 Aug. 1975 Time 12:30 - 12:52

This station is 90 m. west of aid # 19. The wind is still E NE, 5-10 knots. There is some variability in the bottom current (2.4 m) but it is mostly at 170° and 8.4 cm/s. The surface current is slightly less, about 7.4 cm at 170° direction.

20. Station IV-3, 29 Aug. 1975 Time 13:00 - 13:25

This station is 90 m west of aid # 25. The wind is E., 5-10 knots. The bottom current (2.4 m) is about 8.4 cm/s at 170° and the surface current is pretty much the same.

In that record there is a variation in direction of current which is reminiscent of the rotating current observed in station IV-5, (29 Aug. 1975). After the current was 180°, 8.4 cm/s, subsequent observations show a current of 6.4 cm/s at 140°, 100°, 90°, 70°, 30°, 90°, 120°, 140° and back to 170°. This might be the edge of a passing eddy.

## 3.4.0 Dye Study of Carter and Okubo

Relat ed work on shallow water wind driven circulation is discussed in various other sections of this report. A separate section is devoted to the work of Carter and Okubo (1965) since it was performed at the same locale with similar purpose, namely, the prediction of spreading of accidentally released radioactive material in lagoonal and near shore waters. In various respects theirs and the present work are complimentary.

Carter and Okubo use a dye technique, and as a generalization it may be stated that their results are very valuable for assessing the dispersive properties of the system, but provide only indirect insight into the circulation pattern and correlation with the wind. This distinction is enforced by the fact that in the lagoons only samples at 2 ft. were taken, so that there is no direct experimental evidence on the point of vertical shear.

Our method of direct current observation does yield direct information on the circulation, but is little suitable for establishment of diffusion coefficients.

Carter and Okubo have one dye release in each of the areas 2, 3, 4, but none in area 1. They assume vertical homogeneity in temperature and salinity.

The problematic connection between dye experiment and general circulation is reflected in the discussion of p. 115 ff. Considering the shallowness ($\sim$ 3 m) it is extremely doubtful that any Coriolis effect would be noticeable, and therefore equations 4-4 and 4-5 provide an extremely tenuous link between vertically integrated forces in one direction and transport in the perpendicular direction through the Coriolis parameter f. Further, the assumption $\tau_s/\tau_b \gtrsim .1$ is just a rule of thumb which has limited validity as shown in our section 2.2. Since the text on p. 122 refers to computing $M_{x,y}$ it is quite obscure how in tables 10, 11 an "observed" $M_{x,y}$ appear. Therefore the conclusions on p. 125 appear ill-founded, except those which express that "the data are inadequate to define the circulation". We found, contrary to the conclusion on p. 127, that a certain correlation between wind and current can be found, provided one takes the time history of the wind into account which admittedly is not an easy task. The residence time of 150 days (p. 128) seems to rest on rough estimates at best.

I would take issue with Carter and Okubo's assumption that Merian's formula

( $T = 2L/\sqrt{gh}$) would give the characteristic period for the response to variations in wind stress. One has to take into account the character of the drift current profile to arrive at the proper time (see section 2.4). Decay of the slope current is given by the seiche period.

### 3.4.1 Diffusion of the Dye Patch

Carter and Okubo state that "the total spread of the dye patch is determined by the combined effect of diffusion due to small scale eddies and of convection due to the large scale eddies". The proper distinction between small and large is aided by their convenient assumption that the spectrum consists of two well defined peaks well above and below the measurement scale (figure A1 in their report).

Their theoretical interpretation of the observed dispersion of the dye patch is based on an assumed velocity profile which varies linearly in the horizontal and vertical direction. The mathematical development of the problem is quite ingenious, but it is hardly surprising that the resulting effective dispersion coefficients are directly dependent on the coefficients in the assumed linear shear model for the velocity.

In this report it was shown by experiment that the vertical velocity profile is far from linear. It even becomes non-monotonic when slope and drift current combine, and in all cases it is a function of the history of the wind field.

Thus it is impossible from Carter and Okubo's results to derive the turbulent diffusion coefficient valid for a scale below the structure of the vertical profile. Only if they had sampled the dye at various depths, and measured the velocity profile at the same time would have extraction of this information from the data have been possible.

A more complete model of the dispersion in the lagoon would depend on a value for the vertical eddy diffusion coefficient, which so far has not been measured in a comparable environment, as far as is known to this author.

3.5.0 Water Level Measurement at Haulover Canal

The study of Browne (1974) showed the usefulness of water level gauges located at either side of Haulover Canal.

Two Fisher-Porter stilling well type of tide gauges were installed on Aids to Navigation close to the jetties of the canal.

Before any data could be recovered the tide gauge at the east side of the canal was stolen in a very professional way. A replacement from the manufacturer was only received by the end of August and therefore only data from one tide gauge could be recovered.

With two tide gauges a direct measure of the transport of the canal is determined through the difference in height. (See Browne, 1974 for the calibration curve). Either of the two absolute levels of the gauges gives an indication of the overall level in each of the adjoining lagoons; if more gauges were installed, as proposed, inference could be drawn with respect to the current field in the lagoonal areas.

Figure 12 gives a part of the record acquired by the tide gauges at the west end of the Canal.

3.6.0 Summary of Study on Current Transport through Haulover Canal

This study ( Thesis, Browne, 1974) is basically one of hydraulics, and to be more specific, one of open channel flow. Much of the literature reviewed has established theoretically and experimentally the same basic equations for both uniform and nonuniform flow in open channels.

Haulover Canal connects two large bodies of water. The water level of each, as a function of the wind field, undergoes slow changes affecting a flow in the canal in either direction. The rate of change of the water elevations at each end of the canal is believed to be so slow that the flow in the canal may be considered to be steady at any instant. This consideration is evident in the equations of motion developed for the flow through the canal.

Haulover Canal is a prismatic channel (one that is uniform in cross-section and bed slope) running in the $045^{\circ}$ and $225^{\circ}$ directions. It was designed and excavated by the Army Corps of Engineers. The canal has a trapezoidal cross-section

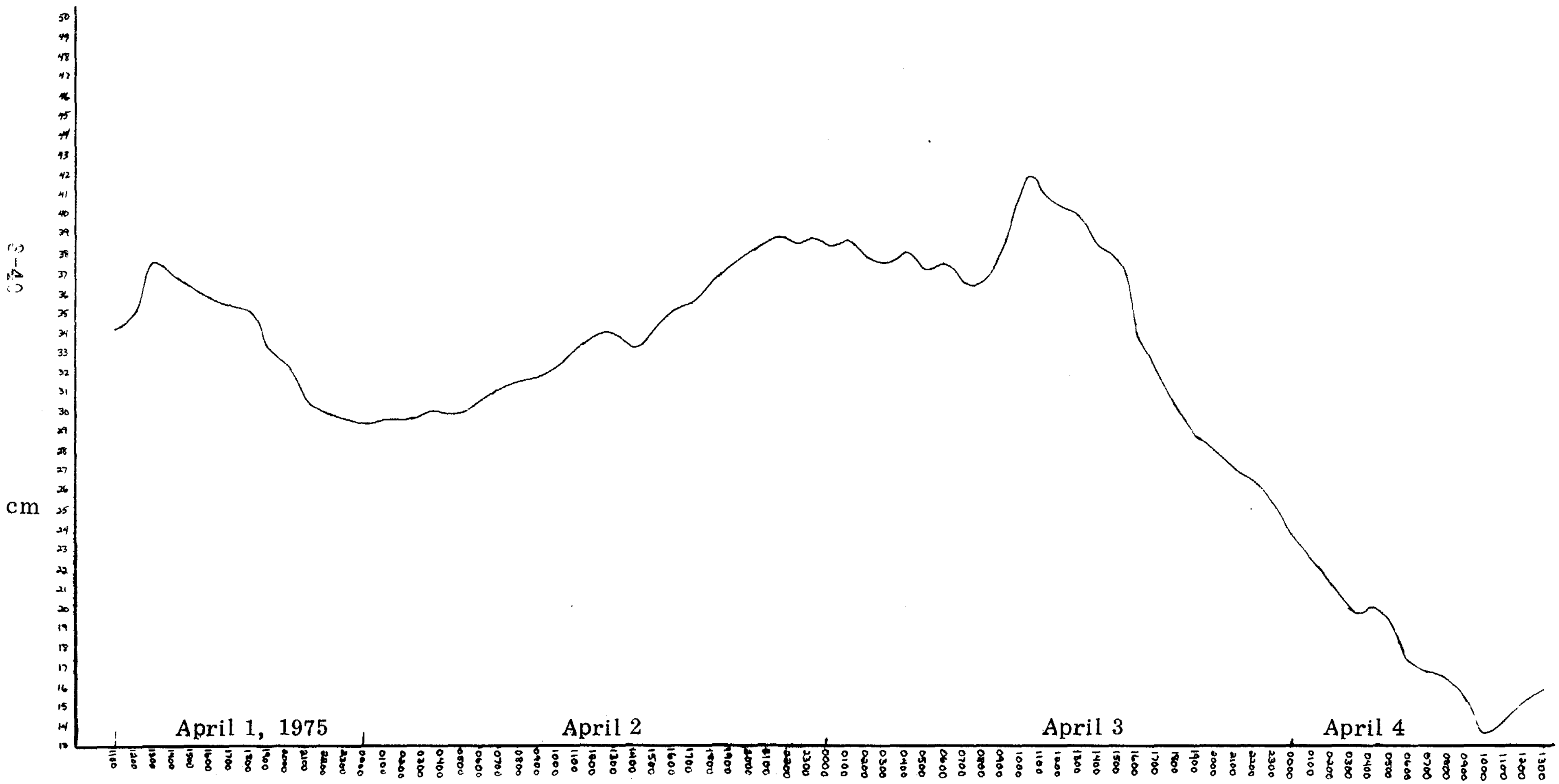



Figure 12. Water level measurements, west end of Haulover Canal

with side slopes of 1 on 1.5. The canal was designed to have a depth of 4.27 m but the average of actual readings indicate an actual depth of 4.53m. There is no bottom slope in the canal and the canal bed is considered parallel with the horizontal datum. The length of Haulover Canal is approximately 2.054 km. From these dimensions the cross-sectional area "A" is calculated to be 203.37$m^2$, the wetted perimeter "P" is calculated to be 54.43m, and the hydraulic radius "R", which is the cross-sectional area divided by the wetted perimeter, is calculated to be 3.74 m.

The transport through the Haulover Canal is related to the slope of the water surface by the Manning equation for uniform flow. The Manning coefficient used in this equation is approximately 0.022 sec $m^{-1/3}$.

The evidence points to the fact that the prevailing winds are the driving force for the transport through the canal. The optimal wind direction for the transport of water from the Mosquito Lagoon to the Indian River was found to be approximately 357°. For the water transport from the Indian River to the Mosquito Lagoon the computed optimal wind direction was found to be in the proximity of 224°.

### 3.7.0 Summary of Study of the Circulation in the Lagoons Encompassing Cape Canaveral, Florida

The hydrodynamics of the Indian and Banana Rivers and Mosquito Lagoon, surrounding the John F. Kennedy Space Center, Florida, is the object of this study. (Thesis, Dill 1974). Data gathered from surface current measurements made with current crosses are compared with simultaneous measurements of the wind field over each lagoon under varying meteorological conditions.

Steady-state and time dependent mathematical models are developed and predicted current velocities are compared with measured values. Extensive discussion is given to the previous work of other investigators in attempting to determine values for such ill-known quantities as eddy viscosity coefficients, dynamic roughness length, wind drag coefficient and bottom stress.

The circulation in these shallow lagoons appears to result from a combination of wind stress and slope currents. Tidal and Coriolis forces seem negligible. Calculations of theoretical surface current velocities under pure wind stress conditions compare reasonably well with measured current velocities.

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Chapter 4

# MICROBIOLOGICAL STUDIES OF THE INDIAN RIVER LAGOONS

W. L. Blevins

## 4.0 Introduction

Microbiological investigations during fiscal years 1973 and 1974 have been previously reported both to the John F. Kennedy Space Center and in the press. During fiscal year 1975, these investigations were continued in the form of two studies; one into the effect of various forms of nitrogen enrichment upon the growth rate of indigenous halophilic bacteria; and the second an investigation into the probable fate of $H_2S$ found in bottom muds but not observed in the water column above the bottom muds. The results of these studies are presented here in the form in which they were accepted for publication.

These studies were conceived and directed by Dr. T.A. Nevin and the final reports edited by him. Dr. Nevin terminated his connections with F.I.T. effective 1 January 1975.

## 4.1 Nitrogen Enrichments for Certain Moderately Halophilic Bacteria Indigenous in a Saline Lagoon, C.L. Noble, T.A. Nevin and W.L. Blevins

### 4.1.1

In continuing studies of the lagoonal system of the Central East Coast of Florida (Nevin, et al. 1973), it has been a usual observation that combined nitrogen could not be detected in the waters by the methods employed. The noted deficiency may be explained plausibly by any of a number of arguments. Few of these, however, admit of ready experimental evaluation.

An approach to the problem described herein employes the indigenous heterotrophic, moderately halophilic bacteria. These creatures are expected to have relatively simple but somewhat exacting requirements for nitrogenous nutrilities (Waksman, et. al., 1933; Zobell, 1946; Brisou and Vargues, 1963; Wood, 1965; Burkholder and Bornside, 1957; Stevensen, 1966; Dundas and Halvorsen, 1966; Norbert and Hofsten, 1969). They should, therefore, assimilate rapidly any soluble nitrogenous compounds made available.

### 4.1.2 Methods and Materials

Samples of lagoonal waters, 6 to 10 liters each, were collected by immersing clean, sterile half-liter bottles 3 to 6 inches below the surface, removing the cap and allowing the bottle to fill. While still below the surface the cap was replaced, and the collected samples were stored in the cold. They were ordinarily used within 24 hours. The temperature, pH and salinity of the water were determined at the sample site in order to ensure that no extreme conditions were encountered.

Several 100 ml aliquots of the sample were dispersed into sterile amber glass bottles, and each was enriched with 10 mg of a single amino acid (NB Co., Cleveland, Ohio). In all, 20 amino acids were so used. The enrichment cultures were then incubated at room temperature (25 degrees C) in the dark for 72 hours. Infrequently, the incubation was continued for an additional 24 hours in the hope that a greater cell crop would be obtained. The appearance of visible turbidity indicated a successful enrichment, and relative amounts of growth were estimated by percent transmittance at 600 mμ in a Bausch & Lomb Spectronic 20 colorimeter. Gram stained preparations of each enrichment culture were examined microscopically. Those amino acids which proved to be growth supporting enrichments were then studied in all combinations to determine any growth enhancing effect of multiple additions.

Four control cultures were carried in parallel. These were 100 ml amounts of lagoonal water enriched with: 5 ml of sterile reconstituted nutrient broth (Difco) which was replaced by a peptone solution in later experiments; or 0.05 mgs. of yeast extract (NB Co.); or 7.6 mgs. of $NH_4Cl$; or unenriched as a control on endogenously supported growth.

The most probable number of organisms which would grow upon enrichment with amino acids was estimated using raw lagoonal water serially diluted from $10^{-2}$ through $10^{-6}$ with sterilized (121°C, 15 lbs. pressure) lagoonal water. Aliquots of each dilution were then inoculated into each of 5 tubes containing a sterile lagoonal water solution of the best growth producing combination of amino acids. Eight isolates were obtained in pure culture during these experiments and have been tentatively identified at the genus level.

A mixture of vitamins including thiamine, pyridoxine, p-aminobenzoic acid, pantothenic acid, niacinamide, biotin and folic acid were used as enrichments of the lagoonal water and were also added to single amino acid enrichments to establish their effect, if any. So too, were an ethanol-ether-chloroform soluble fraction of yeast extract, the insoluble residue, and an acid hydrolysate of the residue. The Biuret and Molisch test (Clark, 1964) were used to determine residual peptides and carbohydrates respectively.

### 4.1.3 Results

Visible evidence of the bacterial growth (cloudiness) occurred when any one of the amino acids: tyrosine, histidine, proline, serine, cystine, methionine or glycine was used as an enrichment in lagoonal water. Several varieties of gram negative rod shaped organisms, both motile and non-motile, as well as cocci and spirilla were always found. The nutrient broth enriched and yeast extract enriched controls, although yielding denser growth did not appear to support a broader variety of organisms.

Of the possible combination of the 7 amino acids, the following groups produced 5% or greater reduction in light transmission at 600 mμ: serine, methionine, proline; cystine, proline, histidine, glycine; serine, histidine, cystine, glycine, methionine. Glycine seemed to inhibit growth when either, or both, cystine and tyrosine were present, but the inhibition was not apparent when serine and histidine were also present. The addition of either cystine or methionine to any other non-inhibiting combination of amino acids always seemed to enhance growth, suggesting a need for supplemental organic sulfur.

The most probable number of organisms which could be grown by amino acid enrichments of water samples taken from 6 different sample sites are presented in Table 1.

Table 1

MPN (1) of organisms in 100 ml of river enriched with 6(2) amino acids

| Sample | MPN x $10^3$ |
|---|---|
| S - 25 | 2.8 |
| S - 26 | 9.2 |
| S - 27 | 0.8 |
| S - 28 | 22.0 |
| S - 29 | 35.0 |
| S - 30 | 35.0 |

(1) Previous data also indicate $10^3$ to $10^4$ organisms per 100 ml when MPN's were determined in Thioglycollate medium prepared with distilled water, but these were gram positive spore formers (Beazley, et. al., 1974).

(2) Clycine, methionine, proline, histidine, cystine, serine.

That they are present in appreciable numbers is evident; however, only 4 genera were tentatively distinguished: Vibrio, Benecka, Agarbacterium, and Pseudomonas according to criteria in Bergeys' Manual of Determinative Bacteriology (7th Ed.).

The cell crop was improved by substituting more complex materials for the amino Acids. The results of these experiments are presented in Table 2. At this point, a commerical peptone was substituted for more complex nutrient broth hitherto used as a control. Yeast extract also proved an excellent growth enhancing substance. Further, the indigenous organisms do not use $NH_4^+$ even when supplied with glucose as a source of organic carbon although glucose, when added to an amino acid mixture did enhance growth. It is, in fact, evident that $NH_4^+$ is distinctly inhibitory to these organisms since their growth is greatly diminished when the ion is added to an otherwise adequate enrichment.

Table 2

Substitutions for or additions to amino acids as lagoonal water enrichments

| Substituent or Additive | Growth as % transmission at 600 mu |
|---|---|
| Peptone | 86 |
| Peptone + $NH_4^+$ | 93 |
| Glucose | 98 |
| Glucose + $NH_4^+$ | 98 |
| 6 Amino acids | 95 |
| 6 Amino acids + glucose | 86 |
| 6 Amino acids + yeast extract | 70 |
| Yeast extract | 60 |
| Yeast extract + $NH_4^+$ | 80 |
| Unenriched control | 100 |

In order to gain some insight into the growth enhancing effect of yeast extract, a mixture of known water soluble vitamins was added to the amino acid enrichment, but this had no demonstrable effect. An ethanol-ether-chloroform extraction of the yeast extract was also carried out. The "lipid" fraction, so obtained, was then added to several combinations of enrichments of sterile lagoonal water. The resulting media were inoculated with pure cultures of 6 of the 8 isolates with only slight enhancement of growth.

The extracted residue however, yielded excellent growth both of the pure cultures, and upon enrichment of freshly collected lagoonal water. This effect was obviated when the residue was hydrolyzed with 12 Normal Hydrochloric acid at 100° for 4 hours. The Biuret (for peptides) and Molisch tests (for carbohydrates) which were rather strong before hydrolysis, were greatly diminished in intensity afterwards. Upon the addition of either of the two products of the acid hydrolysis, exceptionally good growth was obtained with the acid insoluble (presumably unhydrolized) residue, but no significant effect was noted when the acid soluble fraction was used. These data are presented in Table 3.

Table 3

Influence of Yeast Extract derived enrichments
on the growth of lagoonal halophils

| Enrichment | Probable Major Component | | | Growth |
|---|---|---|---|---|
| | Peptide (Biuret) | $CH_2O$ (Molisch) | Lipid (Sudan IV) | % Trans. (600 Mu) |
| EEC[1] sol. | tr. (3) | tr. | str. | 93 |
| EEC insol. | str. (3) | str. | tr. | 61 |
| Acid hydrolyzed[2] EEC insol. | | | | |
| Acid sol. | neg. (3) | neg. | n. d. (3) | 100 |
| Acid sol. + glucose | neg. | tr. | n. d. | 95 |
| Acid insol. | tr. | neg. | n. d. | 86.5 |
| Acid insol. + glucose | tr. | tr. | n. d. | 39 |

1) Ethanol-Diethyl Ether-Chloroform (3, 1, 1)
2) 12 N. HCl, 100 C, 4 Hours
3) tr. = trace; str. = strong; neg. = negative; n. d. = not done

### 4.1.4 Discussion

The waters of the East Coast lagoonal system are notably nitrate and ammonia deficient (Nevin, et. al., 1973). It was anticipated therefore, that any source of nitrogen in available form would serve as an enrichment for the cultivation of indigenous moderately haloduric microbes. This did in fact happen but the response was disappointingly small when amino acids were added singly or in several combinations. The addition of a mixture of known vitamins to the amino acid medium did little to increase the cell yield. This too was disappointing since green plants (Manatee grass, algae, etc.) abound in the area waters and would be expected to provide natural enrichments thereof. Glucose, however, did improve cell crop when 10 mg/100 ml was added.

Obviously glucolysis, which may also imply broader saccarolytic activities, would have been more notable by its failure to appear. The fact that it is associated with peptide metabolism, however, supports the concept of intimate associations of the bacteria with indigenous plants and animals.

The inhibitory effect of $NH_4$ + was at first surprising in view of the characteristic absence of measureable amounts of this ion in the water. However, the paucity of $NH^4$ + in the area waters may have been a selective factor for more exacting organisms which assimilate amino acids and peptides.

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## 4.2 Thiol Synthesis by Halophilic Bacteria Indigenous in a Coastal Lagoon, W.L. Blevins, T.A. Nevin, C.L. Noble

### 4.2.1

The presence of beds of sulfide muds among the sediments underlying the waters of the saline lagoon which forms the major waterway along the central east coast of Florida was established by Nevin et al. (8), and the observations extended to the sediments of a tributary, Banana Creek, by Beazley et al. (1). These authors demonstrated a relationship between the sulfide mud beds, the transport of nutrients, and the numbers of certain anaerobic bacteria. In the present work, preliminary observations indicated the disappearance of $H_2S$ from the water column just above the muds, but no measurable increase in sulfur oxides could be demonstrated. Therefore, investigation into the probable fate of the $H_2S$ was undertaken.

### 4.2.2 Methods and Materials

Lagoonal water samples were collected in sterile 500 ml glass bottles. Sterile 125 ml Nalgene bottles containing 12.5 ml of nutrient broth (Difco) were filled with freshly collected samples. The medium was pre-prepared according to label directions with lagoonal water and sterilized before use. Parallel enrichment cultures were incubated at 37°C for 48 hours under either aerobic or anaerobic conditions. A disposable gas pack (BBL) equipped with an $H_2$, $CO_2$ generator envelope was used to establish anaerobosis.

Pre-incubation, post incubation and control bottles of enriched lagoonal water were studied. The control consisted of filtered sterilized (pre-sterilized 0.4 membrane filters: Millipore Corp.) enriched water.

After incubation percent transmission at 460 mμ was determined with a Bausch and Lomb Spectronic 20 colorimeter, then the cell crop was harvested by centrifugation (International Centrifuge Model HT, head number 856) at 9,000 rpm for five minutes.

Acid liberated $H_2S$ was trapped in 0.1 N $CdCl_2$ at pH 1-2, and established by modified iodometric titration (12). Sulfite ions were also determined iodometrically in an acidified sample (12), and when necessary corrected for sulfide concentration by difference. Sulfate ions were separated by barium precipitation (12) then quantities were estimated turbidimetrically. A photometric standard curve at 420 mμ was used for direct readings between 0 and 3 gm/l.

Qualitative tests used regularly to identify suspect compounds were: the malachite green test for sulfites (3), the mercuric chloride-litmus paper test for thiosulfate (3), and the iodine-azide test for reduced sulfur (3).

Thiols were identified with an alkaline solution of cupric chloride and hydroxylamine hydrochloride (4); primary and secondary thiols by heating with $NH_4OH$ and lead acetate paper (4).

Ether extractions were performed by vigorously shaking approximately 100 ml of ether and 300 ml of the supernatant culture medium after centrifugation for 10 minutes. The water layer was then drawn off and the ether layer decanted into a clean beaker. The ether was allowed to evaporate, leaving a residue suspended in a small amount of water. Infrared analysis of the residue was carried out using a Perkin-Elmer 614 grating infrared spectrophotometer and a 1.5 g KBr pellet.

### 4.2.3 Results

Sulfide production was noted in the enrichments under both aerobic and anaerobic conditions, however only small amounts (0.004 - 0.02 mg/l) were recovered.

The amounts of another iodometrically titratable material increased markedly under anaerobic conditions. This material was estimated as sulfite as a matter of convenience. Surface water samples incubated anaerobically yielded about 3 times (16.75 mg/l) that of identical samples, collected three to six inches above the sediments, yielded greater amounts than did the surface water samples under either condition, and again about 2.5 times more was produced anaerobically (18.30 mg/l) than aerobically (7.25 mg/l). More complete identification of the iodometrically titratable material was then undertaken.

The qualitative iodine-azide reaction for sulfur, present as sulhydryl, disulfide or thiosulfate was positive, whereas qualitative tests for sulfite, metabisulfite, bisulfite and thiosulfate were negative. The iodine-azide reaction was also positive when cystine and cysteine were tested, therefore each of these amino acids was added singly to a grown nutrient broth enriched culture (48 hours incubation, aerobic conditions). Methionine was included as a matter of interest. Each of the three amino acids served as substrate for the production of additional iodometrically titratable material by the mixed bacterial flora, as did $Na_2S$ when added to a freshly prepared nutrient broth enrichment and incubated aerobically. These data are summarized in Table 1.

Continued qualitative testing indicated the production of either a primary or secondary thiol.

Ether extraction yielded an infrared assayable material, which provided a partial identification of the enrichment produced thiol. A grating infrared curve yielded strong peaks at 1600 $cm^{-1}$ indicating a benzene ring. Meta substitution on the ring was evidenced by peaks at 680 $cm^{-1}$ and 450 $cm^{-1}$. The -SH group was identified by weak peaks at 2550 $cm^{-1}$ and 900 $cm^{-1}$ as were $CH_3$-C and $-CH_2-$ groups by strong peaks at 2910 $cm^{-1}$, and 2850 $cm^{-1}$, 1375 $cm^{-1}$, and 1525 $cm^{-1}$. The significant groups on the scan were identified from Dyer's tabulations (2).

Table 1

Increase (mg/l) in iodometrically titratable material upon addition of sulfur containing compounds to aerobically incubated enrichments of lagoonal water

| | initial | final | net increase |
|---|---|---|---|
| amino acid enrichments[1.] | | | |
| control (nutrient broth) | 11.0 | 16.0 | |
| cysteine | 11.0 | 23.0 | 7.0 |
| methionine | 11.0 | 24.0 | 8.0 |
| cystine | 11.0 | 21.0 | 6.0 |
| sulfide enrichment[2.] | | | |
| control (unenriched water) | 2.0 | 3.9 | 1.9 |
| $Na_2S$ and nutrient broth | 2.0 | 19.7 | 15.8 |
| nutrient broth | 1.7 | 12.0 | 8.1 |

1. The amino acids were added to cultures which had been incubated at 37°C for 48 hours. They were then reincubated for 12 hours.

2. The inorganic enrichment was added to the culture initially and incubated for 48 hours at 37°C.

4.2.4 Discussion

The occurrence of organic intermediates in the sulfur cycle has been proposed on several occasions; Peck (9) in reviewing the literature suggested that at some oxidative level, inorganic sulfur was incorporated into an organic molecule. Lees (7) believed that an organic acceptor stripped the -SH groups from the sulfur compounds in the medium and Vogler's (14) work indicated that Thiobacillus thiooxidans synthesized an organic storage product from $CO_2$ during sulfur oxidation. No references, however, have been found concerning the production, identification or function of such organic sulfur compounds, especially in lagoonal-marine environments.

In the present work, an iodometrically titratable material was produced by a mixed bacterial flora which developed in enrichment cultures of lagoonal water. Production of the material was augmented by the addition of any of a variety of sulfur compounds to the enrichment, and tentative identification of the compound was undertaken.

The "cell free" supernatants of freshly grown enrichments were known to react with iodine, and also produced gas when mixed with an iodine-azine reagent indicating sulfur present as sulfhydryl, disulfide or thiosulfate groups (3). Dithionates and polythionates do not react with iodine (6, 11) and were ruled out on this basis. The malachite green test for sulfite, bisulfite and metabisulfite groups and the mercuric chloride test for thiosulfate (3) were negative.

Having eliminated the most probable inorganic sulfur compounds as the iodometrically titratable material, attention was directed toward commonly occurring organic sulfur compounds. Cysteine and cystine reacted in the iodine-azide test, but methionine did not, thus emphasizing the greater probability of either a sulfhydryl (-SH) group or a disulfide (-S-S) group in the bacterial product.

Upon reaction with Hg $(NO_3)_2$ (6), the bacterial product yielded a black precipitate. Cysteine, but not cystine, did also, increasing the probability that a thiol (-SH) group was part of the compound. Thiols are known to react with iodine (5, 10) and qualitative tests of culture supernatants for thiol groups, using an alkaline solution of cupric chloride and hydroxylamine (4) were strongly positive as were alkaline decomposition tests (4) for primary and secondary thiols.

Infrared analysis suggested the most probable chemical structure of the compound to be one of those presented in figure 1. The scan indicated that the sulfydryl and methyl side chains on the benzene ring were in the meta position with respect to each other. The methylene group(s) is most probably located subterminally on either of the meta positioned chains described since no third substitution was indicated. These thiols are remarkably similar in structure to meta-thioanisole, and may eventually prove to be close analogues. The benzene moiety in the natural compound is probably derived from tannins and/or lignins which accumulate in the waters when plant tissues undergo degradation. It is possible then, that thiol synthesis serves two purposes; as a storage depot for reduced sulfur, since the amount produced under anaerobic conditions is 2 to 3 times that found under aerobic conditions, and; as a means of detoxifying the potentially bactericidal natural phenolics.

The thiol was produced whenever recognized inorganic intermediates other than sulfate in the sulfur cycle were added to enrichment cultures. Further, the reactions leading to thiol production are most probably mediated by heterotrophic organisms since the methods used were selective for heterotrophs. whereas those leading to sulfate production are more probably mediated by autotrophic organisms (9, 13).

The failure to demonstrate hydrogen sulfide in water samples particularly those collected above sulfide mud beds is probably resolved since small amounts (1-2 mg/l) of thiol were encountered in all of the unenriched control cultures. Following storms and periods of high winds a noticeable stench, particularly along the shore lines of the subject lagoon, attests to the rapid increase in amount and volatilization of the thiol. The storm induced increase is readily explained as a result of the turnover of the water column, disturbance of the bottom muds, and a concomitant increase in the precursor nutrients in the water, in effect an enrichment. The volatile thiol is then formed by bacterial action.

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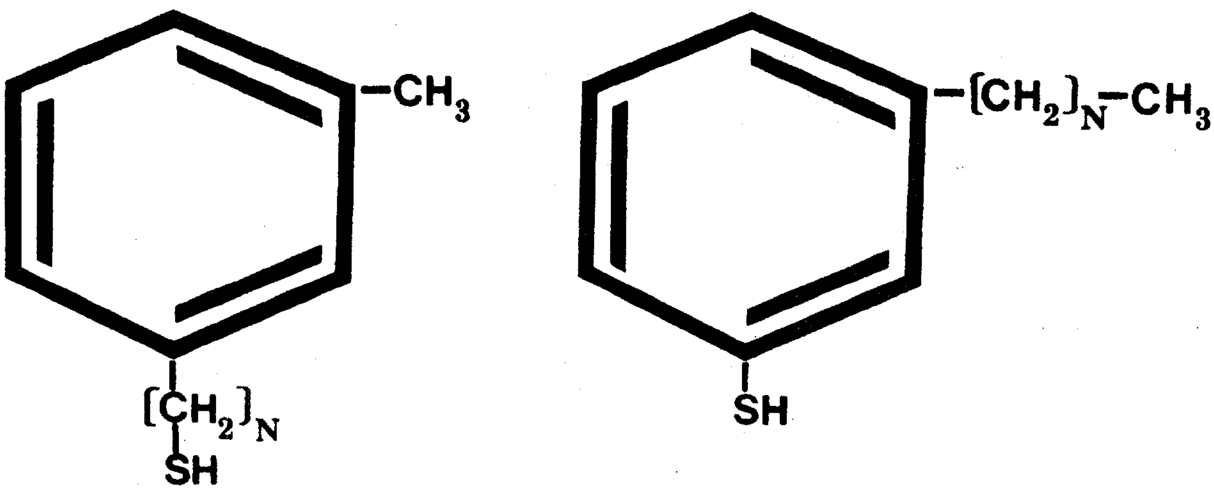


Figure 4-1. The infra red scan suggests that one of the above forms is the most probable structure of the thiol.

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Chapter 5

# SEDIMENTS OF THE INDIAN RIVER LAGOONS

E.H. Kalajian

## 5.0 Introduction

Sediment deposition in lagoonal areas may reflect the influence of man's activities in the recent past. Sediments which accumulate within the lagoons of this study consist primary of terrigenous detritus and biological debris and are a function of the geology, bathymetry, hydrology and biology of an area (Folger 1972). Man's activities however, can introduce pollutants from industrial and domestic waters, agricultural runoff, or accidental spillages.

The sediments in the lagoons surrounding the Kennedy Space Center have been investigated as part of the NASA Grant NGR 10-015-008. It was the intent of this investigation to indentify and characterize the sediments to provide ecological baseline data from which continuous monitoring of the sediments could be conducted.

## 5.1 Geological History

The area under investigation consists of barrier islands composed of relict beach ridges which are mainly Pleistocene sands. These sands also include some silt, clay, broken shells and beds of sandy coquina which comprise the surficial, non-artesian aquifier.

The dominant geological feature in the area is Cape Canaveral, which is one of the larger cuspate forelands in the world. The Cape has a base of about 15 miles and a tip about 4 1/2 miles east of the baseline. The Cape is part of the barrier beach system found along the east coast of Florida.

The geology of the area is discussed by Brown et al, 1962 and can best be summarized by quoting directly as follows:

"The earth materials exposed at the surface in Brevard County are undifferentiated deposits of Pleistocene and Recent Age that form the reservoir rock for the nonartesian water. These surficial sediments are underlain by unconsolidated beds of Late Miocene or Pliocene Age which in turn are underlain by the Hawthorn Formation of Early and Middle Miocene Age. The deposits of Late Miocene or Pliocene Age and the Hawthorn Formation include beds of material of relatively low permeability which serve to confine water under pressure in the underlying limestone formations of Eocene Age. The limestone formations of Eocene Age are the major source of ground water in Brevard County and form part of the principal artesian aquifer in Florida and Georgia."

## 5.2 Methodology

The intent of this investigation was to obtain a general overall view of the physical and some chemical properties of the sediments within the lagoon. Detailed chemical and sediment analysis would then be conducted at selected locations.

In the general overview, the sediments were classified as to grain size, shell content, layering, color, water depth, field measurements of Eh, and laboratory measurements of water content, total volatile solids (TVS) and chemical oxygen demand (COD). Sampling was conducted from 16 foot outboard boats, utilizing hand bearing compasses for navigation and mooring with three anchors in a triangular pattern so as to minimize wind drift. Cores were then taken utilizing a 2" PVC pipe coring device which used a super ball as a check valve. The corer was manually driven into the sediments by means of a T-handle. This equipment was designed at F.I.T. for specific use on this project. In the initial stages of the project, core lengths vary from several inches to approximately 30 inches. Upon collection, the cores were capped and taped to reduce loss of moisture and sealed with wax when brought to the laboratory. Classification, grain size analysis and water content of the cores were conducted within a few days, and the data is presented in Appendix 5 - A. During the latter stages of the study, the core length was reduced to 12 inches and the samples were field classified as to grain size, color, layering, structure, and Eh. Eh measurements were conducted using an Orion Model 404 Research Ion-analyzer. Samples were field sealed for later laboratory measurements of water content, total volatile solids, and chemical oxygen demand. All of the established sites were sampled during this phase of the investigation, with the exception of the twenty six sites set aside for the next phase of the investigation. This data is presented in Appendix 5 - B.

Parameters selected for the second phase of the investigation was based on the intent of the investigation and on pollution criteria set by the Environmental Protection Agency Water Quality Office in "Criteria for Determining Acceptability of Dredged Spoil Disposal to the Nation's Waters." This criteria is based on an investigation of one or more of the following pollution parameters, with the sediment being considered polluted for open water disposal if it exceeds the concentrations stated below.

| Sediments in Fresh & Marine Waters | Conc % (dry wt basis) |
|---|---|
| Volatile Solids (TVS) | 6.0 |
| Chemical Oxygen Demand (COD) | 5.0 |
| Total Kjeldahl Nitrogen | .10 |
| Oil - Grease | .15 |
| Mercury | .0001 |
| Lead | .005 |
| Zinc | .005 |

The EPA also suggests that the following correlation between volatile solids and chemical oxygen demand should be made:

$$TVS\,\%\,(dry) = 1.32 + .98\,(COD)\%$$

If the results show a significant deviation from this equation then additional samples should be analyzed to insure reliable measurements. Total volatile solids and COD analyses should be made first and can be used to characterize the samples as polluted if the maximum limits are exceeded.

In addition to the analyses above, the EPA suggests the following parameters be investigated, where appropriate and pertinent; Total Phosphorous, Total Organic Carbon, Immediate Oxygen Demand, Settleability, Sulfides, Trace Metal, Pesticides, Bioassay.

The detailed chemical and physical analysis of the sediments consisted of measuring the concentrations of the major nutrients, (nitrogen, phosphorous, carbon, sulfur) in the surface sediments in addition to the above conducted analysis at twenty-six selected sites, representing a variety of conditions throughout the lagoons. This data is presented in Appendix 5 - C.

Twenty-two of the sites corresponded with previously established sampling locations. This made it possible to correlate the new data with many months of observations of the water chemistry, and in some instances, the biology and geology of the area. In addition to these, four special sites were established, each located within 10 meters of past or presently operating sewage treatment plant outfalls. These special sites are designated by a letter S following the numbers of the nearest previously established site, e.g. site 2-1 S is at the point of effluent emission of the Titusville North sewage treatment plant, which lies adjacent to site 2-1.

The sites selected for this phase of the investigation fall into four major categories. Sites 1-11, 1-15, 1-23, 1-26, 2-1, 2-2, 4-12 and 4-16 were chosen because of their proximity to the discharge pipes of the four treatment plants in the area. Sites 2-17, 2-9, 2-24, 3-12 and 1-6 (in addition to some of the sites previously mentioned) were selected for their close proximity to the Intracoastal Waterway. Sites 1-2, 1-8, 1-19, 2-30, 3-3, 3-7, 3-9 and 4-18 were selected because they are in rather remote areas and might give a picutre of what "natural" conditions are like. Finally, certain sites, ( including some mentioned) were selected for individually specific reasons. Sites 1-20 and 1-19 were chosen because this area had been previously shown to be one of high biological activity. Site 1-26, downstream in Banana Creek from the discharge site of a treatment plant, was selected because of high bacteria count that had been observed there during the summer of 1972. Sites 1-23, 2-2, 2-24 and 4-16 are all in an area of reduced water circulation due to the construction of causeways. Although this non-random method of choosing sample sites will not give the "average picture" of the area the way a random sampling procedure would, it will provide specific information about certain aspects of man's impact on the lagoonal sediments.

Samples for the detailed physical and nutrient analysis were taken during the first five months of 1975, and each site was sampled only once. This implies that the results obtained may not be representative of the year-round physio-chemical structure of the sediments; however, since the characteristics of sediments are longer lived than those of the water column, it is felt that the results are useful in assessing "baseline" conditions. It should also be pointed out that the nature of the bottom in these lagoons, especially at depths of less than 1.5 meters, is often very patchy (visual observation) with areas of clean sand lying between areas of marine grasses (chiefly Diplanthera wrighti and Cymodoceum manatorum). Hence a small amount of drifting could place the boat over an entirely different sedimentary substrate. A total of four cores were taken at most of these twenty-six sites.

At these site locations, a water sample was taken approximately 1.4 meter above the bottom for later testing of pH and salinity. The temperature and dissolved oxygen content of the water just above the surface were measured with a YSI Model 45 Dissolved Oxygen Meter and recorded. Three cores were then taken for grain size using 2" PVC pipes approximately 30 cm. long and a T-type coring handle, referred to earlier. These cores were capped and taped for transport back to the laboratory. Finally, sediments for nutrient analysis were collected in a 30 cm. 2" diameter PVC pipe that had been cut in half lengthwise. The two halves were held together for coring by the core handle above and hose clamp below. This arrangement was designed for the purpose of taking samples in the field directly from the corer and placing them in jars containing the appropriate preservative. Once the core wason board the boat, the hose clamp was removed and the sediment extracted from the handle. Whatever water was collected in the corer above the sediment was allowed to slowly drain out the two slits along the side of the core tube, allowing suspended matter to settle onto the sediment's surface. The alternative method, that of pouring off the top portion of the water, was felt to be unsuitable for surface sediment analysis, as it was impossible to avoid pouring off some of the sediment with the water. After the water was drained, a knife was inserted through the slits in the PVC pipe and pulled down through the sediment, dividing it neatly into two halves. These were separated, and the Eh of the sediment was measured immediately using an Orion Model 404 Research Ionanalyzer. Finally the top 4 cm. of sediment was removed and evenly divided into four separate containers, one each for carbon, phosphorus, nitrogen, and sulfide analysis. These were then placedin an ice chest until they could be frozen in the laboratory's freezer in order to slow biological activity.

Four sites were sampled during each of six sampling trips. On one occasion (sites 2-2 and 2-1S), rough water and a balky motor made it necessary to limit sampling to only two sites.

The oxidation-reduction potential (Eh) was performed using an Orion pH meter and a platinum electrode. The electrode was lowered into the core and immersed in the surface sediments before the cores were extruded. After extruding the core, at a later time, the Eh was read at four centimeter intervals down the core length to a depth of 30 centimeters. The pH, which is a measure of acidity or alkalinity of the sediment, is done using a Beckman pH meter with a glass electrode and a calomel reference electrode. This test is done immediately after the cores are returned to the laboratory, again before they were extruded. Water content analyses were conducted by weighing a sample scooped from the surface sediments, drying in an oven at 105$^{o}$C for 24 hours and reweighing (Bowles 1970).

After the cores were extruded, a physical description was done on each core, including a color classification using the Munsell Color Chart. The chemical oxygen demand was then determined as described by Standard Methods (p. 510-511) using a one gram sample, 25 mls. of potassium dichromate, 25 mls. of $H_2SO_4$ mixed with $AgSO_4$, and about one gram of $HgSO_4$. This mixture was then heated and refluxed for two hours.

The volatile solids analysis was performed as described by Standard Methods (p. 534-535). The dried sediment from the water content test was heated to about $600^{\circ}C$ for one hour and reweighed, thus driving off the volatile matter and producing an ash residue.

The last test done on the cores was the grain size analysis, as it is not affected by time. This was performed as described in Bowles, 1970, using the following sieve numbers: 4, 10, 20, 40, 60, 100, 200.

In analyzing the nutrient concentrations in the sediments, it was necessary to add preservatives in the field to the samples to be analyzed for nitrogen, phosphorus, and sulfides. The sample containers were prepared in the laboratory with preservatives added prior to collection of the sediment, and in the case of nitrogen and phosphorus, the sample containers were weighed before and after sample collection. This weighing was necessary because wet samples were used in the phosphorus and nitrogen tests, and corrections had to be made which required accurate knowledge of exactly how much sediment had been collected. Samples remained in the freezer at $-1^{\circ}$ to $-5^{\circ}$ C. until immediately prior to testing. Phosphate and nitrate tests were run immediately after thawing, while carbon and sulfide tests were conducted on sediments oven dried at $105^{\circ}C$. Table 5-1 gives a summary of nutrient species analyzed, the preservatives used and laboratory analysis employed. Specific laboratory procedures and calculations are discussed in detail in Appendix 5-D.

In the earlier stages of the investigations, Daggett (1973), carbon determinations were conducted using the dry combustion train method described by Volborth (1969). Inorganic carbon was determined again using the acid attack method and organic carbon determined by difference techniques. Results presented in this report for organic carbon are uncorrected values. Many investigators feel that correction factors should be utilized. Some investigators feel that these values

Table 5-1.

Summary of Nutrient Species Analyzed, Preservatives Used, and Laboratory Analyses Employed

| Nutrient Species | Preservative used | Lab Procedure used |
|---|---|---|
| $NH_3$ | Dilute $H_2SO_4$ ( .8 ml. conc. $H_2SO_4$ / liter) | Semi-micro Kjeldahl (Hengar Co.) Procedure adapted from Standard Methods |
| $NO_3$ | " | " |
| P dissolved | HgCl Solution ( 40 mg HgCl/liter) | Stannous Chloride determination (Standard Methods) |
| P total | | Sulfuric acid - Nitric acid digention followed by Stannous Chloride determina |
| Sulfides | 2 N zinc acetate solution | Titrimetric (Iodine) Method (Standard Methods) as modified by Sould & Oguri 1974 |
| $CO_3$ | None | Acid attack, modified from Gross (1967) as outlined by Daggett (1973) |
| Organic Carbon | None | Chromic acid oxidation technique Holme and McIntyre (1971) |

should be corrected for organic carbon which is not recovered due to the laboratory techniques and a correction factor of 1.33 can be applied. Since the trend of this investigation was to look at relative values, the correction factors were not utilized. The reader is referred to Peffer (1975) for additional discussion.

## 5.3 Presentation and Discussion of Results

The bathymetry and texture of bottom sediments is presented in Figure 5-1. This texture description is the result of the analysis of cores conducted in the laboratory and presented in Appendix 5A and C, or by field classification as presented in Appendix 5B.

The majority of the surface sediments can be classified as fine uniform sand with traces of shell. Mean grain size of the materials was approximately 0.15 mm, corresponding to 2.7 phi units, with ranges of 0.11 mm to 1.22 mm. Uniformity coefficients for the material analyzed was in the range of 1.5. In some spot locations silt size materials were found; these seem to correspond with deeper water depths.

Sedimentary structure found within the cores included color banding, layering, and heavy shell layers. Shell layers were quite predominant at various depths from 6 to 15 inches in the cores and were of varying thickness from 2 to 6 inches. In some cores, multiple distinct layers of shell were found. Mottling of sediments was common in many cores indicating benthic organism migration within the sediments.

Some core samples were taken in the impounded waters and these samples identified the impounded waters as being of two distinct environments. Many of these samples could be characterized as being former marsh areas, e.g. peats and humus sediments, while others could be identified as being former lagoon or creek areas. Sedimentary structures found in the impounded water sediments include color banding, layering and shell layers. Shell layers were associated with former creek areas which had an exchange with the river (e.g. Station 112, 116, and 412.) The grain size of the impounded water sediments varied from the clay range up to sand size deposits.

Water content of the sediments in the lagoon areas varied between a low of 20% to a high of 188%. The data are presented in Figures 5-2 thru 5-5. One major difficulty which occurs in the water content determination is the loss of water due to leakage from the core sampler, especially in sand samples. In cores

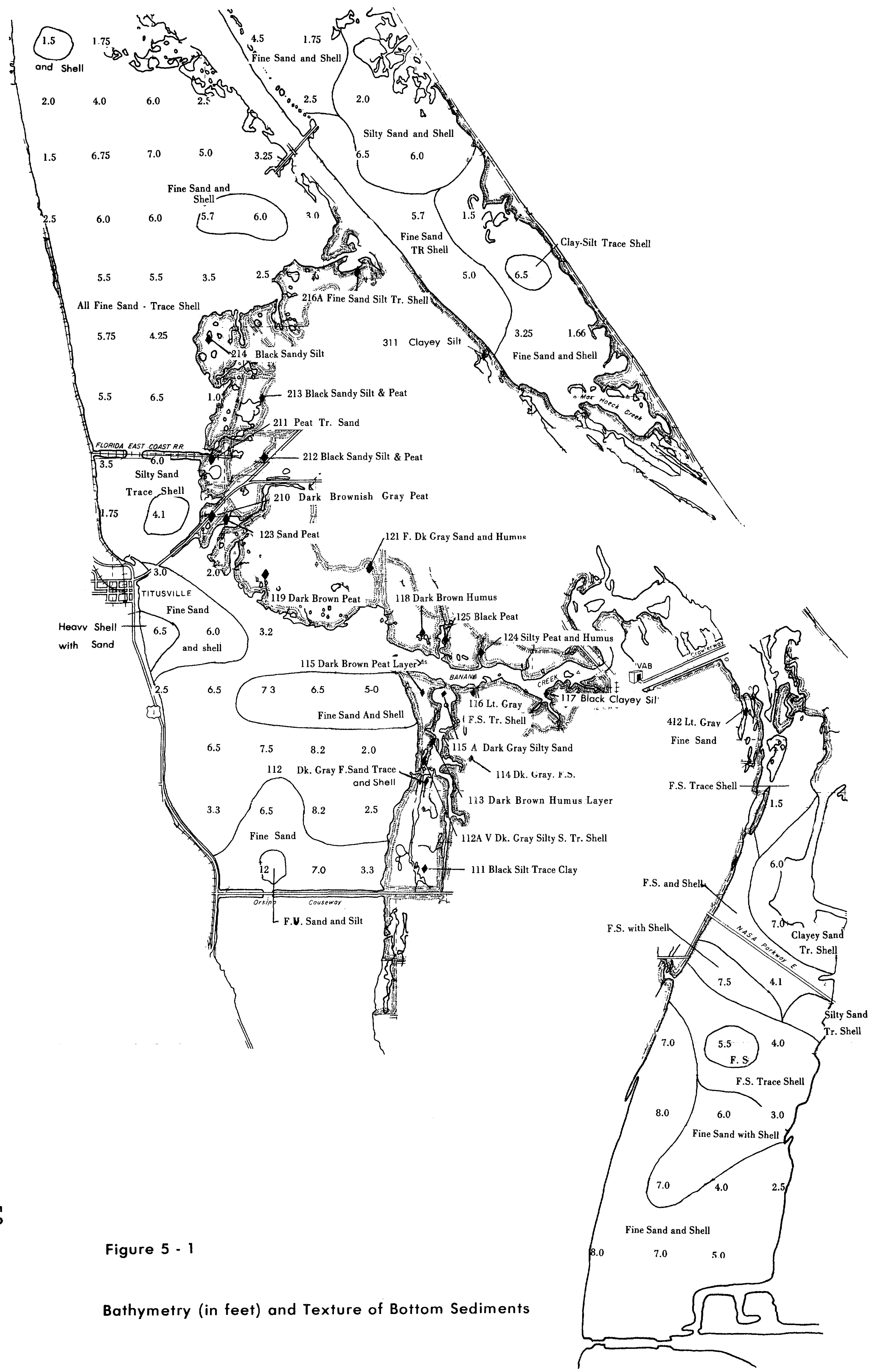



Figure 5 - 1

Bathymetry (in feet) and Texture of Bottom Sediments

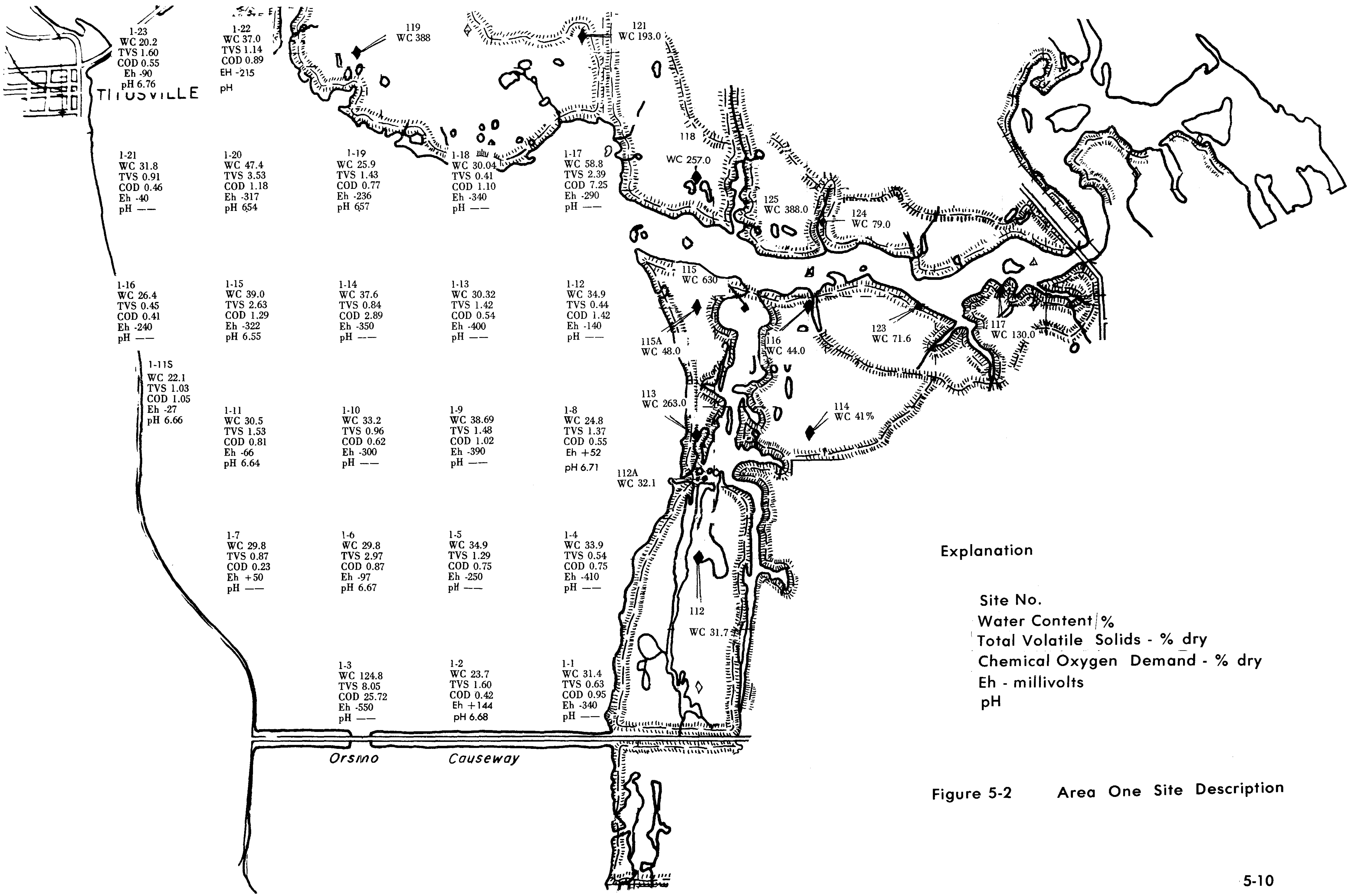
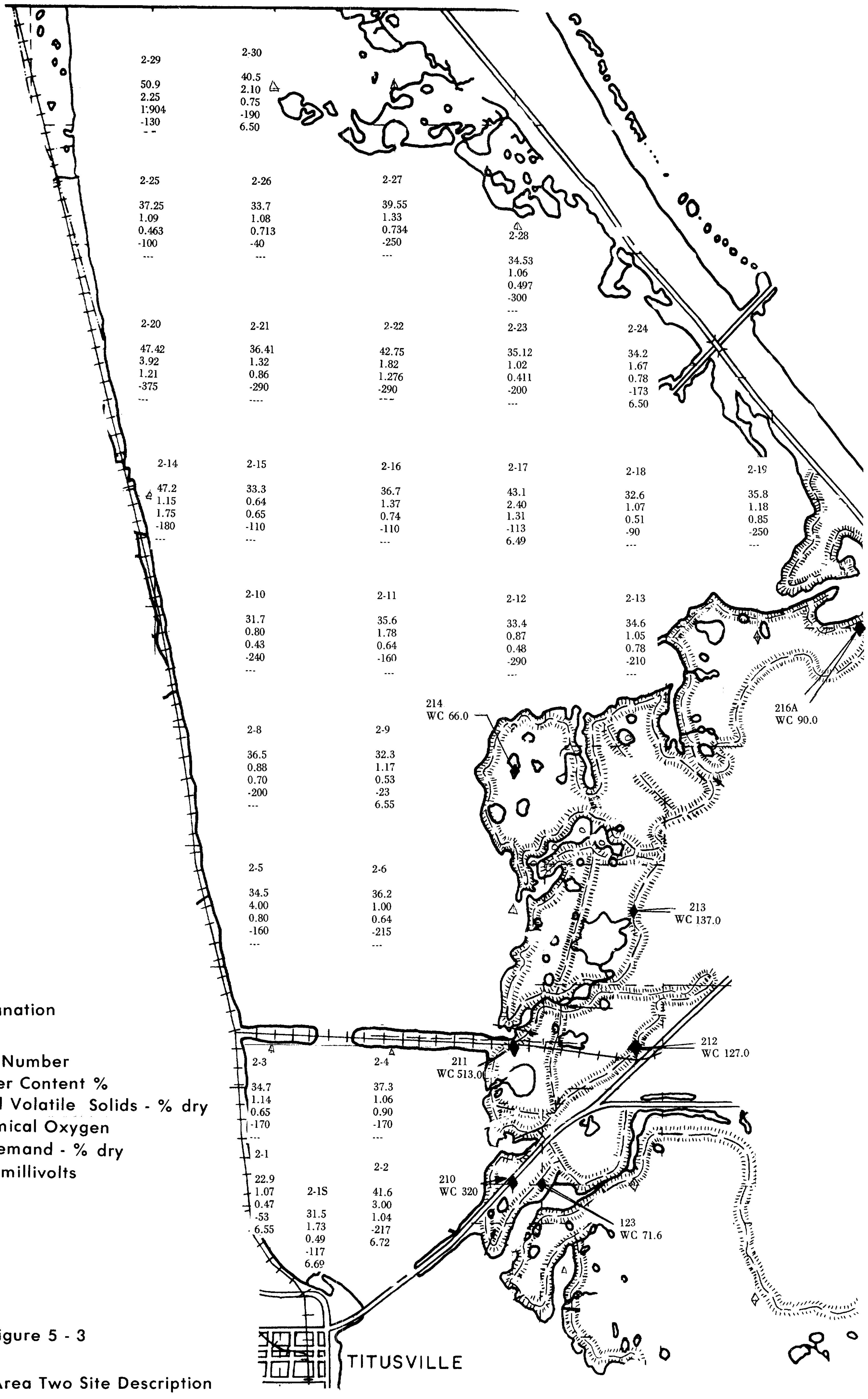



Figure 5-2 Area One Site Description

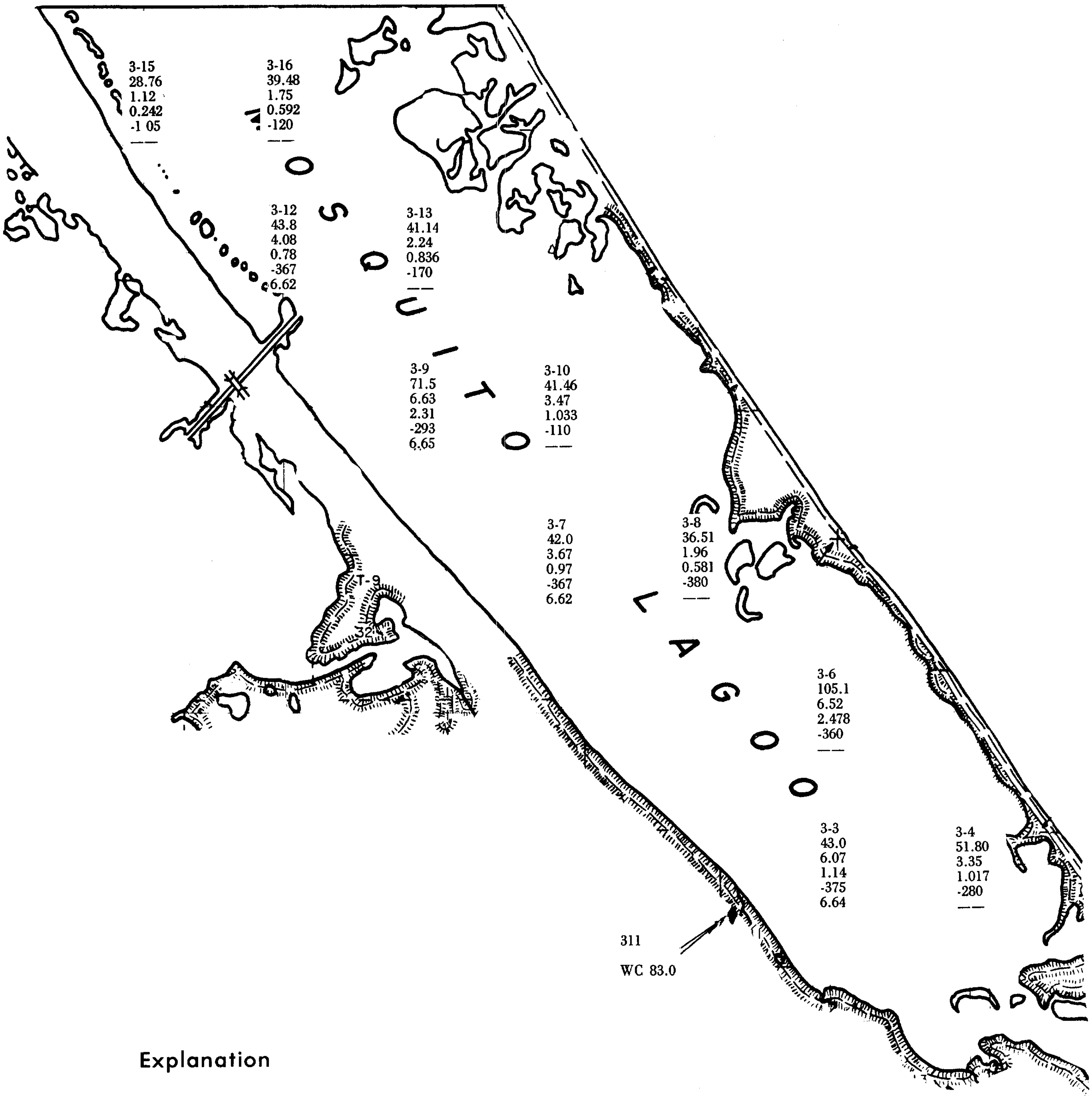



Explanation

Site Number
Water Content %
Total Volatile Solids - % dry
Chemical Oxygen
Demand - % dry
Eh - millivolts
pH

Figure 5 - 3

Area Two Site Description




Explanation

Site No.
Water Content %
Total Volatile Solids - % dry
Chemical Oxygen Demand - % dry
Eh - millivolts
pH



Figure 5 - 4 Area Three Site Description

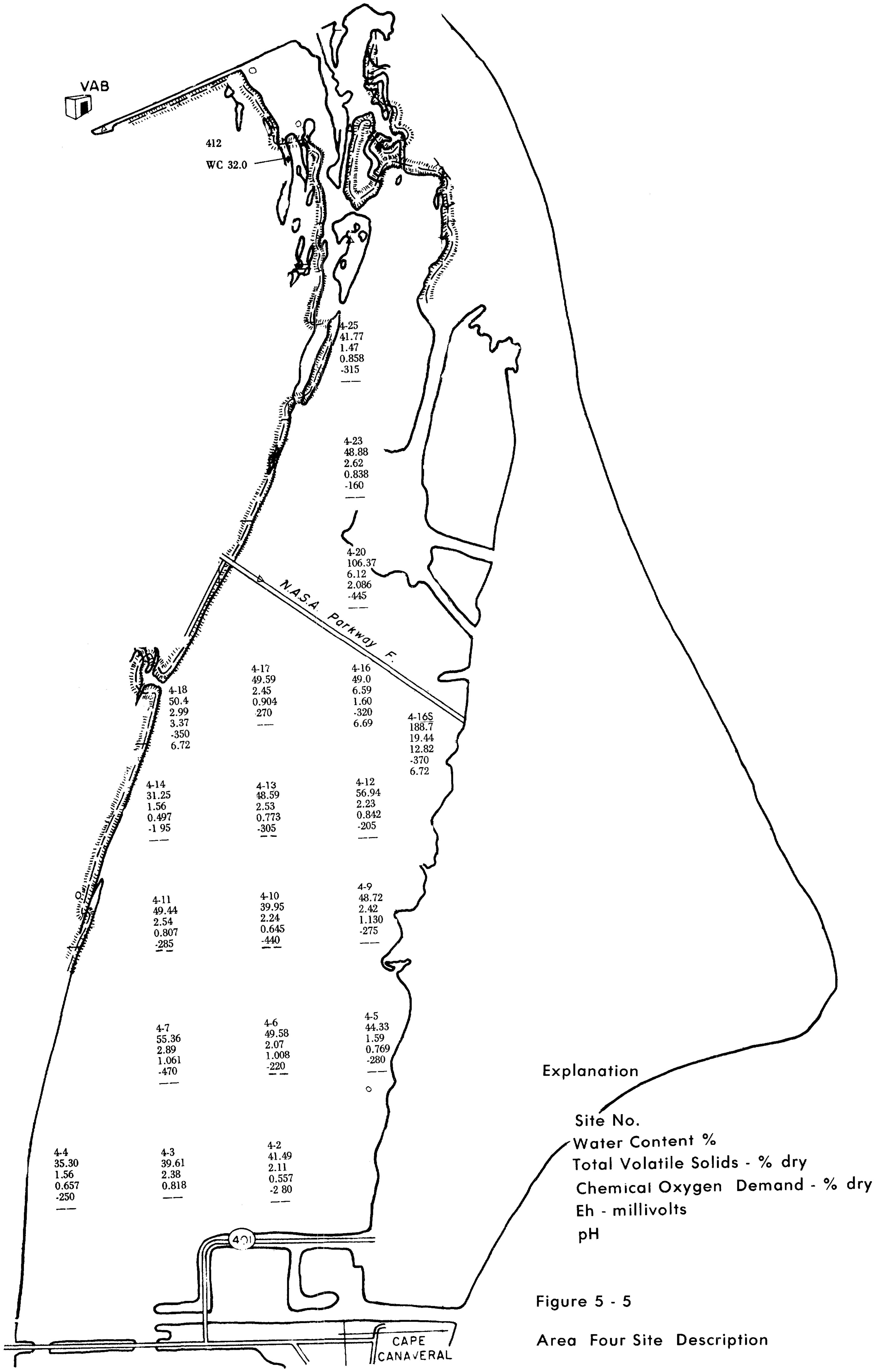



Figure 5 - 5

Area Four Site Description

taken later, samples were taken in the field and placed directly into water content cans for analysis. This reduced some of the error in reporting water content. Water content increased as the grain size of the sediments became finer. Within the impounded waters, the peat and humus sediments were found to have values as high as 450%. These values would be expected in this type of sediment.

The pH of surface sediments varies from 6.6 to 6.85. Measurements were conducted at 26 sites; the data are presented in Figures 5-2 thru 5-5 and in Table 5-1. There did not seem to be any specific pattern of variation from site to site. The pH of the surface sediments is close to that of the overlying water within 1/4 m of the bottom, as reported in Table 5-2, and this is probably due to the reworking of the sediments caused by wind driven currents. It should be pointed out that the pH of the overlying water column was in the range of 8.0 (Lasater 1974). In discussion with other principal investigators in the study, it was concluded that the water samples taken by Lasater et al were not obtained from within this 1/4 m range. The difference in the observed pH is probably due to the production of acids in the sediments, which would tend to lower the pH. This conclusion could be verified in the future by using an immersible pH probe over the side of a boat and recording pH versus depth from in situ measurements.

The oxidation-reduction potentials (Eh) in the surface sediments were in general negative, with the exception of two positive values. Values range from + 170 millivolts to -570 millivolts and are shown on Figures 5-2 to 5-5. The Eh values fall in the range given by Bass Becking et al, (1960) for marine waters. Figure 5-6 shows a plot of Eh versus pH for the sediments investigated. This data is also typical of marginal marine sediments as reported by Bass Becking et al. The positive values of Eh are probably due to a thicker than normal oxidation layer. It was observed that during sampling, the top 1/2 cm of core sample was light brown in color as compared to the typical dark gray and very dark gray. The Eh of the top layer was very difficult to measure due to core disturbance.

It is believed that this thin layer of sediment is due to reworking of the surface sediments by wind waves and would probably be a well oxygenated layer, accounting for the positive values. Eh values observed in the bottom water were all positive and are shown in Table 5-3.

TABLE 5-2

TABLE
Sediment Data

| Site | pH | Eh(mv | Eh (mv) Field | C.O.D. (% dry wgt.) | Vol. Sol. (D dry wgt.) | Water Content % |
|---|---|---|---|---|---|---|
| 1-2 | 6.682 | +144.2 | ND | 0.42 | 1.60 | 23.7 |
| 1-6 | 6.625 | - 97.2 | ND | 0.87 | 2.97 | 29.8 |
| 1-8 | 6.710 | + 51.7 | ND | 0.55 | 1.37 | 24.8 |
| 1-11 | 6.641 | - 66.2 | ND | 0.81 | 1.53 | 30.5 |
| 1-11S | 6.664 | - 26.7 | - 40 | 1.05 | 1.03 | 22.1 |
| 1-15 | 6.554 | -321.7 | -300 | 1.29 | 2.63 | 39.0 |
| 1-19 | 6.572 | -236.7 | -310 | 0.77 | 1.43 | 25.9 |
| 1-20 | 6.539 | -316.7 | -370 | 1.18 | 3.53 | 47.4 |
| 1-23 | 6.755 | - 90.0 | -180 | 0.55 | 1.60 | 20.2 |
| 2-1S | 6.682 | -116.7 | -280 | 0.49 | 1.73 | 31.5 |
| 2-1 | 6.551 | - 53.3 | -270 | 0.47 | 1.07 | 22.9 |
| 2-2 | 6.724 | -216.7 | -310 | 1.04 | 3.00 | 41.6 |
| 2-9 | 6.551 | - 23.3 | -100 | 0.53 | 1.17 | 32.3 |
| 2-17 | 6.488 | -113.3 | ND | 1.31 | 2.40 | 43.1 |
| 2-24 | 6.501 | -173.3 | -250 | 0.78 | 1.67 | 34.2 |
| 2-30 | 6.496 | -190.0 | -180 | 0.75 | 2.10 | 40.5 |
| 3-3 | 6.635 | -375.0 | -360 | 1.14 | 6.07 | 43.0 |
| 3-7 | 6.625 | -366.7 | -330 | 0.97 | 3.67 | 42.0 |
| 3-9 | 6.647 | -293.3 | -340 | 2.31 | 6.33 | 71.5 |
| 3-12 | 6.625 | -366.7 | -350 | 0.78 | 4.03 | 43.8 |
| 1-26 | 6.533 | -450.0 | -410 | 1.08 | 2.60 | 46.2 |
| 1-29S | 6.567 | -570.0 | -200 | 1.11 | 2.30 | 42.8 |
| 4-12 | 6.724 | -290.0 | -300 | 1.39 | 4.69 | 26.5 |
| 4-16 | 6.692 | -320.0 | -380 | 1.60 | 6.59 | 49.0 |
| 4-16S | 6.767 | -370.0 | -330 | 12.82 | 19.44 | 188.7 |
| 4-18 | 6.718 | -350.0 | -490 | 3.37 | 2.99 | 50.4 |

ND - No Data Taken

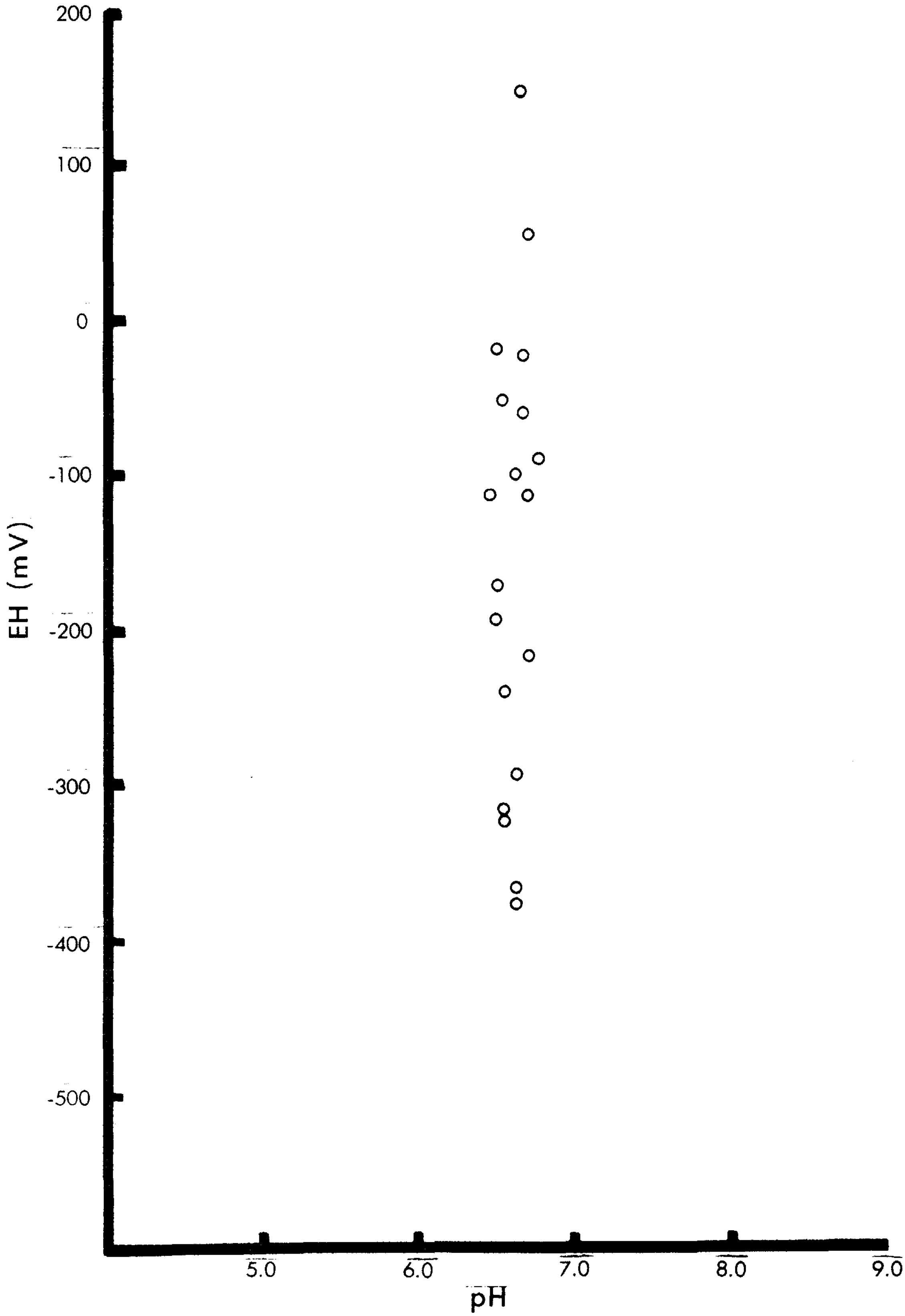



Figure 5-6.
EH versus pH for Lagoon Surface Sediments

## TABLE 5-3

### Bottom Water Data

| Site | D.O. (ppm) | Salinity (ppt) | ph | Eh(mv) | Temp. (c) | Depth (m) |
|---|---|---|---|---|---|---|
| 1-2 | 8.33 | 24 | 6.885 | +114 | 18.5 | 1.60 |
| 1-6 | 9.20 | 25 | 6.818 | +107.9 | 18.0 | 2.00 |
| 1-8 | 10.87 | 25 | 6.830 | +169.9 | 22.5 | 0.50 |
| 1-11 | 8.83 | 26 | 6.880 | +147.1 | 19.0 | 2.00 |
| 1-11S | 7.87 | 30 | 6.624 | +120 | 21.0 | 0.50 |
| 1-15 | 7.07 | 28 | 6.612 | + 85 | 27.0 | 2.00 |
| 1-19 | 8.07 | 32 | 6.602 | +110 | 22.0 | 1.00 |
| 1-20 | 7.87 | 29 | 6.601 | + 60 | 28.0 | 1.75 |
| 1-23 | 7.67 | 33 | 6.604 | + 50 | 23.0 | 1.00 |
| 2-1S | 11.27 | 30 | 6.702 | + 65 | 23.5 | 0.75 |
| 2-1 | 8.67 | ND | ND | ND | 24.0 | 0.50 |
| 2-2 | 7.73 | 28 | 6.730 | + 90 | 18.0 | 1.25 |
| 2-9 | 6.83 | 32 | 6.541 | +170 | 27.0 | 1.30 |
| 2-17 | 6.27 | 35 | 6.514 | +160 | 26.0 | 1.75 |
| 2-24 | 7.93 | 35 | 6.521 | +150 | 28.0 | 1.00 |
| 2-30 | 7.90 | 35 | 6.508 | +160 | 29.0 | 0.50 |
| 3-3 | 9.10 | 36 | 6.678 | + 40 | 28.0 | 1.00 |
| 3-7 | 8.47 | 35 | 6.639 | +100 | 28.0 | 1.75 |
| 3-9 | 6.77 | 36 | 6.634 | +105 | 27.0 | 2.00 |
| 3-12 | 7.43 | 34 | 6.665 | + 95 | 27.0 | 0.75 |
| 1-26 | 6.87 | 30 | 6.596 | + 90 | 30.0 | 0.75 |
| 1-29S | 5.60 | 26 | 6.609 | + 60 | 28.0 | 0.50 |
| 4-12 | 8.80 | 25 | 6.783 | + 80 | 29.0 | 0.25 |
| 1-16 | 6.80 | 26 | 6.829 | + 85 | 26.0 | 1.25 |
| 4-16S | 7.00 | 23 | 6.802 | + 82 | 28.0 | 0.25 |
| 4-18 | 3.60 | 25 | 6.788 | + 95 | 26.0 | 0.50 |

ND - No Data Taken

Table 5-4

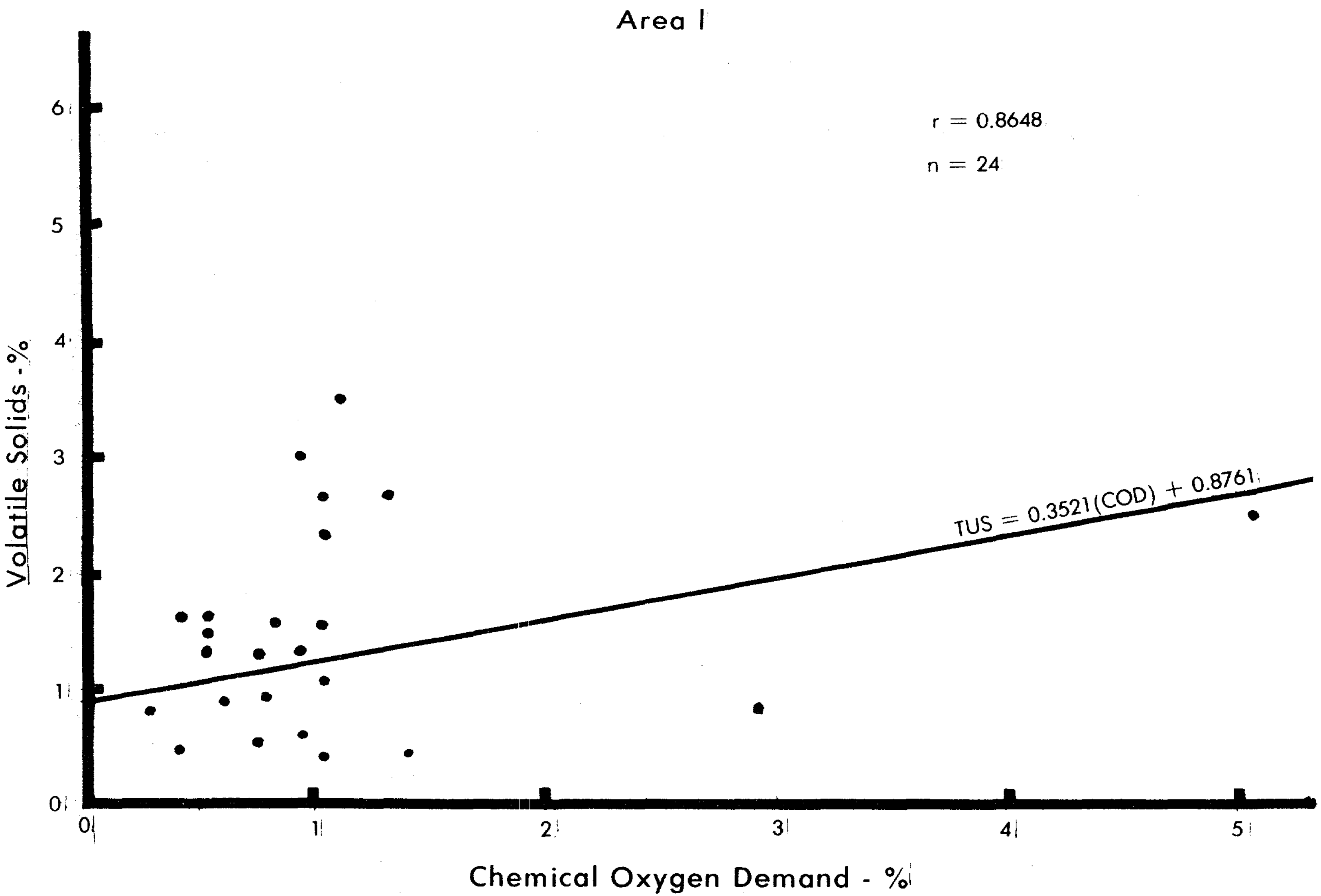
Regression Analysis of TVS - COD Data

| Area | | Correlation | Relationship |
|---|---|---|---|
| I. | Indian River | .865 | TVS = .876 + .352 (COD) |
| II. | Indian River | .433 | TVS = 2.702 + 5.30 (COD) |
| III. | Mosquito Lagoon | .875 | TVS = .266 + 3.138 (COD) |
| IV. | Banana River | .956 | TVS = 1.045 + 1.543 (COD) |
| | Overall | .501 | TVS = .210 + 1.52 (COD) |
| | EPA Criteria | | TVS = 1.32 + .98 (COD) |
| | Soule and Oguri | | TVS = 0.0 + .833 (COD) |

Measurements of total volatile solids (TVS) and chemical oxygen demand (COD) were conducted over the entire study area. The data are presented in Figures 5-2 thru 5-5. Values of total volatile solids ranged from 0.5% to 6.5% on a dry weight basis with average values in the range of 2.57%. Higher values of total volatile solids (i.e. greater than 4%) were found in Areas 3 (Mosquito Lagoon) and 4 (Banana River). The highest value recorded was 19.44% at site 4-16 S. Only six sites exceeded the EPA specified 6% concentration of volatile solids, permitting use of the material for dredge spoil. An explanation for these higher values follows in later discussions.

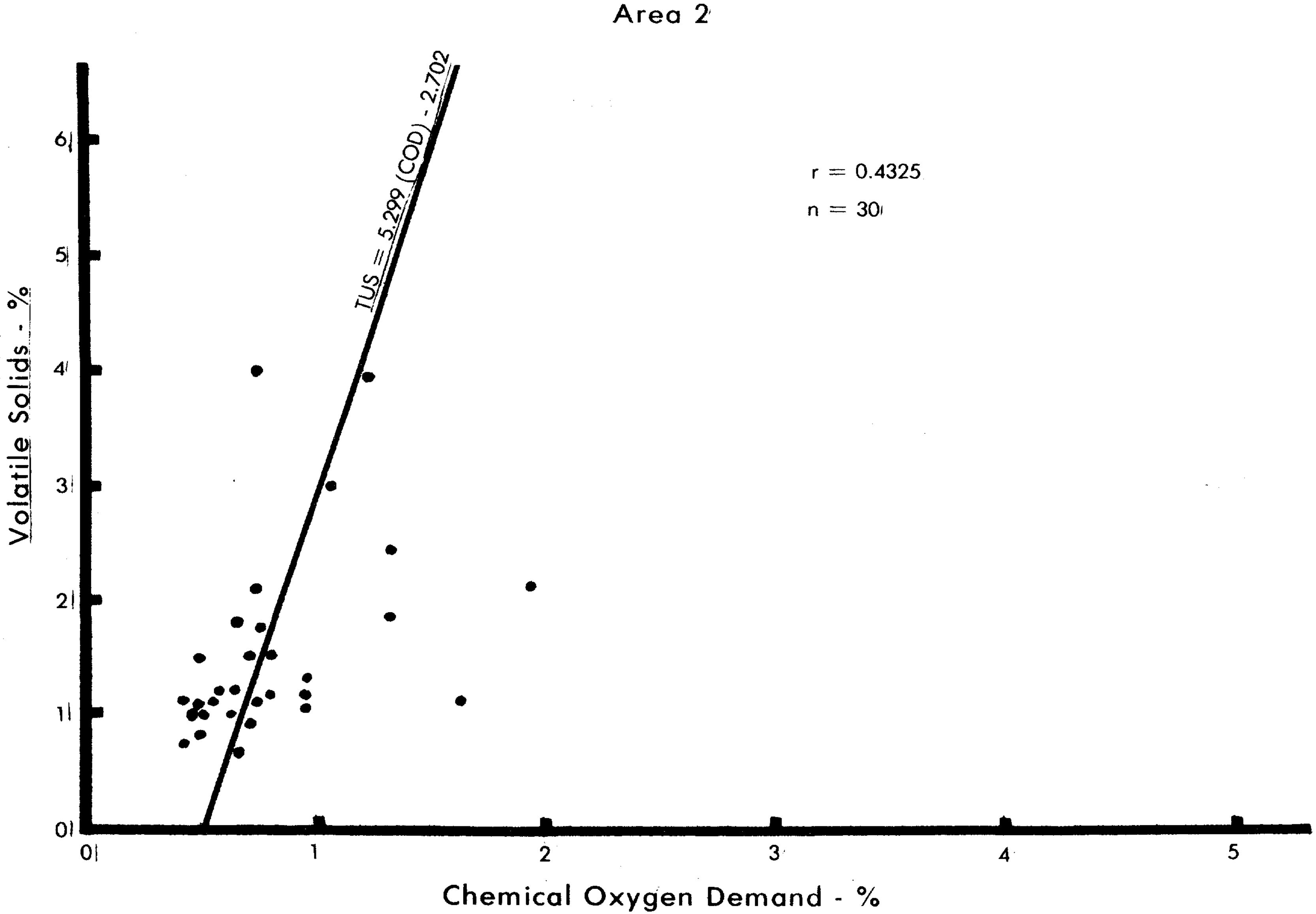
Values of chemical oxygen demand ranged from 0.5% to 3 % with average values of 1.83%. Two extreme values of 7.2% and 12.82%, found respectively at sites 1-17 and 4-16 S, exceeded the 5% concentration specified in the EPA dredge spoil criteria.

Total volatile solids were plotted versus chemical oxygen demand for comparison to data presented by Soule and Oguri (1974) and the equation given by EPA in their dredge criteria. These values are shown in Figures 5-7 thru 5-10 on an individual area basis. All four areas showed good correlation as shown in Table 5-4. A linear regression analysis was made for each area. The results are compared



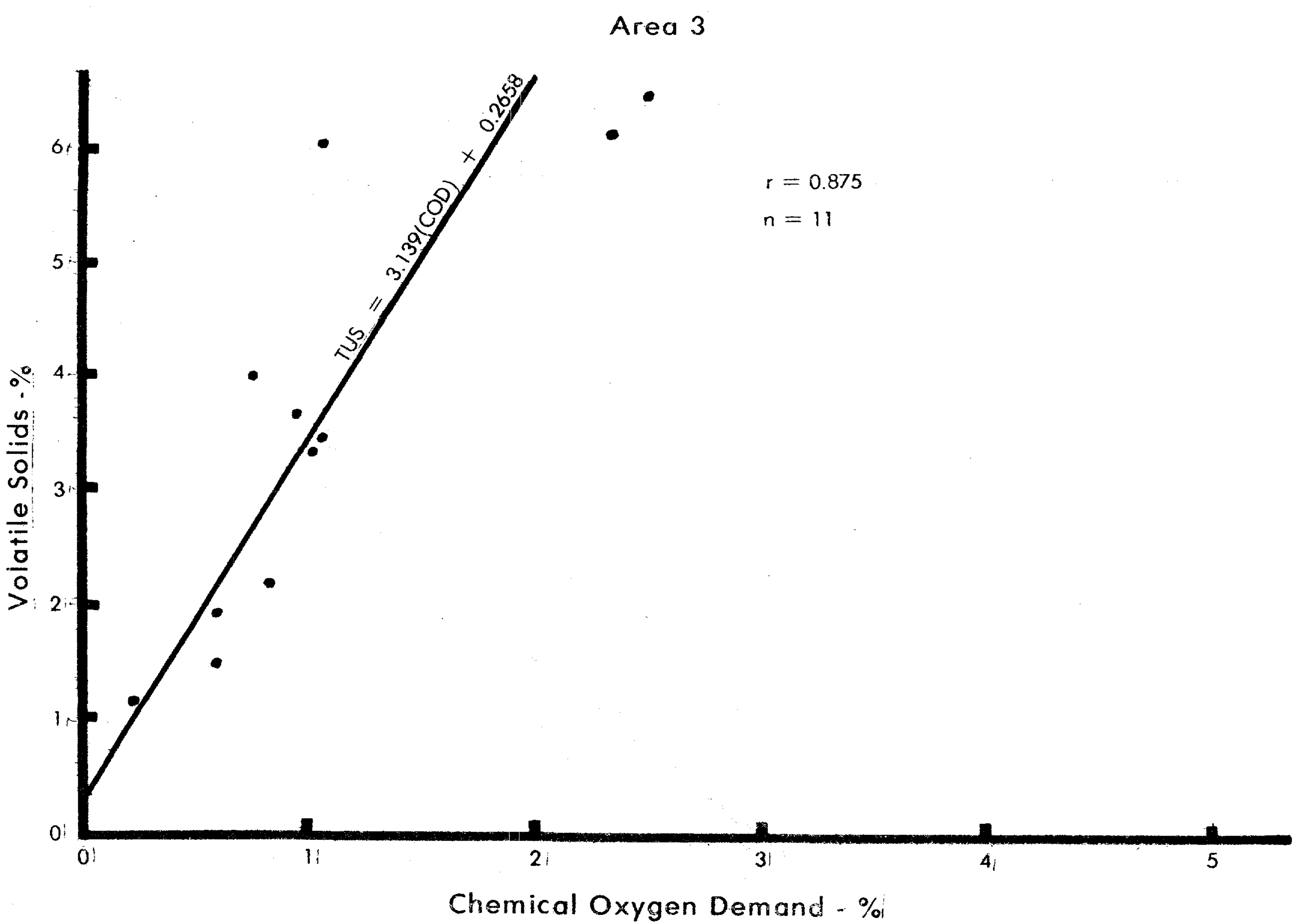
Area I
r = 0.8648
n = 24
TUS = 0.3521(COD) + 0.8761
Volatile Solids - %
Chemical Oxygen Demand - %
0
1
2
3
4
5
6


Figure 5 - 7



Area 2
TUS = 5.299 (COD) - 2.702
r = 0.4325
n = 30
Volatile Solids - %
0
1
2
3
4
5
6
Chemical Oxygen Demand - %
0
1
2
3
4
5


Figure 5 - 8



Area 3
TUS = 3.139(COD) + 0.2658
r = 0.875
n = 11
Volatile Solids - %
Chemical Oxygen Demand - %
0
1
2
3
4
5
6


Figure 5 - 9

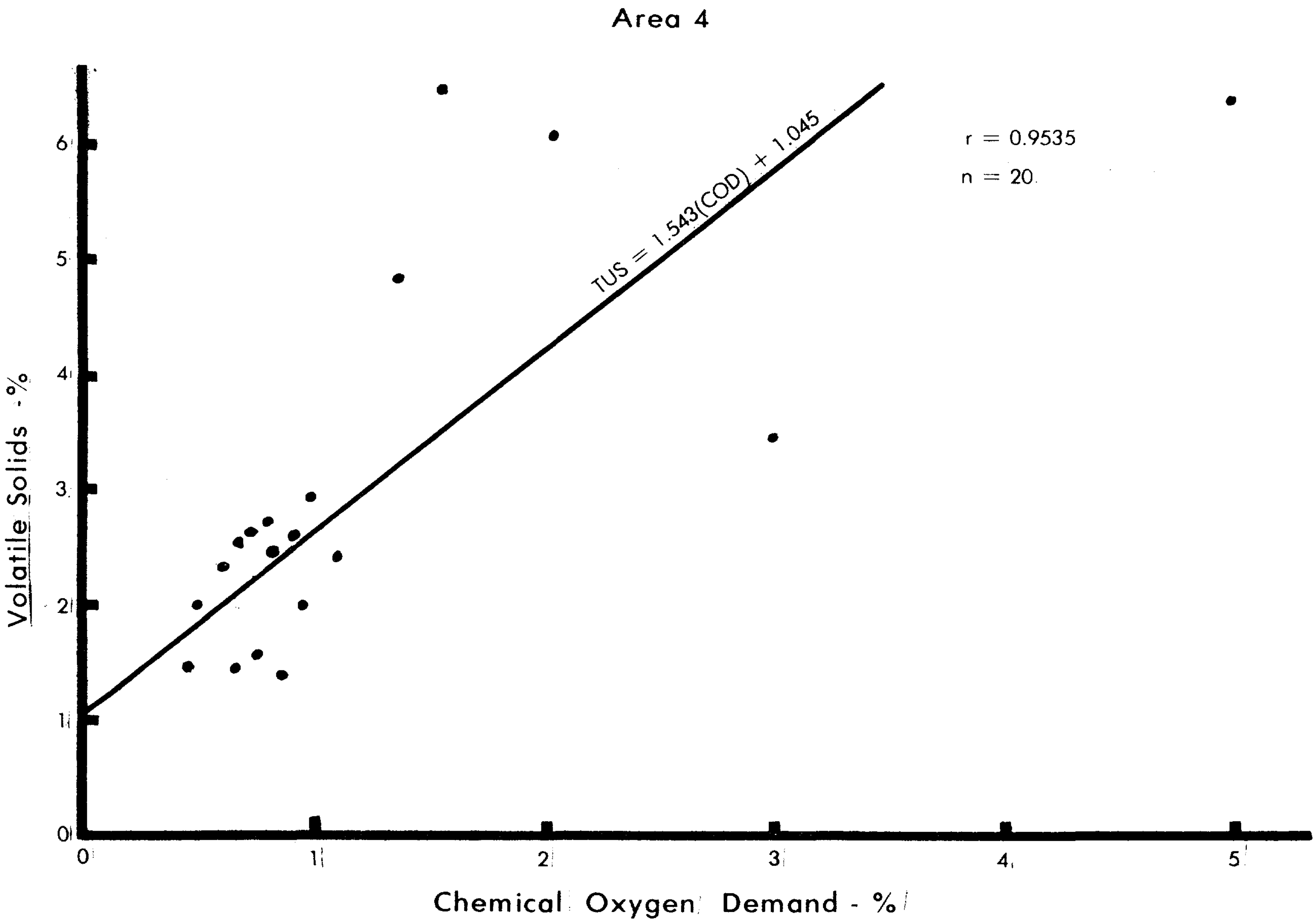

Area 4
TUS = 1.543(COD) + 1.045
r = 0.9535
n = 20
Volatile Solids - %
0
1
2
3
4
5
6
Chemical Oxygen Demand - %

Figure 5 - 10

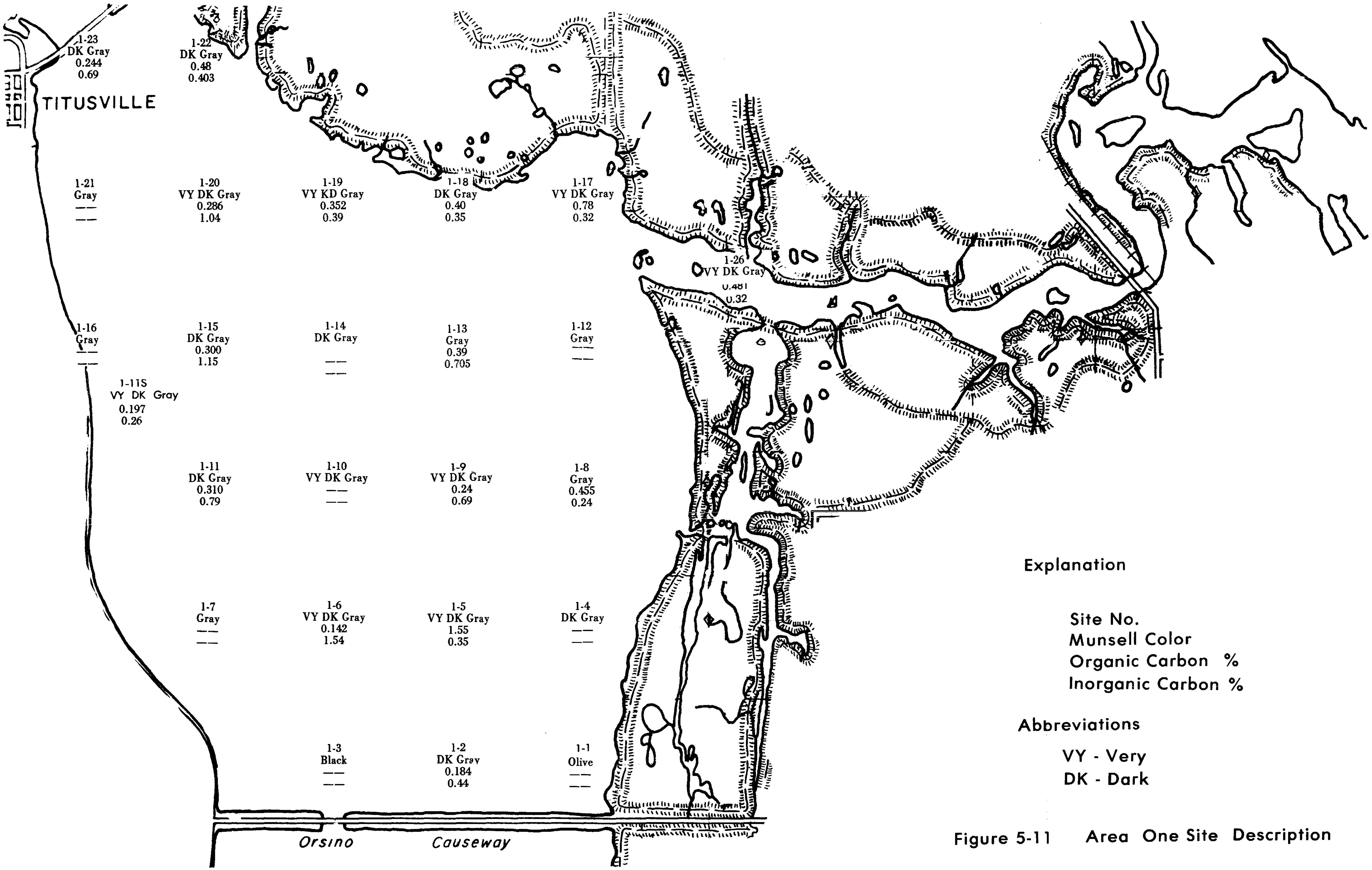
to EPA criteria and to data from Soule and Oguri in Table 5-4.

Soule and Oguri (1974) have stated that in broad terms, polluted sediments generally release higher content of trace contaminants and nutrients than natural sediment. The EPA relationship for TVS and COD is probably based on empirical data and the work conducted by Soule and Oguri for Surface Sediments of the San Pedro Basin did not agree with the EPA criteria . Likewise the data obtained in this investigation shows extensive variation from the EPA criteria.

Surface sediment colors were found to be in the gray to very dark gray range using Munsell color charts, and are shown in Figure 5-11 thru 5-14. There were only three sites in lagoonal waters with black (5 Y 2.5/1 and 5 Y 2.5/2). Two of these sites, 1-3 and 4-16S showed higher values of total volatile solids, and were associated with silt size material found in disburbed areas. Earlier it was pointed out that a very thin layer (lcm) of light brown sand was found on some cores. This layer was not used in color descriptions, however, in retrospect it is felt that it is significant. Nelson (1972) has stated that sediments from the James Estuary with thick oxidation layers are olive brown colored, whereas sediments with thin oxidation layers are grayish olive or olive.

Inorganic carbon tied up as calcium carbonate is found in the sediments. This carbonate in the lagoonal sediments is almost exclusively pelecypod shell debris. As discussed earlier, many of the cores had thick layers, up to 10 cm, of shell deposition and some of the cores were found to have multiple layers separated by fine sands. Inorganic carbon contents ranged from a low of 0.21% at sites in Area 2 to highs of 2.3% at sites 3-9 and 4-12. Area 4, Mosquito Lagoon stood out as having the highest ranges of carbonate content in surface sediments. This correlates well with the core descriptions for the area.

Organic carbon has been widely used as a major parameter for nutrient levels in the sediments. Folger (1972) has compiled data on 45 estuaries and lagoons around the United States and in some cases organic carbon was the only nutrient reported. Organic carbon contents are reported herein in either % or in mg/gm. Values reported in Figure 5-11 thru 5-14 range from a high of 0.8% to a low of 0.1 % for the lagoonal waters. One exception to this value was at site 4-16S, where an organic carbon content of 5.35% was found.



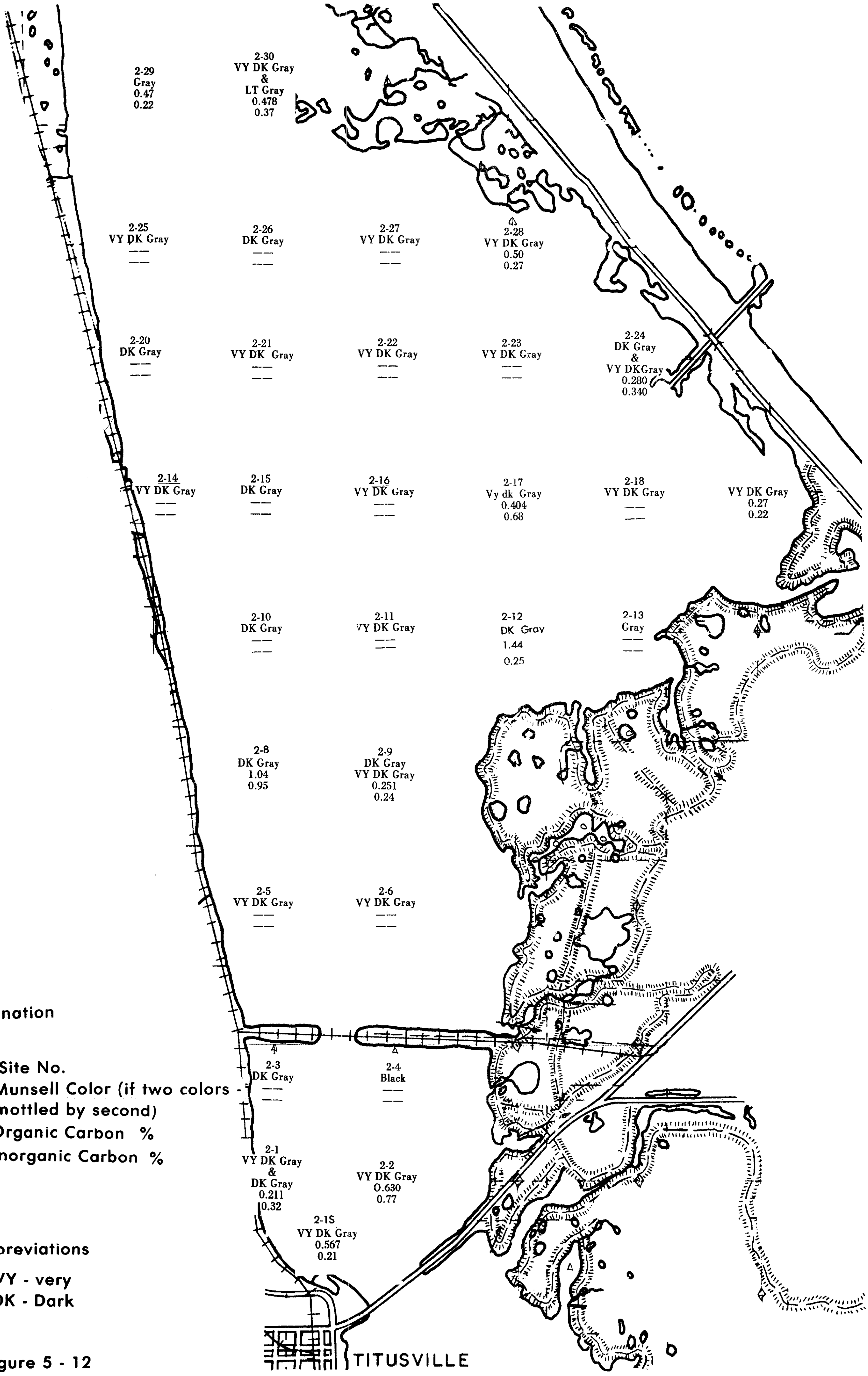

**Explanation**

Site No.
Munsell Color
Organic Carbon %
Inorganic Carbon %

**Abbreviations**

VY - Very
DK - Dark

Figure 5-11 Area One Site Description



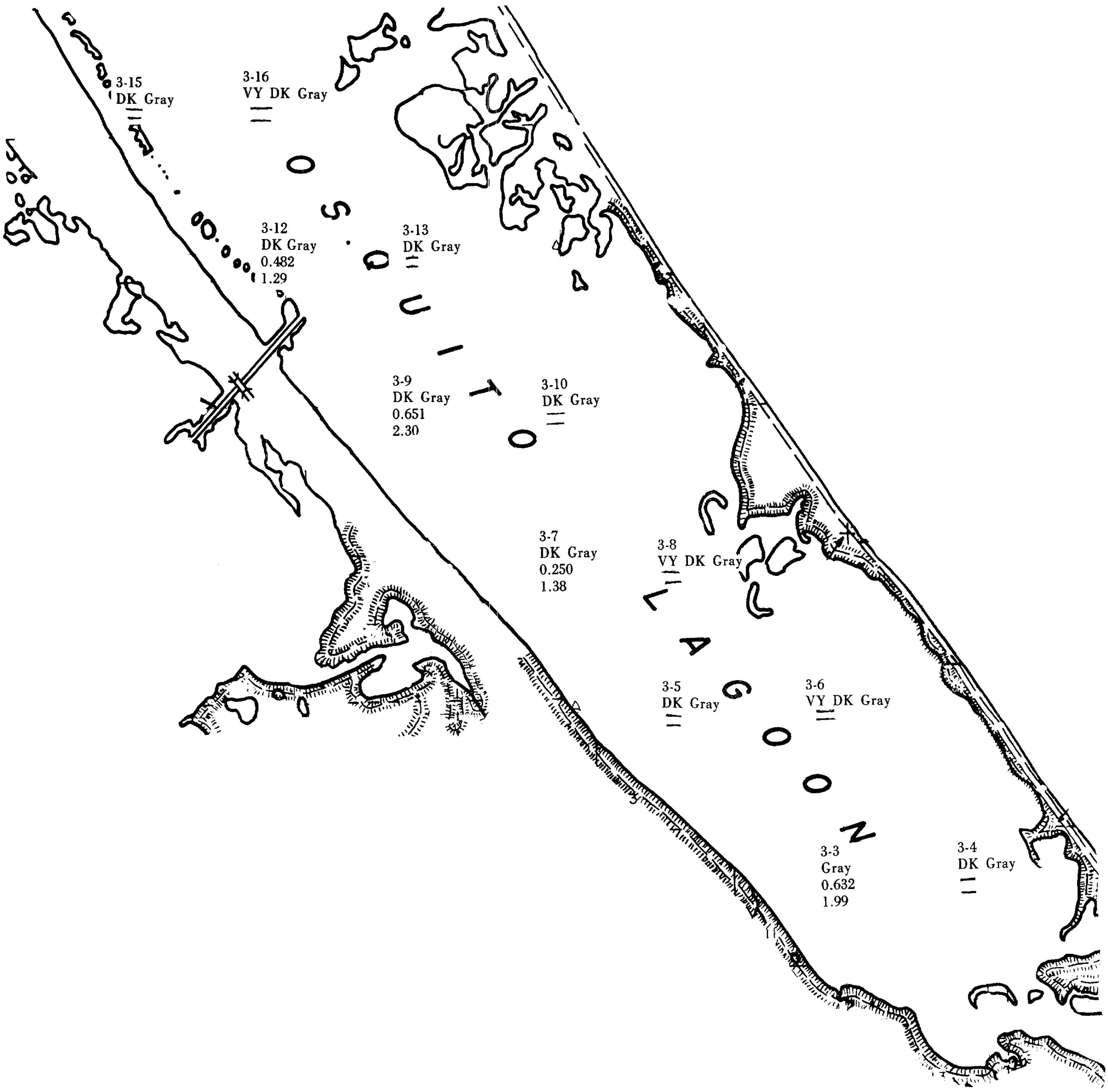

**Explanation**

Site No.
Munsell Color (if two colors - mottled by second)
Organic Carbon %
Inorganic Carbon %

**Abbreviations**

VY - very
DK - Dark

Figure 5 - 12
Area Two Site Description




Explanation

Site No.
Munsell Color
Organic Carbon %
Inorganic Carbon %

Abbreviations

VY - very
DK - Dark

Figure 5-13 Area Three Site Description

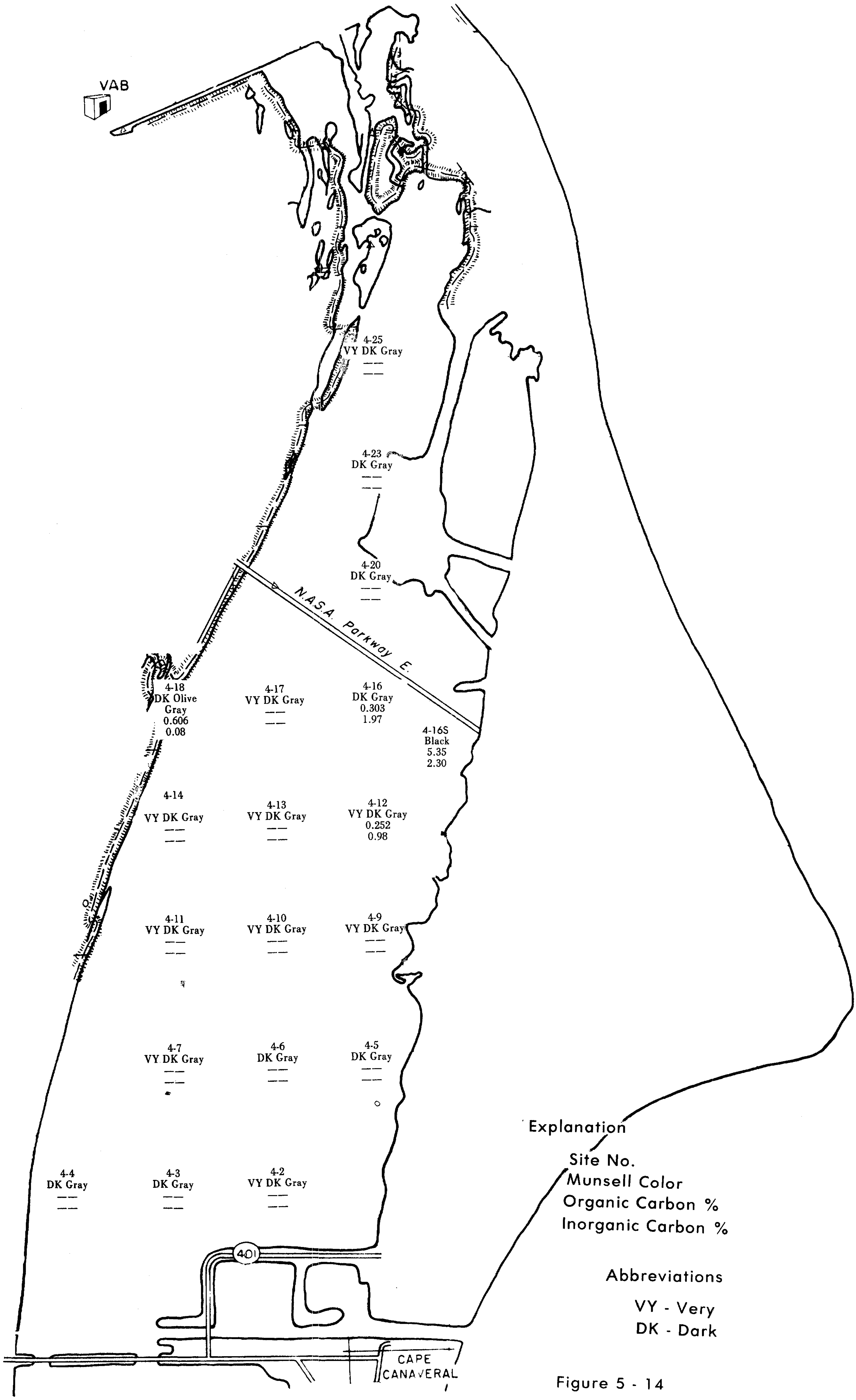



Figure 5 - 14

Area Four Site Description

Median grain sizes of the lagoon surface sediments versus organic carbonate % were plotted in Figure 5-15 and show a correlation coefficient of 0.47052. However it should be pointed out that the variation in grain size of the sediments is small (all fine sands) and a good correlation could not be expected. The data on organic contents compares well with that described for other marginal marine sediments of similar size range by Folger (1972). Folger indicates that organic carbon contents are less than 1% for sand size sediments unless factors such as water circulation or sewerage outfalls are an influence. Site 4-16S with high values of organic content is adjacent to an outfall carrying effluent from the Air Force Station Sewerage Treatment Plant.

An inverse relation between organic carbon and grain size of the sediment was observed when the cores from the impounded waters were considered; Daggett (1973). The organic carbon values for clays and silts with mean grain size between 0.02 mm and 0.07 ranged from 1.39 % for site 1-25 to 2.9% for core 117. Exceptions to this trend were found in humus rich layers taken from the impounded waters such as Site 113, which had a grain size of 0.2 mm. yet gave organic carbon values of 1.86% and core 118 which had organic carbon values of 3.56%.

Major nutrient concentrations were examined at the twenty-six selected sites during the latter stages of this investigation, Peffer (1975). Organic carbon concentrations were used as the framework for the nutrient analysis, since the concentration of organic carbon in the sediments represents about half the total organic matter present there and consists of both natural plant and animal remains, and of various pollutants. Folger (1972).

Mean organic carbon values are summarized in Figure 5-16. The sampling sites have been grouped and categorized according to the guidelines presented earlier, and are presented in Table 5-5. All figures are in mg/g dry weight.

Six sites were considered representative of natural conditions in Area 1, although three of these are located in close proximity to the Intracoastal Waterway and are included in that grouping also (note that a number of sites fall into more than one category). The average value of organic carbon in these sites is 3.17 mg/g with highs of 4.81 and 4.55 found at the shallow sites 1-26 (0.75m) and 1-8 (0.5m) respectively. The lowest values were found at the deeper sites 1-2 (1.84 mg/g C, 1.6m) and 1-6 (1.42 mg/g C, 2.0m). This inverse correlation with depth is ex-

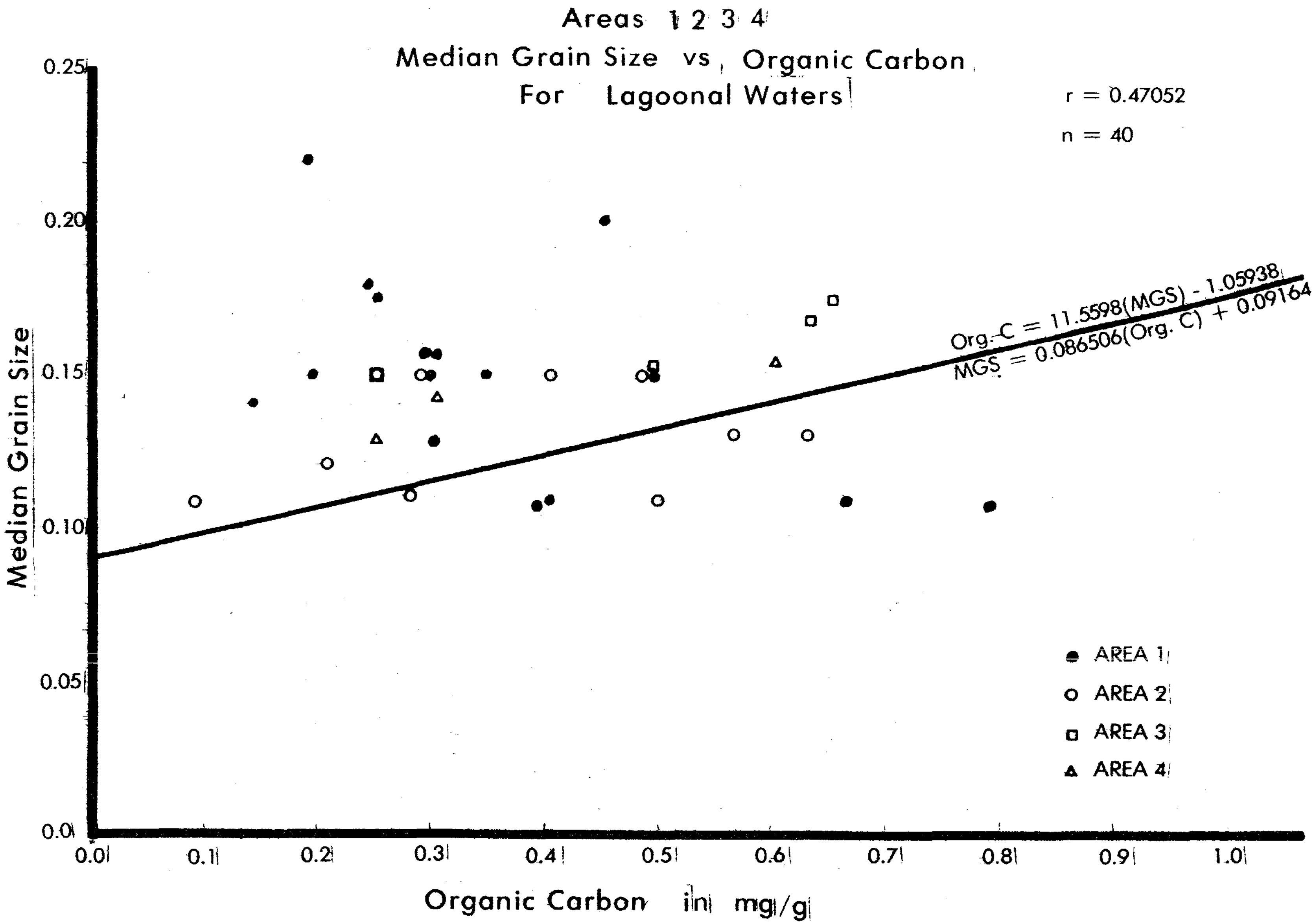

Areas 1 2 3 4
Median Grain Size vs Organic Carbon
For Lagoonal Waters
r = 0.47052
n = 40
Org. C = 11.5598(MGS) - 1.05938
MGS = 0.086506(Org. C) + 0.09164
Median Grain Size
0.25
0.20
0.15
0.10
0.05
0.0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Organic Carbon in mg/g
AREA 1
AREA 2
AREA 3
AREA 4

Figure 5 - 15

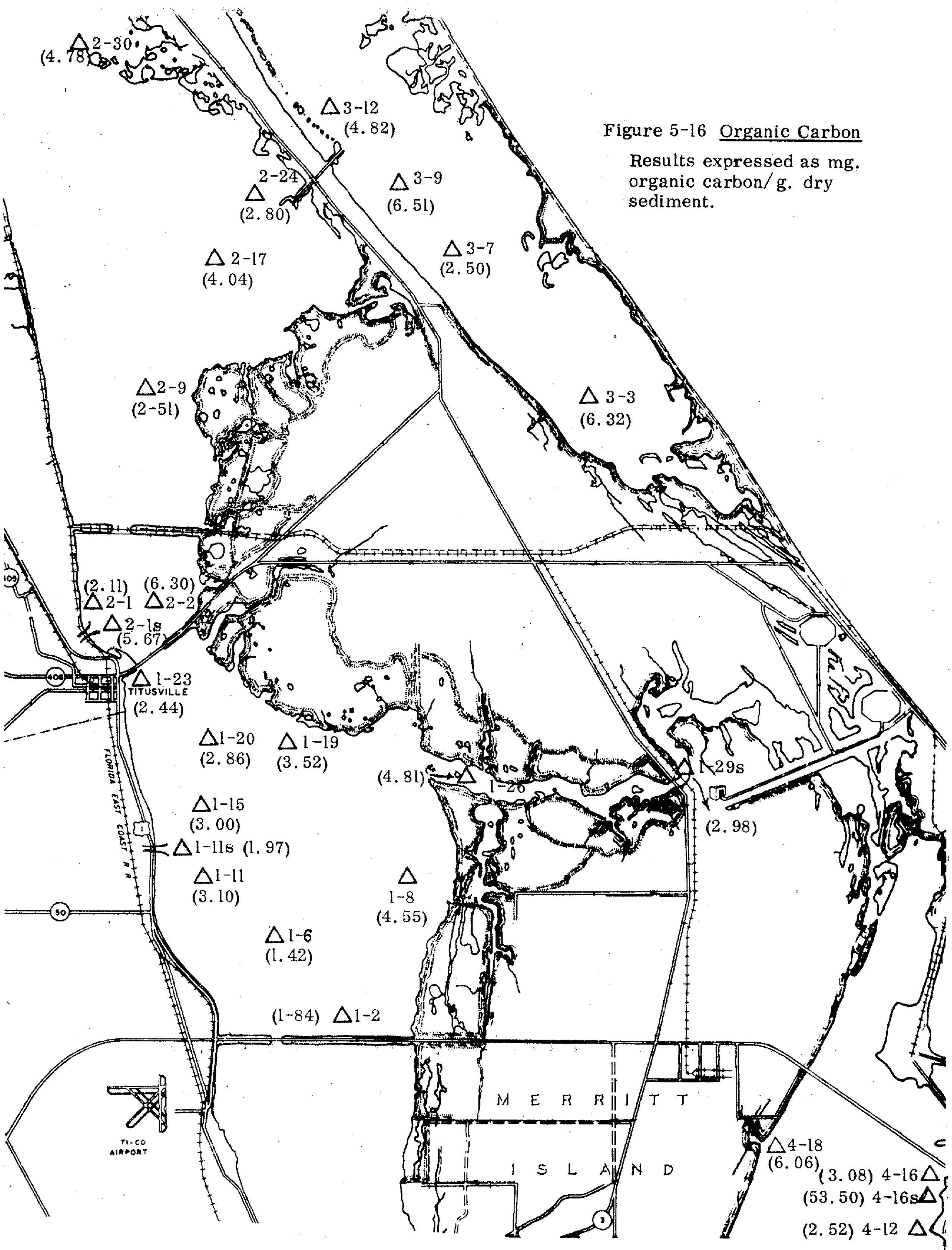



Figure 5-16 Organic Carbon

Results expressed as mg. organic carbon/g. dry sediment.

Table 5 - 5

| ORGANIC CARBON (mg/g) | | | | | |
|---|---|---|---|---|---|
| SITE | DEPTH | NATURAL | WATERWAY | OUTFALL | OTHER |
| 1-2 | 1.6m | 1.84 | | | 1.84 |
| 1-6 | 2.0 | 1.42 | 1.42 | | |
| 1-8 | .5 | 4.55 | | | |
| 1-11 | 2.0 | | 3.10 | 3.10 | |
| 1-11S | .5 | | | 1.97 | |
| 1-15 | 2.0 | | 3.0 | 3.0 | |
| 1-19 | 1.0 | 3.52 | | | 3.52 |
| 1-20 | 1.75 | 2.86 | 2.86 | | |
| 1-23 | 1.0 | | | | 2.44 |
| 1-26 | .75 | 4.81 | | | |
| 1-29S | .5 | | | 2.98 | |
| (MEAN) | | 3.17 | 2.60 | 2.69 | |
| 2-1 | .5 | 2.11 | | 2.11 | |
| 2-1S | .75 | | | 5.67 | |
| 2-2 | 1.25 | 6.30 | | 6.30 | |
| 2-9 | 1.3 | 2.51 | 2.51 | | |
| 2-17 | 1.75 | 4.04 | 4.04 | | |
| 2-24 | 1.0 | 2.80 | | | 2.80 |
| 2-30 | .5 | 4.78 | | | |
| (MEAN) | | 3.77 | 3.27 | 4.69 | |
| 3-3 | 1.0 | 6.52 | | | |
| 3-7 | 1.75 | 2.50 | | | |
| 3-9 | 2.0 | 6.51 | | | |
| 3-12 | .75 | 4.82 | 4.82 | | |
| (MEAN) | | 5.09 | | | |
| 4-12 | .25 | 2.52 | | 2.52 | |
| 4-16 | 1.25 | 3.08 | | 3.08 | 3.08 |
| 4-16S | .25 | | | 53.5 | |
| 4-18 | .5 | 6.06 | | | |
| (MEAN) | | 3.89 | | 2.80 | |

plained by the fact that high carbon values were obtained from those shallow areas where there was extensive growth of root-vegetation, and thus a high level of organic detritus. Grasses are known to slow the circulation of water and allow suspended materials to settle out, while at the same time the broken and dead fragments of the grasses are being accumulated and recycled through the food chain.

The sites near the Intracoastal Waterway in Area 1 have average organic carbon values of 2.60 mg/gm, with a low at the south end (1-6, 1.42) and a high near the Knox McCrae (Titusville South) treatment plant outfall. The lower carbon values in these sites reflect their greater average depth compared to the natural areas.

The three sites used to measure the impact of the treatment plant have an average value in between those of the waterway and the natural areas (2.69 mg/gm), but here it is interesting to note that the depth relationship is reversed, with the shallower site (1-11S) showing lower values than the deeper values. Two factors probably account for this. Firstly, there was no evidence of rooted vegetation at 1-11S, and secondly, the turbulent action evident in this vicinity could well have scoured the bottom clean (values for organic nitrogen and total phosphorus were also lower at 1-11S than at the two nearest sites). Another factor which may be of consequence here is that the effluent from the treatment plant is fresh water, and therefore may not mix immediately with the saline waters of the lagoon. There may be a tendency for the lighter fresh water to disperse on the surface before inter-mixing with the river water, and suspended material may be carried some distance away from the discharge site prior to settling out.

Sites 1-26 and 1-29S, located on the opposite sides of State Road 3 in the Banana Creek, show the high average organic carbon value of 3.90 mg/gm. Since the sewage treatment plant adjacent to the VAB no longer empties into Banana Creek, and since Banana Creek had been dammed midway between these sites during the construction of the Space Shuttle runway and crawlerway, this high value can be regarded as representative of the large amount of detritus present in the creek, and not due to the treatment plant. Banana Creek has the highest shoreline to water volume ratio of all the areas studied here, and probably is the most affected by surface runoff. The averages for organic nitrogen, sulfides, and total phosphorus were higher in Banana Creek than in any other grouped category in Area 1.

In Area 2, averages for organic carbon are higher than in Area 1 in all three major categories (natural, waterway, and outfall). This may be due in part to the influence of the Titusville North treatment plant, which produces 3.5 times the effluent of its southern counterpart (the figures are 1.2 and 4.2 million gallons per day, respectively) (Mendelsohn 1975). The average for the sites in natural areas is 3.77 mg/g, while the average for the area of restricted circulation between the Titusville Causeway and the railroad bridge which lies further north is 4.69 mg/g. While it is possible that the sewage effluent is having an enriching effect on the water mass and producing the concomitant proliferation of phytoplankton which eventually find their way to the sediments, the fact that Area 3, which has no sewage input, shows an even higher average value (5.09 mg/g) leads one to suspect that the higher values in Area 2 compared with Area 1 are the result of a larger area of shallow water and a higher standing crop of biomass. The sites adjacent to the waterway in Area 2 have an organic carbon average of 3.27 mg/g again reflecting lower average values with greater depth.

In Area 3, all sites can be considered natural, and the only site that is likely to be influenced by man is 3-12, which lies adjacent to the Intracoastal Waterway. The average organic carbon value found here was 5.09 mg/g, the highest of all four areas in the natural site category. The Indian River Lagoon (as Mosquito Lagoon is now known) is the least disturbed of all the areas studied. It is also the shallowest of the lagoons surrounding the space center, and has vast expanses of both rooted vegetation and unattached algae. A highly organic sludge has been reported near the southwestern shore here, but this was not encountered during sampling for this study. This sludge is thought to have originated from untreated sewage discharged from the houses along this shore before the Kennedy Space Center took control of the area, but this is still unconfirmed. It is not known whether this sludge deposit is influencing the organic carbon content of the sediments in Area 3, but the high values there are easily explained in context with the large area of grass flats. Sites 3-3 and 3-9 had the high values of 6.52 and 6.51 mg/g respectively, site 3-12 had an intermediate 4.82 mg/g, and the low value of 2.50 mg/g was obtained at site 3-7. The inverse correlation of organic carbon content and depth was not apparent in Area 3, and a closer examination of the proximity of the grass beds to the sampled sites would be necessary in order to explain this observation.

The sites selected in Area 4 represent a wide variety of natural conditions. The highest values for all nutrients (except ammonia) of all the sites sampled were found at the mouth of the small drainage canal that is the drain conduit for the sewage treatment plant serving the industrial area of the Air Force Station adjacent to Cape Kennedy. The organic carbon value measured here (53.5 mg/g) is nearly ten times the highest previously reported value. The flow from the canal is not fast, and there is no evidence of the turbulence that characterized the discharge of effluents in the Indian River. Furthermore, at the mouth of the canal stood a medium sized mangrove tree (Rhizophora mangle), which slowed the current even more, allowing suspended materials to settle out. The net result was the deposition of a highly organic sediment, the only one that manifested a strong $H_2S$ odor when opened in the field. Sites 4-12 and 4-16, which were the established sites closest to this outfall, did not show extraordinarily high values for organic carbon (2.52 and 3.08 mg/g respectively) indicating that the effect of the treatment plant was localized in the vicinity of the effluent canal. Values obtained for all other nutrients did show higher than average values for these sites, however, and when all factors are considered together, this area represented the most enriched area of all those studied in this project. On the opposite side of the Banana River is a small creek, in the mouth of which lies site 4-18. On the day that this site was sampled, a large quantity of grass (principally Cymodoceum manatorum) was observed floating on the surface of the water there, and it appeared as if this accumulation was caused by an easterly wind. The organic carbon value measured here was 6.06 mg/g, a relatively high value but not an unexpected one in light of the detritus that was flushed from the creek and the large amount of decomposing vegetation in the overlying water.

Organic (Kjeldahl) nitrogen had the highest correlation (Peffer 1975) with organic carbon of all the nutrients measured (0.97). The empirical relationship between these two nutrients was determined through a linear regression and produced the following equation:

Organic nitrogen (ug/g) = 256 (Organic cargon (mg/g)) + 106

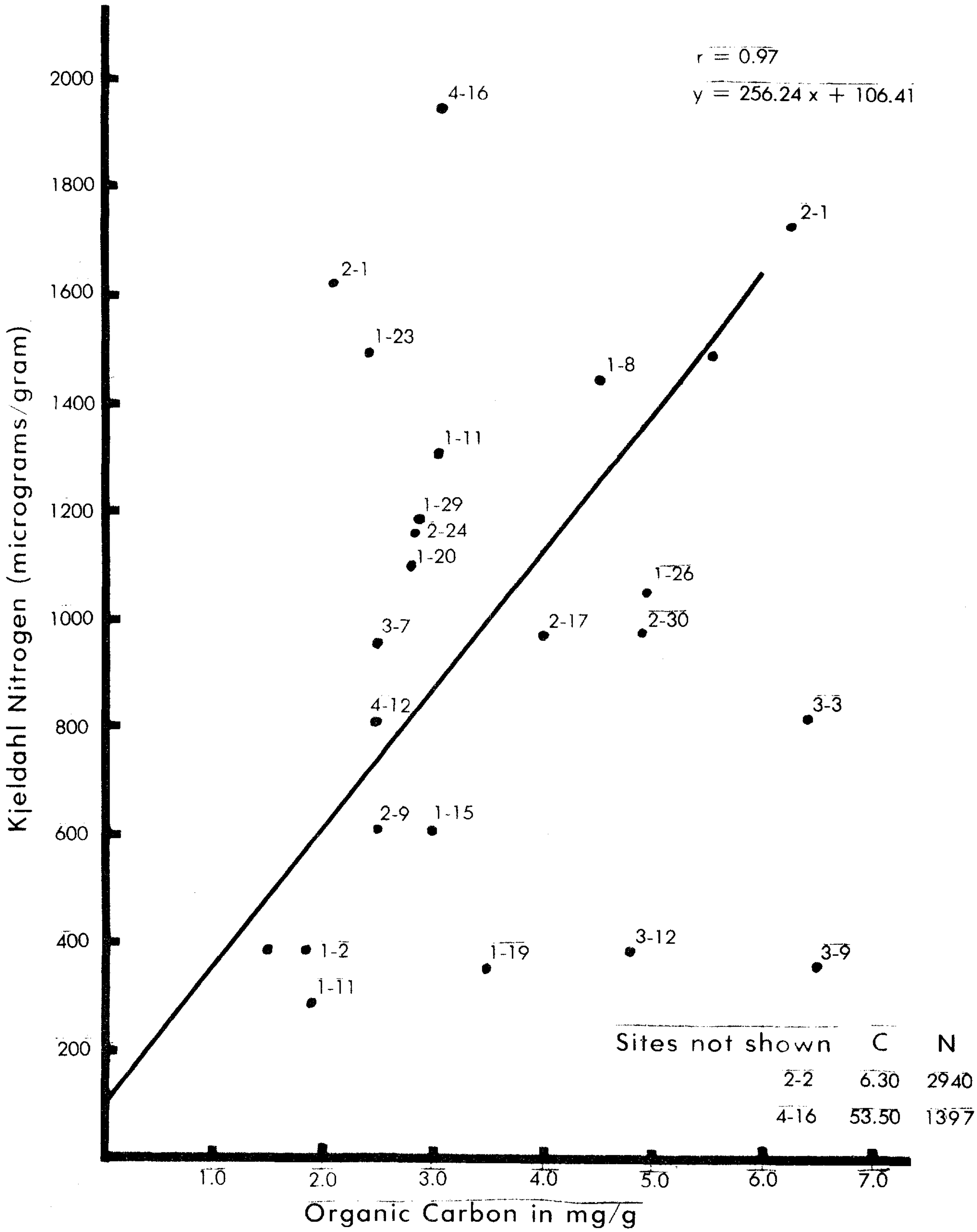
Since the relationship of ug/g to mg/g is 1:1000, the average carbon to nitrogen ratio for the entire lagoonal system is quite close to four (1000/256 = 3.9), which compares to the C:N ratio of five that is often reported for detrital food sources with high bacterial populations. The relationship between carbon and nitrogen is graphed in Figure 5-17 and the results of the organic nitrogen determinations are categorized in Table 5-6. Ammonia determinations are reported in Figure 5-18 and in Table 5-7.

The natural sites in Area 1 had an average organic nitrogen value 782.4 ug/g, and ranged from a high of 1469 ug/g at 1-8 to a low of 313.5 at 1-19. This low value, coupled with the relatively high amount of carbon found at 1-19, produced the highest carbon to nitrogen ratio of any site in Area 1. Higher C:N ratios often indicate that the detritus has not been completely reworked, and that a large amount of the organic material is still only partially decomposed. On the other hand, this high value may indicate that the plants in the area have extracted most of the available nitrogen from the sediments, leaving the excess carbon. The above average value for ammonia found at this location may point to the fact that the available nitrogen is tied up as ammonia.

The deeper waterway sites contained a higher average organic nitrogen value than did the natural sites, which contrasts with the relationship observed for organic carbon, and ammonia paralleled this result (845.3 ug/g) for the natural areas, and 450 ug/g for the waterway.) While one may speculate that this is caused by a lack of uptake of nitrogen by rooted plants at the deeper sites, the fact that the natural areas in Area 2 have almost twice the organic nitrogen values as the waterway sites there (1371 vs 782 ug/g) would seem to indicate that another explanation is necessary.

The sites in and around the Titusville South treatment plant discharge pipe did not show an accumulation of organic nitrogen, but did show high levels of ammonia (861 ug/g N-org, 830 ug/g $NH_3$). Again the sites sampled in Banana Creek showed the highest averages in both categories (1102 ug/g for N-org, 1039 for $NH_3$). Site 1-23, located just south of the western portion of the Titusville Causeway and adjacent to a dredged navigational channel running from the Intracoastal Watersay to a nearby marina showed very high values for both organic nitrogen (1458) and ammonia (2994). No explanation is apparent for this anomaly, since values for the other nutrients at this site are all somewhat below the area averages.

The averages for the natural sites in Area 2 are almost double those for Area 1 for both organic nitrogen (1371 ug/g), and ammonia (1677), which may again indicate the possible enrichment effect of the north treatment plant. The enclosed



r = 0.97
y = 256.24 x + 106.41
Kjeldahl Nitrogen (micrograms/gram)
2000
1800
1600
1400
1200
1000
800
600
400
200
Organic Carbon in mg/g
1.0
2.0
3.0
4.0
5.0
6.0
7.0
4-16
2-1
2-1
1-23
1-8
1-11
1-29
2-24
1-20
1-26
2-30
2-17
3-7
4-12
3-3
2-9
1-15
1-2
1-19
3-12
3-9
1-11
Sites not shown C N
2-2 6.30 2940
4-16 53.50 1397


Figure 5-17

Table 5-6

Organic (Kjudahl) Nitrogen
(ug/g)

| Site | Natural | Waterway | Outfall | Other |
|---|---|---|---|---|
| 1-2 | 381.8 (1.6) | | | 381.8 (1.6) |
| 1-6 | 394.3 (2.0) | 394.3 (2.0) | | |
| 1-8 | 1469.0 (.5) | | | |
| 1-11 | | 1307.3 (2.0) | 1307.3 (2.0) | |
| 1-11S | | | 273.0*(.5) } 737.1 | |
| 1-15 | 782.4 av | 631.0 (2.0) | 631.0 (2.0) | |
| 1-19 | 313.5 (1.0) | | | 313.5 (1.0) |
| 1-20 | 1111.5 (1.75) | 1111.5 (1.75) | | |
| 1-25 | | | | 1458. (1.0) |
| 1-26 | 1025 (.75) | | 1025 | |
| 1-29S | | | 1179* (.5) } 1102 | |
| 2-1 | 1631.5 (.5) | | 1631.5 | average |
| 2-1S | | | 1499.3 (.75) | 2023.6 |
| 2-2 | 2940. (1.25) | | 2940 | |
| 2-9 | 615. (1.3) | 615. (1.3) | | |
| 2-17 | 949.5 (1.75) | 949.5 (1.75) | | |
| 2-24 | 1148. (1) 1371.1 | | | 1148 (1) |
| 2-30 | 942.5 (.5) | | | |
| 3-3 | 807.5 (1) | | | |
| 3-7 | 947.5 (1.75) | | | |
| 3-9 | 323.5 (2) 617.8 | | | |
| 3-12 | 392.5 (.75) | | | |
| 4-12 | 816.5 (.25) | | (.25) 816.5 | |
| 4-16 | 1915.5 (1.25) 1489.3 | | (1.25) 1915.5 } 1366 5328.3 | 1915.5 (1.25) |
| 4-16S | | | (.25)13972.5 | |
| 4-18 | 1736 (.5) | | | |

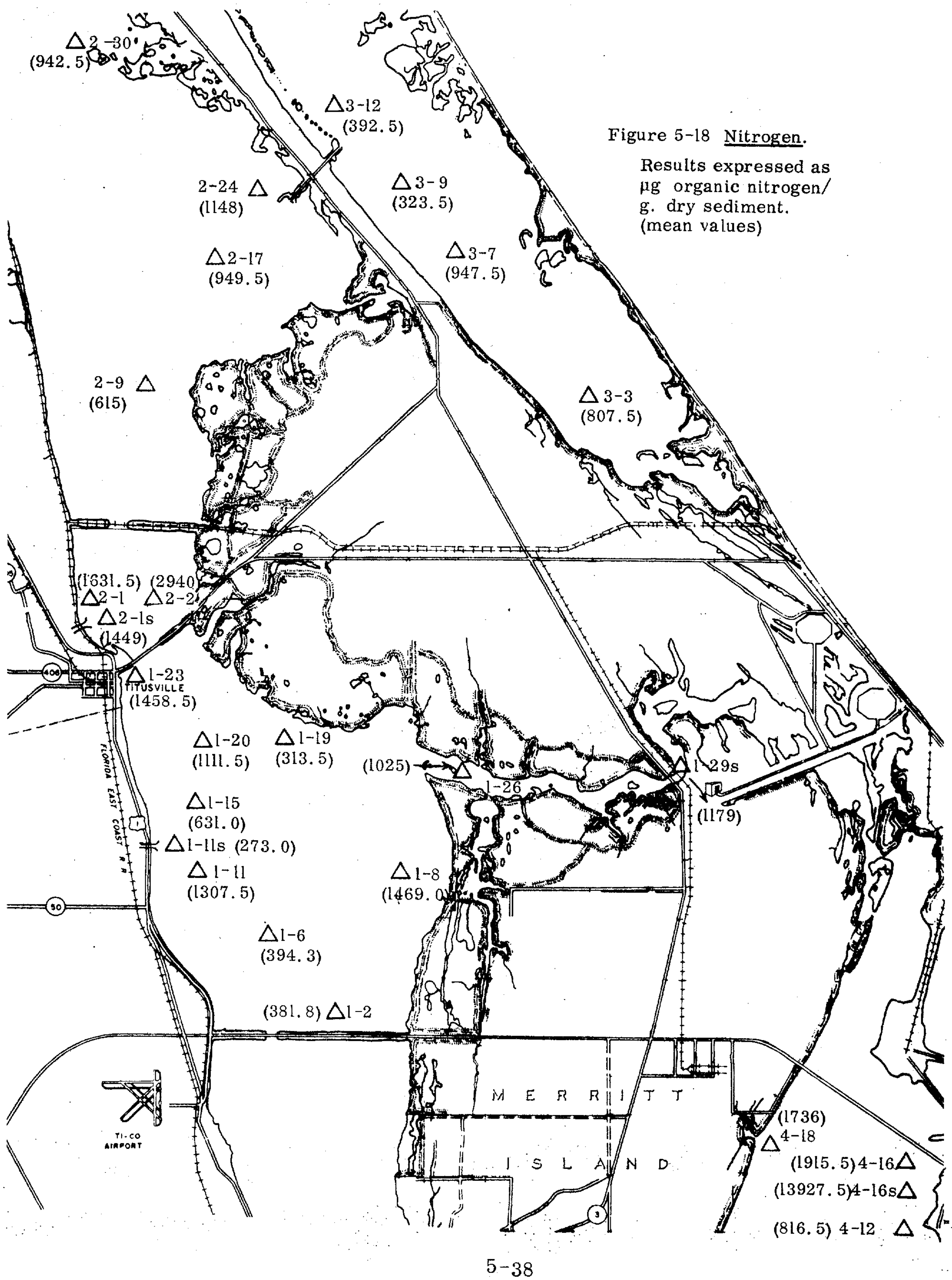



Figure 5-18 Nitrogen.

Results expressed as µg organic nitrogen/ g. dry sediment. (mean values)

Table 5-7

Ammonia (ug/g)

| Site | Natural | Waterway | Outfall | Other |
|---|---|---|---|---|
| 1.2 | 1658.5 | | | 1658.5 |
| 1-6 | 49.3 | 49.3 | | |
| 1-8 | 1035.6 | | | |
| 1-11 | | 925.6 | 925.6 | |
| 1-11S | | | 1191.5 830.7 | |
| 1-15 | | 375. | 375 | |
| 1-19 | 1142.0 | | | 1142.0 |
| 1-20 | 0 845.3 | 0 450.0 | | |
| 1-23 | | | | 2994.5 |
| 1-26 | 1186.5 | | 1186.5 1039.3 | |
| 1-29S | | | 892* | |
| 2-1 | 2702.5 | | 2702.5 | |
| 2-1S | | | 1027.6* | |
| 2-2 | 1549.3 | | 1549.3 | |
| 2-9 | 1493 | 1493 | | |
| 2-17 | 2228.5 1676.9 | 2228.5 1860.8 | 1759.8 | |
| 2-24 | 944.5 | | | 944.5 |
| 2-30 | 1144. | | | |
| 3-3 | 254 | | | |
| 3-7 | 400.5 | | | |
| 3-9 | 784.5 607 | | | |
| 3-12 | 989 | 989 | | |
| 4-12 | 467.5 | | 467.5 945.5 | |
| 4-16 | 1423.5 788.7 | | 1423.5 | |
| 4-16S | | | 2827.5* 1572.7 | 2827.5 |
| 4-18 | 475 | | | |

area around the outfall had the very high values of 2024 and 1760 for organic nitrogen and ammonia respectively. The highest organic nitrogen value reported in Area 2 was opposite the outfall at site 2-2 (2940 ug/g) while the lowest values were obtained at the sites near the waterway (av.782. 3). Ammonia averages were fairly consistent throughout the area (1677 natural, 1861 waterway, and 1760 ug/g outfall) and these differences are probably not significant in view of the difficulties associated with the laboratory determination.

The average values for the sites sampled in the Indian River Lagoon are 618 ug/g for organic nitrogen and 607 ug/g for ammonia. The carbon to nitrogen ratios there were the highest found anywhere in the lagoonal complex (average 10. 7 with a high of 20. 15 at 3-9 and a low of 2. 64 at 3-7). This again points to the conclusion that the nitrogen here is either mostly bound in the vegetation or that the detritus is at a lesser level of degradation.

In the Banana River the value of 1489 ug/g, representing the averages of the natural sites, was the highest of all the four areas. The mouth of the discharge drainage canal had a value of 13, 972, about an order of magnitude greater than the averages in all other areas. The two sites adjacent to the outfall averaged 1366 ug/g, with the closer 4-16 showing 1916 and 4-12 showing 817. (It was observed that concentrations were higher for all nutrients at 4-16 than at 4-12, which can be assumed to indicate a gradient of high to low concentrations leading from the discharge site.) The sample taken from the mouth of the creek on the opposite bank of the river showed the relatively high value of 1737 for organic nitrogen, ranking it fourth among all the sites sampled. Contrary to expectations, the concentration of ammonia found at 4-16 S was notthe highest of all sites, but took second place behind the aforementioned anomolous 1-23. Grouping the other three sites in Area 4 produced the moderate averageof 789 ug/g for ammonia.

Total phosphorus concentrations (reported in ug/g throughout) in the natural sites of Area 1 averaged 223, with a high at 1-20 (419) and a low at 1-6 (81). The waterway average was slightly lower at 185, while the sites around the outfall had a very low concentration average of only 86. (Figure 5-19) Indeed, the lowest total phosphorus value found anywhere in the lagoonal system was immediately next to the discharge pipe at site 1-11S (Table 5-8) Since sewage effluent is known to contain large quantities of phosphates, this is a clear indication that the nutrients from the treatment plant are not settling in the immediate area of the outfall but

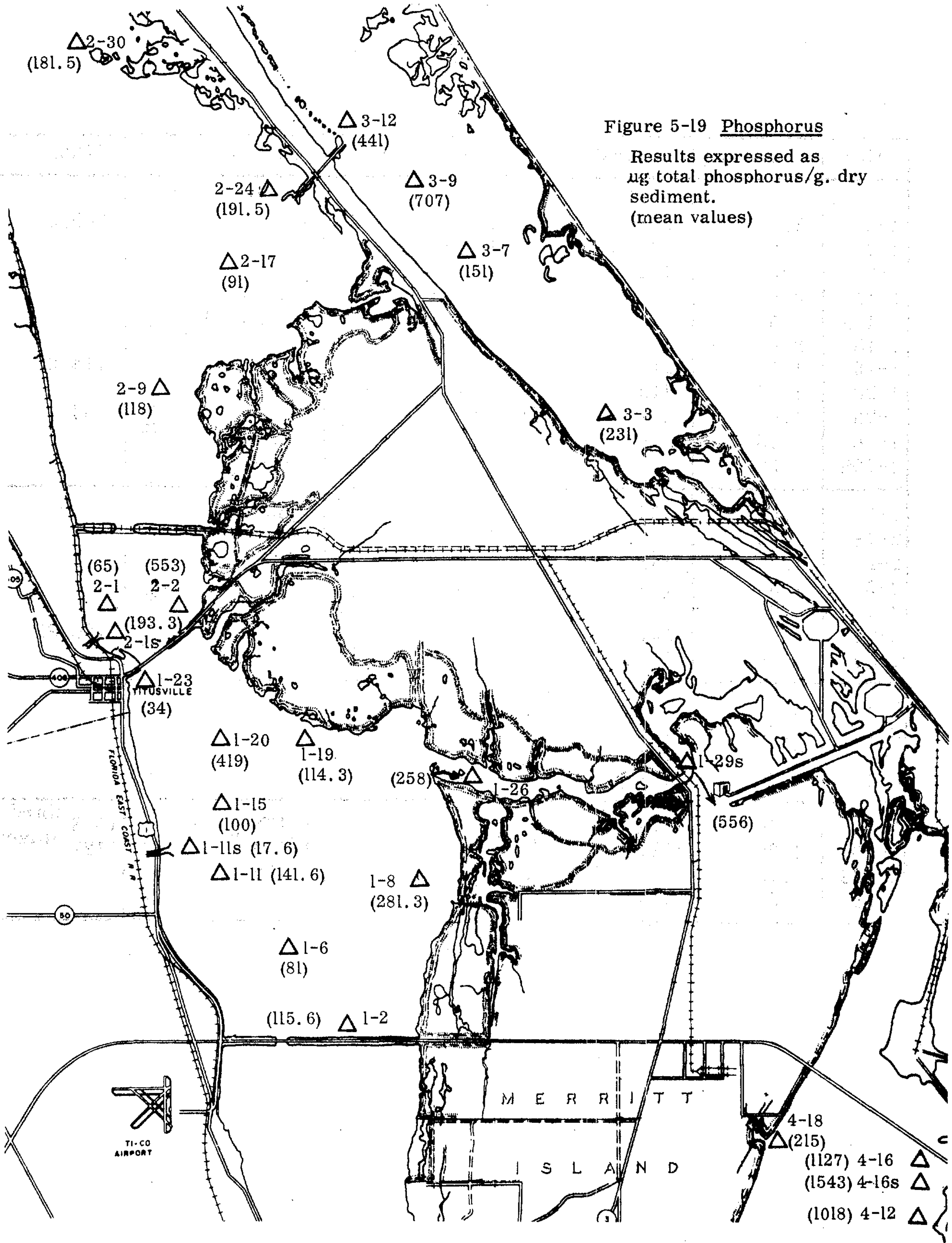


Figure 5-19 Phosphorus
Results expressed as µg total phosphorus/g. dry sediment. (mean values)
2-30 (181.5)
3-12 (441)
2-24 (191.5)
3-9 (707)
2-17 (91)
3-7 (151)
2-9 (118)
3-3 (231)
(65) 2-1
(553) 2-2
(193.3) 2-1s
1-23 (34)
TITUSVILLE
1-20 (419)
1-19 (114.3)
(258) 1-26
1-29s (556)
1-15 (100)
1-11s (17.6)
1-11 (141.6)
1-8 (281.3)
1-6 (81)
(115.6) 1-2
MERRITT ISLAND
4-18 (215)
(1127) 4-16
(1543) 4-16s
(1018) 4-12
FLORIDA EAST COAST R R
TI-CO AIRPORT

Table 5 - 8

Total Phosphorus (ug/g)

| Site | Depth (m) | Natural | | Waterway | | Outfall | | Other |
|---|---|---|---|---|---|---|---|---|
| 1-2 | 1.6 | 185.6 | | | | | | 185.6 |
| 1-6 | 2.0 | 81 | | 81 | | | | |
| 1-8 | .5 | 281.3 | | | | | | |
| 1-11 | 2.0 | | | 141.6 | | 141.6 } | 86.4 | |
| 1-11S | .5 | | | | | 17.6 * } | | |
| 1-15 | 2.0 | | | 100 | | 100 } | | |
| 1-19 | 1.0 | 114.3 | | | | | | 114.3 |
| 1-20 | 1.75 | 419 | 223.2 | 419 | 185.4 | | | |
| 1-23 | 1.0 | | | | | | 407 | 34 |
| 1-26 | .75 | 258 | | | | 258 } | | |
| 1-29S | .5 | | | | | 556 * } | | |
| 2-1 | .5 | 65 | | | | 65 | | |
| 2-1S | .75 | | | | | 193.3* | | |
| 2-2 | 1.25 | 553 | | | | 553 | | |
| 2-9 | 1.3 | 118 | | 118 | | | | |
| 2-17 | 1.75 | 91 | | 91 | | | | |
| 2-24 | 1 | 191.5 | 200. | | 104.5 | | 270.43 | 126.98 |
| 2-30 | .50 | 181.5 | | | | | | |
| 3-3 | 1 | 231 | | | | | | |
| 3-7 | 1.75 | 151 | | | | | | |
| 3-9 | 2 | 707 | | | | | | |
| 3-12 | .75 | 441 | 382.5 | 441 | | | | |
| 4-12 | .25 | 1018 | | | | 1018 } 1072.5 | | 1018 (bird island) |
| 4-16 | 1.25 | 1127 | 786.7 | | | 1127 } | 1229.3 | 1127 |
| 4-16S | .25 | | | | | 1543* | | |
| 4-18 | .5 | 215 | | | | | | |

are being transported via currents and mixing to more distant locations. The averages of the Banana Creek sites again yielded the highest P-total concentration of all the averages in Area 1, and on a system wide basis were surpassed only by the values obtained in Area 4.

The natural sites in Area 2 averaged 200 ug/g, which is lower than that reported for Area 1. This is the first indicator which strongly suggests that the higher nutrient characteristics generally observed in Area 2 are due to natural causes, rather than due to the influence of the north treatment plant. If the treatment plant was the primary source of enrichment, high phosphate levels should be observed here. The sites near the outfall did show a high concentration average of 270, but this is not substantially greater than the averages for the natural areas in the Indian River.

The average level of total phosphorus in the Indian River Lagoon was 383 ug/g, with a high of 707 at 3-9 and a low of 151 at 3-7. Site 3-9 also had a high concentration of organic carbon, yet it showed the lowest organic nitrogen level in area 3. Data from the sediments alone is not sufficient to explain this result. It would be necessary to know more about the circulation and biology of this area.

In Area 4, where the natural sites had the highest average value for all four areas (787 ug/g), the highest concentration of all was of course found at the discharge canal at 4-16S (1543). This concentration is only about 150% the average for the adjacent sites (1072.5), which is in sharp contrast to the differences reported for the other nutrients (where the factor was about 1000%). The high level reported for site 4-12 probably reflects the fact that this site was immediately adjacent to an island used as a rookery by a number of species of shore birds. (These birds did not appreciate the intrusion of a noisy outboard motor and three graduate students.)

Nitrogen is concentrated in protoplasm by a factor of 15 times that of phosphorus. (Hill 1966) Since the concentrations of total phosphorus in these lagoons averages about one third that of the organic nitrogen in the natural areas, the evidence again suggests that nitrogen is the limiting nutrient in these ecosystems.

Sulfides and organic carbon correlated with a coefficient of + 0.86, and the equation produced by regression analysis was:

Sulfides (ug/g) = 4.72 (Organic carbon (mg/g) ) + 48.94 (Figure 5-20)

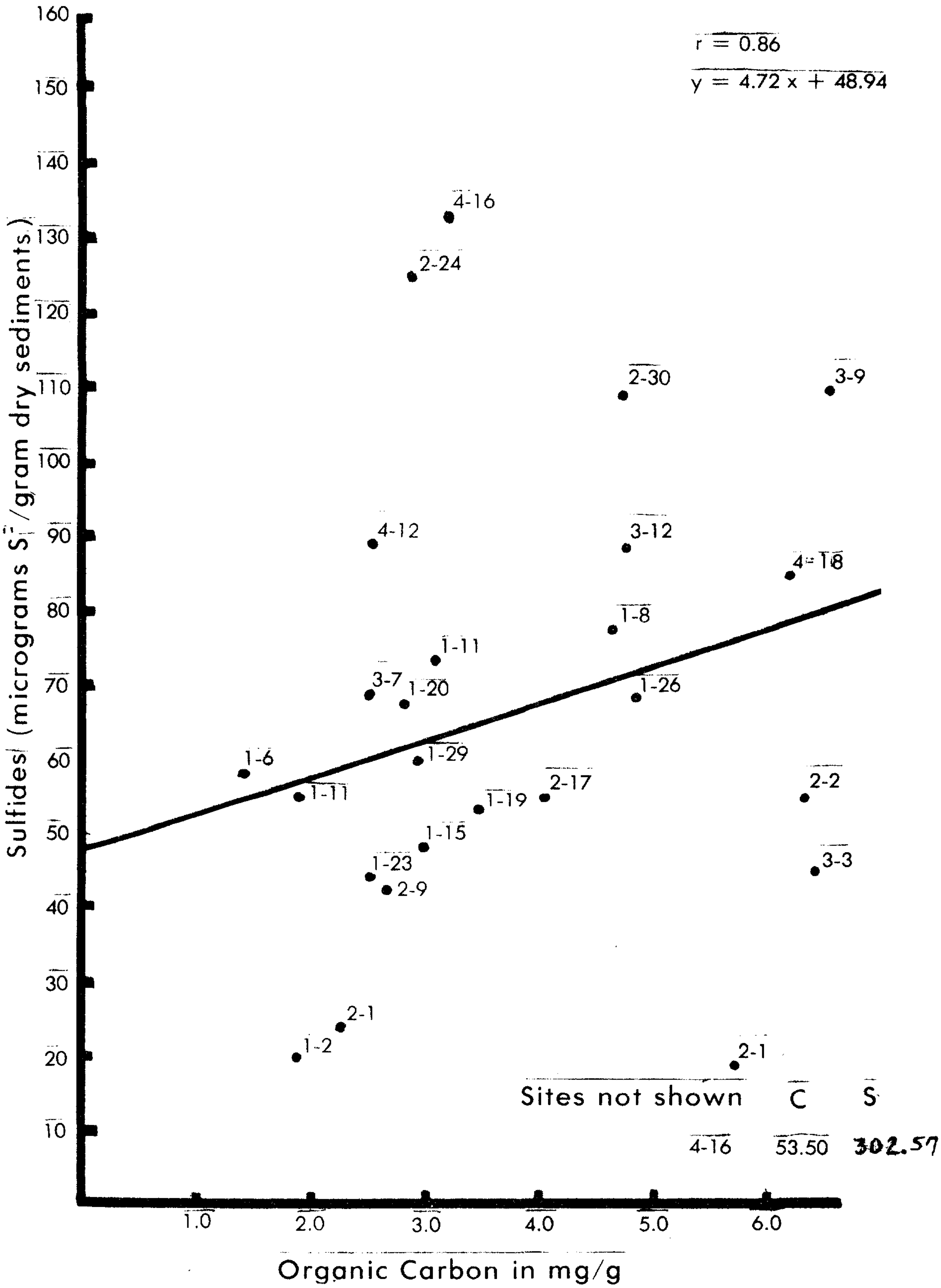

r = 0.86
y = 4.72 x + 48.94
Sulfides (micrograms S⁼/gram dry sediments)
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
4-16
2-24
2-30
3-9
4-12
3-12
4-18
1-8
1-11
3-7
1-20
1-26
1-6
1-29
1-11
2-17
2-2
1-19
1-15
1-23
3-3
2-9
2-1
1-2
2-1
Sites not shown
C
S
4-16
53.50
302.57
1.0
2.0
3.0
4.0
5.0
6.0
Organic Carbon in mg/g

Figure 5-20

The natural sites of Area 1 had an average sulfide concentration of 54.62 ug/g, while the waterway sites showed an only slightly higher concentration of 61.51 (Table 5-9). There was no strong correlation of sulfides with depth, and the magnitude of difference between the lowest and the highest measured values was the least for sulfides as compared to the other nutrients (approximately 15:1). The second highest concentration measured in the sediments of Area 1 was found at site 1-26 near the mouth of Banana Creek (69-91) while the other site in the creek, 1-29S, had a more normal value of 59.57. The highest concentration measured in Area 1 was 76.33 at site 1-8, where high organic values are often observed. (Figure 5-21) The high value at site 1-20 corresponds with the high concentration of phosphate found at this site, as these two nutrients are often found in conjunction with one another, especially when iron is present. The sites around the Knox McCrae treatment plant continued to show low values (average 42.06 ug/g).

In Area 2, the natural areas showed higher averages (68.78) than those in Area 1, while the sites near the waterway were somewhat lower (48.54). This time, however, the area of reduced circulation around the north treatment plant outfall showed the lowest average for Area 2 (32.74). The highest concentration of sulfides here was observed at site 2-24 near the mouth of Haulover Canal. The lowest concentration occured at 2-1S, adjacent to the effluent discharge pipe.

The sites in Area 3 ranked second highest in sulfide concentration with an average of 78.95 ug/g. The high value (112.10) was observed at the deepest site (3-9), while the lowest concentration was measured at the southermost location (3-3, 45.95).

The Banana River showed the highest average sulfide concentrations with an average value of 122.57 ug/g. Site 4-16 had the highest concentration of the natural areas with a value of 133.68, while 4-12 and 4-18 came in about even at 89.34 and 84.70 respectively. The highest value for the lagoonal system was again recorded at 4-16S, reaffirming the nutrient trapping effect so evident at this location.

In general it can be said that the higher sulfide concentrations in all areas were found in those locations where the currents and mixing effects of the water were likely to be least evident, such as in the deeper sites (1-11, 3-9), those near grass beds (1-8, 2-30, 3-12, 4-12 ), or where man made structures have reduced the circulation of the water (2-24, 4-16). The sulfide levels reported for the surface sediments are probably representative of the conditions deeper in the substrate, where the greatest concentrations of sulfides occur, but this conjecture should be

Table 5 - 9

Sulfides (ug/g)

| Site | Depth (m) | Natural | | Waterway | | Outfall | | Other |
|---|---|---|---|---|---|---|---|---|
| 1-2 | 1.6 | 20.11 | | | | | | 20.11 |
| 1-6 | 2.0 | 56.87 | | 56.87 | | | | |
| 1-8 | .5 | 76.33 | | | | | | |
| 1-11 | 2.0 | | | 73.36 | | 73.36 | | |
| 1-11S | .5 | | | | | 55.8* | 42.06 | |
| 1-15 | 2.0 | | | 47.01 | | 47.01 | | |
| 1-19 | 1.0 | 53.66 | 56.62 | | 61.51 | | | 53.66 |
| 1-20 | 1.75 | 68.81 | | 68.81 | | | | |
| 1-23 | 1.0 | | | | | | | 44.81 |
| 1-26 | .75 | 69.91 | | | | 69.91 | 64.74 | |
| 1-29S | .5 | | | | | 59.57 * | | |
| 2-1 | .5 | 23.44 | | | | 23.34 | | |
| 2-1S | .75 | | | | | 18.10 | | |
| 2-2 | 1.25 | 56.69 | | | | 56.69 | | |
| 2-9 | 1.3 | 41.95 | 68.78 | 41.95 | 48.54 | | | |
| 2-17 | 1.75 | 55.14 | | 55.14 | | | 43.74 | |
| 2-24 | 1 | 126.98 | | | | | | 126.98 |
| 2-30 | .5 | 108.51 | | | | | | |
| 3-3 | 1 | 45.95 | | | | | | |
| 3-7 | 1.75 | 68.81 | 78.95 | | | | | |
| 3-9 | 2 | 112.1 | | | | | | |
| 3-12 | .75 | 88.94 | | 88.94 | | | | |
| 4-12 | .25 | 89.34 | | | | 89.34 | 111.51 | |
| 4-16 | 1.25 | 133.68 | 102.57 | | | 133.68 | | |
| 4-16S | .25 | | | | | 302.57 | 175.18 | |
| 4-18 | .5 | 84.70 | | | | | | |

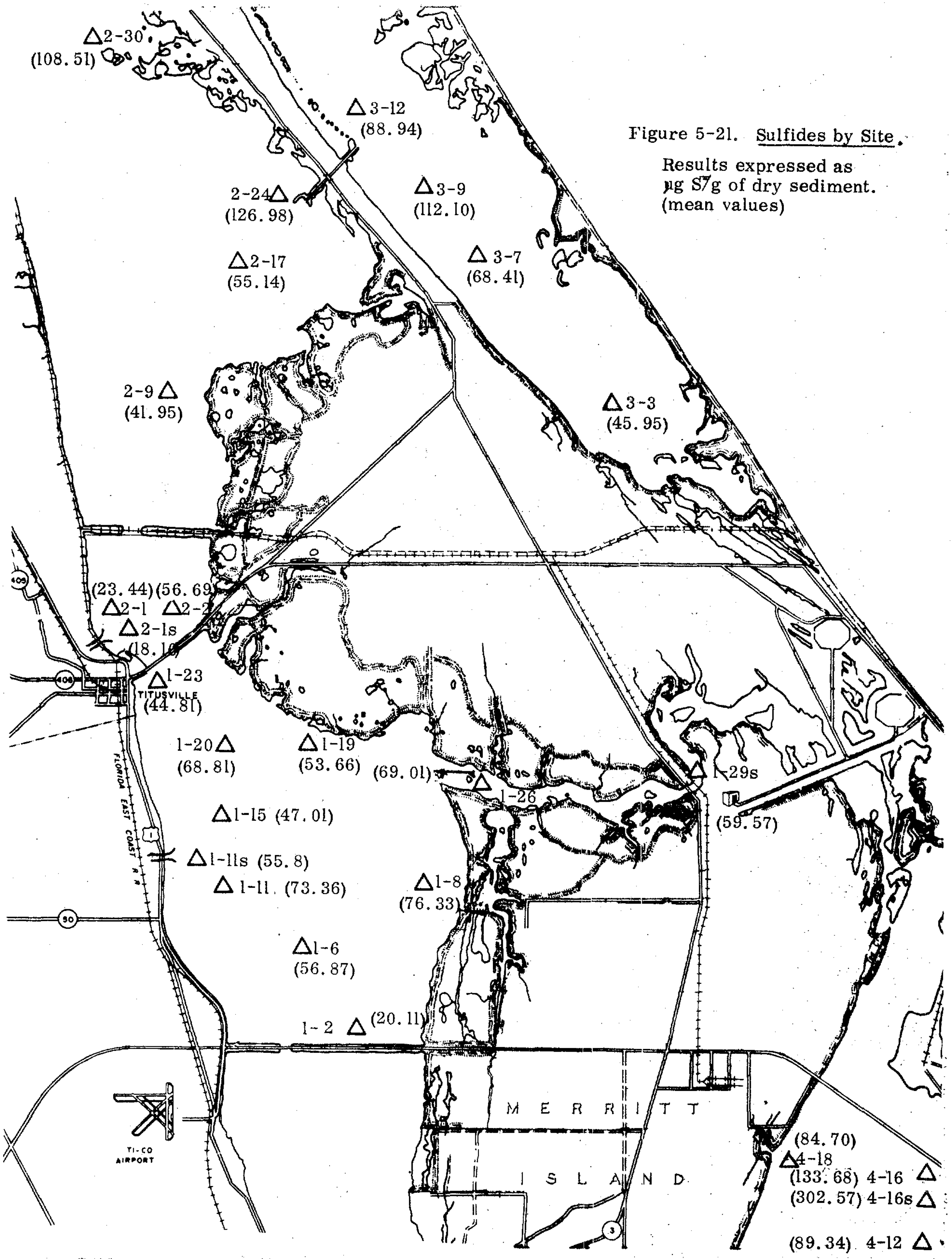



Figure 5-21. Sulfides by Site. Results expressed as µg S/g of dry sediment. (mean values)

tested by future researchers in order to determine the validity of surface sediment measurements for sulfide studies.

## 5.4 Conclusions

The lagoonal sediments surrounding the Kennedy Space Center can be essentially characterized as being undisturbed natural areas. The type of sediment and values of water content, Eh, pH, Total Volatile Solids and Chemical Oxygen Demand, compared well with data from other similar marginal marine areas reported in the literature.

EPA concentrations of total volatile solids and chemical oxygen demand were exceeded at only a few specific sites. There appears to be small variation in nutrients from site to site although some local influences are being felt. Areas 3 and 4 which appear to have the least physical influences such as surface runoff, Intracoastal Waterway, and sewage outfalls have the highest concentration of nutrients. This is probably due to the shallow water found in these areas and the resulting biological detritus.

The only area of immediate concern is in the vicinity of site 4-16S, where high concentrations of nutrients were found to be accumulating due to the effluent of the Air Force Station sewage treatment plant. It is recommended that this area should be investigated further, with special reference to the possibility of extending an effluent discharge pipe into the Banana River. Sediment analysis has shown that this procedure works well in this lagoonal system, as evidenced by the fact that the sediments taken from the immediate vicinity of the Titusville treatment plants' discharge pipes, showed no substantial accumulation of nutrients, and indeed often showed extremely low values when compared to the adjacent areas. The accumulation of nutrients at site 4-16S has been shown by Tower (1975) to be paralleled by an accumulation of trace metals, and it is felt that this may present danger if left unchecked.

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Chapter 6

# WATER CHEMISTRY STUDIES OF THE INDIAN RIVER LAGOONS

J.A. Lasater

## SUMMARY

One of the primary objectives of the study of the water quality parameters of the lagoons in the vicinity of KSC was to establish baseline conditions. This objective was attained for the usually measured parameters of temperature, salinity, pH, nitrate, orthophosphate, and turbidity. Through the use of statistical treatment of the data, it was established that the values were dependent upon the geographical area (or basin) of the lagoonal complex. It was possible to reduce the number of water sample sites from 129 to 20, where three per basin (or 12 sites) yield values representative of the basin and two per basin (or eight sites) were the most atypical. Routine measurements at the selected sites will permit maintenance of the baseline and indicate any long term trends which may develop.

Trace metal studies established that the levels of cadmium, chromium, copper, iron, lead, and zinc are low in both the sediments and the leaves of the principal shore line plant - the white mangrove. Thus, it may be concluded that the lagoons surrounding KSC are relatively free of metal contamination and that KSC is not making a significant contribution in this regard.

The waters in the vicinity of KSC appear to be experiencing some degree of degradation, but this degradation is primarily a consequence of the influx of nutrient materials derived from urban and agricultural runoff rather than effluents derived from space oriented activities.

## Water Quality Parameters

### 6.1.0 Introduction

Kennedy Space Center's (KSC) stragetic location on Merritt Island is astride the point of closest approach for the three segments of the Lagoons of East Central Florida: Indian River Lagoon (formerly Mosquito Lagoon), the Indian River and the Banana River. Accordingly, events and activities at KSC have the potential of exercising a direct influence on all elements of the lagoonal complex.

Man's activities have altered the nature of these waters. The construction of vehicular crossings has divided the lagoons into a series of slowly interacting basins while the dredging of the Atlantic Intracoastal Waterway (ICWW) and the Canaveral Barge Canal have provided navigational connections between the three segments. In addition, the construction of the railroad to KSC (and Cape Canaveral) and the Saturn V Crawlerway severed a high-water link between the southern extremes of Indian River Lagoon and the upper reaches of the Banana River in the vicinity of the "headwaters" of Banana Creek. Thus, there was at one time, a tenuous connection between these lagoons.

There are two general constraints which exercise dominating influence over the water quality parameters in the lagoons. These are the geophysics of the area and the prevailing meterological conditions. Since man-made structures have altered the terrain and the inter-connections between the components of the lagoonal complex, it must be assumed that the water quality parameters are not the same as the pristine values.

Superimposed upon the geophysical and meterological influences are a number of biological and geochemical processes which also influence the values of the water quality parameters. These processes, often in opposition to one another, result in the observed values encountered. It is convenient to consider the various parameters as a participant or a moderator of the cycles involving carbon, nitrogen, phosphorous, and sulfur.

Space activities require the utilization of exotic fuels and specialized alloys. Therefore, the level of a number of "trace metals" is an important facet in a description of the environment represented by these lagoonal waters.

## 6.1.1 Geophysical Aspects

Indian River Lagoon is almost classical in character since it is separated from the Atlantic Ocean by a barrier beach and has an oceanic connection via Ponce de Leon Inlet located near New Smyrna Beach, Florida. Ponce de Leon Inlet is some 50 km (27 n. m.) north of KSC Headquarters. The waters in the vicinity of KSC are open but shallow, with 51.0 percent of the $52.7 \times 10^6 m^2$ having a depth of 0.61 m (two feet) or less. The only significant amount of "deep" water (c. 12 feet) is in the dredged channel of the Intracoastal Waterway.

North of the KSC property, Indian River Lagoon is dotted with mangrove studded islands, and the bulk of the shoreline is also mangrove. The prinicpal species present is the black mangrove (Avicinnea nitida), however white (Laguncularia Racemora) and button mangroves (Conocarpus erecta) are present.

In the open water areas, the bottom is relatively dark with a good coverage of manatee grass (Cymodoceum manatorum). During rough weather large amounts of the manatee grass is broken off and frequently collects along the southwestern shoreline where a wide band of peat-like material has formed.

There are a number of places where this barrier beach is both narrow and low-lying. Consequently during storms, ocean water frequently breaks over the barrier island and enters the lagoon.

There are no natural streams emptying into Indian River Lagoon although a few man-made canals still exist. Since there are no permanent habitations in the area, little if any, sewage or storm sewer effluents reach Indian River Lagoon.

The southern portion of Indian Lagoon is connected to the upper portion of the Indian River via Haulover Canal (part of ICWW). Extensive water exchanges occur between these two segments due to wind driven currents (Brown, 1974).

The Banana River is also almost a classical lagoon since it is separated from the ocean by a barrier beach; however, it does not have a natural connection to the ocean. A man-made ocean connection exists as a consequence of a set of locks at Port Canaveral but the locks are so operated that water exchange is practically nil. Oceanic influence is achieved by its connection to the Indian River in the vicinity of Melbourne, Florida.

The Banana River separates KSC and the Cape Canaveral Airforce Station (CCAS) and modifications attendent with the space age were made. In the vicinity of KSC, the Banana River has been divided into two basins by vehicular roadways. The northern terminus of the Banana River is the Crawlerway from the Vehicle Assembly Building (VAB) to the Saturn V launch pads and an extensively modified basin exists between the Crawlerway and the causeway connecting KSC and CCAS. Within this basin is located the Vertical Integration Building (VIB) complex and the Titan III launch pads. Land for the construction of these facilities was made by dredging river bottom material. In addition a navigational channel exists from the locks at Port Canaveral to the Turning Basin adjacent to the VAB. Most of the material removed to form the channel in this basin was used to fill low-lying land around the VAB and the VIB.

A second basin exists between the KSC-CCAS Causeway and the Bennett Causeway (SR-528). Numerous spoil islands,most now submerged, are adjacent to the navigational channel and in at least one instance an emergent spoil island has become a rookery. This second basin includes the locks at Port Canaveral and the eastern extreme of the Canaveral Barge Canal (to the Indian River).

Although there is only a limited development of the shoreline in the KSC-CCAS area, extensive development of both the barrier island and the southern part of Merritt Island has occurred. Thus, significant amounts of both sanitary sewer and storm sewer effluents enter the Banana River.

Most of the natural vegetation has been removed from the lagoonal shoreline of Cape Canaveral Airforce Station, but a significant amount of the native vegetation is still present along the Merritt Island shoreline of KSC. As in the case of Indian River Lagoon, mangroves are abundant and there are extensive manatee grass beds in the Banana River.

There are no natural streams emptying into the Banana River, but there are numerous man-made canals which connect to it, especially in the developed areas. Prior to the construction of the Canaveral Barge Canal, there was a water course which had its head waters just south of the KSC Headquarters and drained the central portion of Merritt Island. This water course, or Sykes Creek, emptied into the Banana River via Newfound Harbor. However, the Barge Canal severed Sykes Creek.

Since the Canaveral Barge Canal connects the upper portion of the Banana River to the Indian River, water exchange occurs due to wind driven currents.

In the vicinity of KSC, the Indian River has the least classical lagoonal character since it is separated from the ocean by both a barrier island and Merritt Island. In addition, there is a small fresh stream, Turnbull Creek, which enters the northern most part of the lagoon. Another stream (Banana Creek) which drains a portion of the KSC complex is saline but it does receive substantial land drainage from the launch pad areas and the land in the vicinity of the VAB. Banana Creek drains into the Indian River just south of the Titusville Causeway (SR 402).

Man-made structures have divided the Indian River abutting KSC into three basins. The most northern basin extends from the upper reaches of the lagoon to the Florida East Coast Railway (FEC) bridge. This basin is connected to Indian River Lagoon via Haulover Canal. This basin has an area of $87.8 \times 10^6 m^2$ with 32.3 percent of it having waters with depths of 0.61 m or less.

A second basin with an area of $9.6 \times 10^6 m^2$ lies between the FEC bridge and the Titusville Causeway. Some 24.7 percent of this basin has a depth of 0.61 m or less.

A third or the lower basin is bounded by the Titusville Causeway and the NASA (or Orsino) Causeway. This basin has an area of $55.9 \times 10^6 m^2$ of which only 13.3 percent has a depth of 0.61 m or less. Banana Creek drains into this basin. The Canaveral Barge Canal connects with Indian River in the next basin to the south (NASA Causeway - Bennett Causeway).

Since Haulover Canal is part of the ICWW, the ICWW traverses the bulk of these three basins of the Indian River. Numerous spoil islands were created in the construction of the ICWW; however, only ten of these islands are still emergent and several of these will probably be awash in the near future.

Shoreline vegetation along the KSC side is principally of the native type with black and white mangrove being common components. A fairly good stand of red mangrove (Rhizophora Mangle)is present in the protected waters of Banana Creek. Natural vegetation has been essentially stripped from the western shoreline especially in the urbanized areas. Verdant manatee grass beds are found throughout this portion of the Indian River.

Sanitary sewage and storm sewer effluents derived from the Titusville area are dumped into Indian River. A trivial amount (infiltration pond overflow) of sanitary sewer effluent enters Banana Creek in the vicinity of State Road 3.

### 6.1.2 Meterological Aspects

East Central Florida's climate is sub-tropical with short, mild winters and hot humid summers. During the warmer portions of the year, there is little or no change in the general weather pattern; however, during the winter sharp temperature gradients often develop along the 240 km (150 mi) length of the Indian River Lagoon/Indian River whenever cold continental air masses spill over peninsular Florida. These sharp gradients are usually short lived.

Sturrock (1959) noted the inadequacies of the classification of southern Florida as sub-tropical, due to the warm oceanic current (Florida current) which flows southward along the west coast of the state and then northward along the east coast, therefore the climate from St. Petersburg to Vero Beach was given the classification of insular. However, the warming influence of the ocean is readily noticeable as far north as Cape Canaveral, especially on the barrier islands.

As a general rule, the weather pattern of East Central Florida, from April to October, is dominated by southeast winds traveling around the Bermuda Anti-cyclone. In October the prevailing winds shift abruptly to the north or northwest and movement of polar air masses into the region gives a distinct continental flavor to the climate.

The principal rainy season is usually from June through October. Initially the rainfall is a consequence of the advent of the thunderstorm season, however, the rains occurring in the latter part of the season are frequently associated with tropical storm activity. Winter rains are commonly a consequence of frontal activity. Summer rains (thunderstorms) can be heavy, of short duration, and very localized. Winter rains (frontal activity) tend to be light and reasonably uniform in distribution. Mean annual rainfall for KSC is 1.1 m (44 in).

### 6.1.3 Fresh Water Sources

Rainfall is the principal source of fresh water entering the lagoonal system. This fresh water enters the lagoon either by direct land drainage or by percolation through the undifferentiated deposits of the Pleistocene and Recene Age (Brown et al, 1962). The surface soils of the barrier islands and mainland adjacent to the lagoons are fine to medium uniform sand which is both porous and permeable. Thus, the water table conforms to the land surfaces and rises and falls rapidly in response to recharge and discharge of the aquifer (Brown et al, 1962). Since these sediments contain significant amounts of shell fragments, thin lenses of clay, limestone, and silt and other solubilizable material, the percolated ground water is usually mineralized.

Other fresh water sources of significance are sanitary sewer effluent and the (artesian) Floridan aquifer which is found in limestone formations of the Eocene Age and permeable beds of the Miocene Age (Brown et al, 1962). Although the volume of water entering the lagoon derived from the Floridan aquifer is not large, it is of importance since this water contains noticeable amounts of hydrogen sulfide, dissolved and suspended ferrous sulfide as well as calcium salts and there is wide spread use of this water for watering (lawns, grasses, etc.) and air conditioning cooling. In the latter case the spent water is frequently disposed of directly into storm sewers or the lagoons.

### 6.1.4 General Lagoonal Processes

The importance of meteorological influence on the character of the lagoons was noted earlier. One of the more important meteorological contributions is the wind-driven circulation. Whenever the wind direction is from a southerly direction, there is a general migration of the lagoonal water to the north. The presence of the Canaveral Barge Canal and Haulover Canal act as "escape valves" for the northward moving water in the Banana River and the Indian River, respectively. Conversely, whenever the wind direction is from a northerly direction, there is a migration of the lagoonal water to the south with water from the Indian River Lagoon passing through Haulover Canal and entering the Indian River. Winds from a northerly direction cause water from the upper reaches of the Banana River to move into southerly portions of that lagoon and can cause a west to east movement through the Canaveral Barge Canal.

Carter and Okubo (1965) observed wind driven currents with speeds of 1-4 cm/sec. in these lagoons. These values have been verified by independent studies performed at F.I.T. Since a current of 1.0 cm/sec. corresponds to a movement of only 0.86 km/day (0.47 nm/day), it is evident that the frequent wind shifts due to local weather patterns results in considerable "ebb and flow" of the lagoonal waters along the longitudinal axis of the lagoons. It also follows that any non-degradable or slowly degradable substance entering the lagoonal waters will have a lengthy residence time.

In addition to the wind-driven water motion, the prevailing wind has other significant effects. Among these effects are mixing of the water column and wind-tides. A sustained wind of 15 knots will cause the water column to be thoroughly mixed to the depth of the ICWW. Gravitational tides are essentially non-existent except, perhaps, in the vicinity of the inlets (due to influx of oceanic water), but wind-tides of the order of a meter are not uncommon.

Since the weather for the KSC area is generally sub-tropical in character and the latitude is less than $30^{o}$N (c. $28.5^{o}$N), the noon time insolation generally exceeds 1600 joules/$cm^2$/hr. (Bolz & Treve, 1970). This energy influx combined with the dark bottoms results in substantial heating of the lagoonal waters. These solar heated waters are subjected to an average wind speed of eight knots having a relative humidity between 66 and 90 percent; thus, the evaporation is comparatively high and exceeds the precipitation and runoff during the dry periods.

It has also been noted that there are extensive beds of manatee grass throughout the lagoonal complex. Since this grass is the principal primary producer of the area and there are only a limited number of primary consumers in these waters, the food web is detrital based (Thomas, 1974). Since a detrital based system involves microbiological degradation, the water quality parameters are inherently linked to these processes. Microbiological activity has other important roles in the water quality parameters, especially in those instances where the sediments have high organic content (e.g., muck).

It has been found that the bulk of the sediments, even "clean" sand types, have a negative oxidation-reduction potential (Eh). Consequently, the sediments are acting as a nutrient trap (Peffer, 1975).

## 6.2.0 Measurement Program and Rational

Selection of water quality parameters for detailed study during the first two years was based on Chapter 17-3 (Water Pollution) of the State of Florida Administrative Code. However, this code is addressed primarily at fresh water bodies; therefore, appropriate adaptations to meet the requirement of the saline water present were made. The parameters selected for intensive study were salinity, temperature, pH, turbidity, nutrients, and dissolved oxygen. Periodic checks were made on the sulfate and chloride levels, and biological oxygen demand (BOD).

Numerous subsidiary observations and measurements were accomplished by students engaged in work for master's thesis or senior research projects in the Oceanography and Ocean Engineering Department of Florida Institute of Technology. Most of these theses and senior project efforts were not part of the KSC study; however, the information gained in these efforts has relevance to the characterization of the lagoonal complex. Accordingly, these aspects which are pertinent are included in the subsequent discussion.

### 6.2.1 Sample Site Location

Since the lagoonal complex in the vicinity of KSC represents a substantial area (c. 300 $km^2$) with water depths ranging up to 3.6 m (12 ft), it was necessary to devise a site array which proportionally sampled the varying depth regions. In order to achieve the above objective, the sample sites were uniformly distributed throughout the area, with sites being designated at the intersection of each minute of longitude and latitude. In addition to uniform site distribution, the use of longitude-latitude made it easy to transfer from one map type to another. This transfer from one map type to another was necessary since no single map type was adequate for all purposes.

Water samples were acquired using a device especially designed by F.I.T. personnel for shallow water sampling. This device is shown schematically in Figure 6.1. Samples were taken from just below the water surface at 0.61 m (2.0 feet) intervals until the intake head encountered the bottom. All water which was "contaminated" by bottom sediments was rejected.

### 6.2.2 Routine and Special Measurements

Water quality parameters selected for routine measurement were temperature, salinity, pH, dissolved oxygen, orthophosphate, nitrate, and turbidity. This selection of parameters is consistent with similar studies carried out by the University of Florida (Savelle, 1966) and a five year analysis of Tampa Bay (Conservation Consultants, 1975). It is also consistent with Florida's Administrative Code for Pollution of Waters (Chapter 17-2).

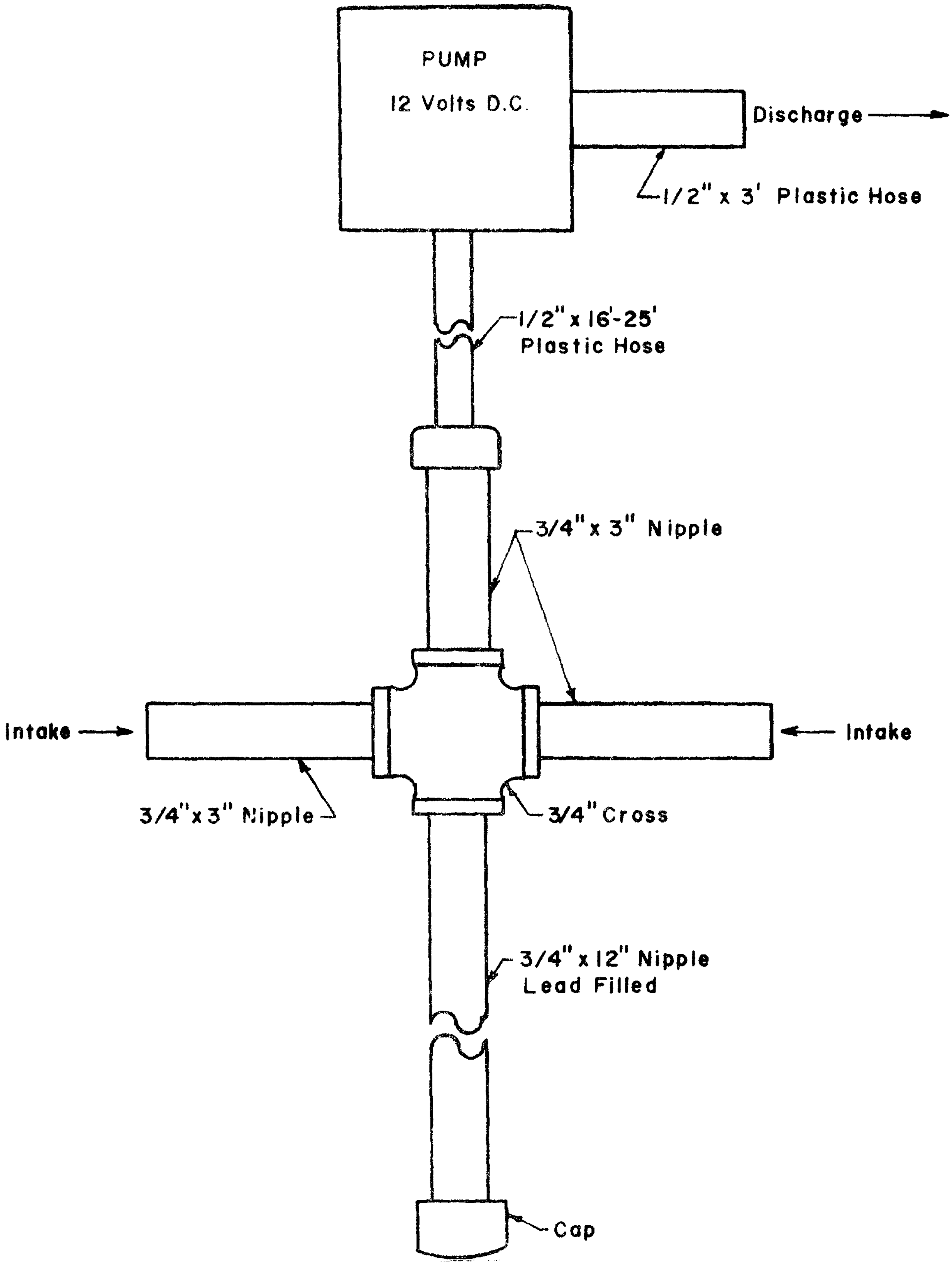



Figure 6.1

Schematic Diagram of Water Sampler

Special studies were performed at various times to evaluate particular aspects deemed desirable in order to develop a more complete understanding of the lagoonal processes. These studies involved an evaluation of the levels of chloride, nitrite, ammonia, and sulfate present and the BOD (biological oxygen demand). In addition, a detailed determination of the levels of chloride/ion ratios of the lagoonal waters were compared to oceanic values. The specific ions studied were sodium, potassium, calcium-strontium, magnesium and sulfate (Hutchison, 1973). A detailed study was also made of the chloride, calcium, magnesium, phosphate, and sulfate content of the ground water of the KSC property adjacent to the lagoons (Woodsum, 1974). Since the studies by Hutchison and Woodsum represent master thesis topics, these efforts were above and beyond the intended scope of the project.

### 6.2.3 Trace Metal Studies

"Practically all the materials that man uses are drawn from natural repositories of fairly stable character that may be called natural "sinks". These materials he disrupts, extracts, transforms, or combines with growing ingenuity and increasing frequency to produce a multitude of products, which he then proceeds to discard, disrupt, or transform into something he calls "waste". This in turn is dumped into another not so natural sink." (Lee, 1973). Thus, it may be concluded that trace metals have always been a component of the environment, but man's utilization has resulted in unusual and in some cases detrimental concentrations to occur in natural water systems. One of the more striking examples of the trace metal problem is "Minamata disease" which struck fishermen of the prefecture of Kumamoto, Japan in 1953. This "disease" was ultimately traced to excessive levels of mercury.

It has been established that the mercury levels in the Indian River were so minimal (Scofield, 1973) that a search for this metal could not be justified. Thus, the metals selected were the six which were considered as those most apt to be present in significant quantities. The particular metals studied were cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), lead (Pb) and zinc (Zn). The chemistry of these metals combined with the general environmental character of the lagoonal waters strongly suggested searches in the water column itself would be an inordinately complex process, but their presence in sediments would not be as involved laboratory procedure. Thus, a study of the levels of the six trace metals in the sediments in the vicinity of KSC was carried out (Tower, 1975). A subsequent study, currently in progress but nearing completion, is determination of biological concentration of these metals in the leaves of the white mangrove (Fettes, 1975). Both of these efforts represent master's thesis topics and both studies received extensive logistical support from NASA's KSC Micro Chemical Analysis Section of the Laboratories Division (James F. Jones, Section Chief).

### 6.2.4 Related Studies

It would be impractical to attempt to recognize the myriad investigations carried out by other staff and students (graduates and seniors) which have contributed to the present level of understanding of character of the lagoonal waters abutting KSC. In general, it will suffice to note that the studies performed under the direction of Dr. K.B. Clark (marine biology), Dr. E.H. Kalajian (sediments), Dr. P.S. Dubbelday (physical processes) and Dr. T.A. Nevin (microbiology) were monitored during the course of the investigations and pertinent fact were gleaned for future use. However, there were a number of "land mark" studies which it is deemed appropriate to cite here.

One of the unresolved problems encountered in the early phases of F.I.T.'s study of the lagoonal complex concerned the prevalence of hydrogen sulfide ($H_2S$) particularly in the organic rich sediment (muck) areas. This facet of the lagoonal processes was elucidated by the work of Sherman (1972) and amplified by the studies of Beazley (1973) and Blevens (1974). The pertinent information derived from these studies was that the production of hydrogen sulfide was shown to be a consequence of microbiological activity.

It had been suspected that blue-green algae (Cyanophyta) were abundant in these lagoonal waters. This fact was clearly demonstrated by the study performed by Carey (1973). The presence of blue-green algae is of chemical significance because of their ability to "fix" atmospheric nitrogen in the euphotic zone if orthophosphate is present (Wolk, 1973).

Since manatee grass is the principal primary producer in these lagoons, its growth and decay plays a central role in the absence or presence of chemical species in the water. The rate of decomposition of manatee grass in situ was established by Chen (1974) while the thermal influence on the rate of growth of this grass was determined by Salituri (1975). An unexpected by-product of Salituri's work was the finding that a bloom of red algae (Rhodophyta) occurred whenever the water temperature reached 29$^{o}$C.

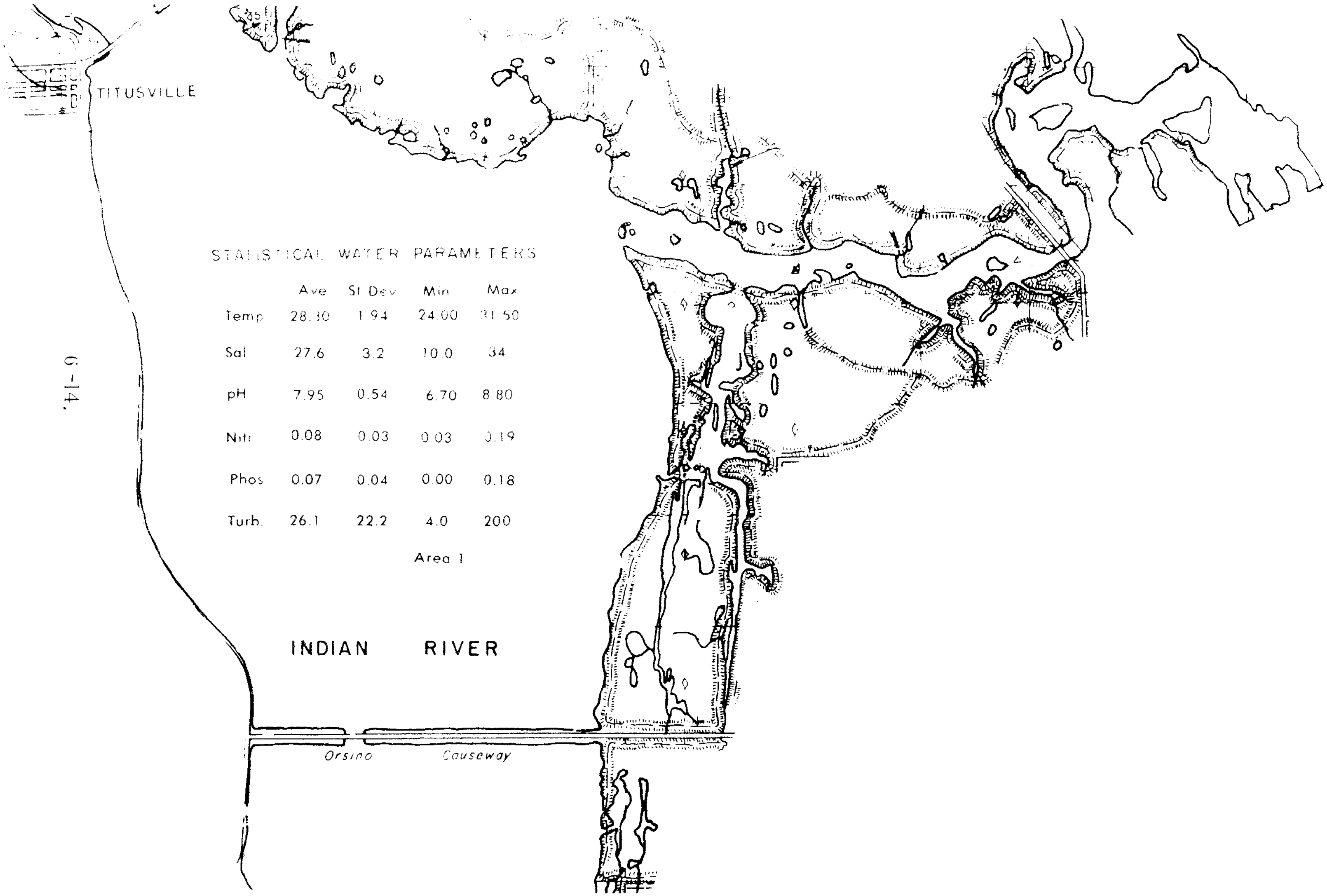
Peffer (1975) has shown that the sediments act as a nutrient trap and that almost all of the sediments, even the surface layer, are a reducing environment (i.e., a negative Eh). The reducing environment is especially evident where the surface sediments contain appreciable amounts of organic material (Gallop, 1975).

## 6.3.0 Observed Water Quality Parameters

One of the primary objectives of this study was to establish baseline conditions of the lagoonal waters. This objective was accomplished. The essential baseline values were determined by intensive sampling and analysis of these waters during 1973-74 and confirmed by observations made in 1975.

All data acquired during the first two years was subjected to extensive statistical analysis procedures. That is, all data was first treated as a lump sum and the usual statistical values obtained (i.e., average value, standard deviation, etc). Then it was analysed according to the time of year (monthly and quarterly) the data was acquired and further subdivided according to the four general areas of the lagoonal complex. As to be expected, the massing of the data yielded the greatest standard deviations, while the subdivision into area and time of year yielded the smallest standard deviations. From a practical standpoint, the yearly values by area appear the most useful set of working values; however, the seasonal values may be more appropriate for evaluating individual sampling operations. Corresponding histograms were also computer determined for the various parameters on the same basis as the statistical analysis.

For operational identification purposes, the portion of the Indian River between the NASA (Orsino) Causeway and the Titusville Causeway (S.R. 402) was designated as Area 1. The statistically determined values for the water quality parameters for 1972-73 in Area 1 are given in Figure 6.2 and the corresponding values for 1973-74 are listed in Table 6.1.




STATISTICAL WATER PARAMETERS

| | Ave | St Dev | Min | Max |
|---|---|---|---|---|
| Temp | 28.30 | 1.94 | 24.00 | 31.50 |
| Sal | 27.6 | 3.2 | 10.0 | 34 |
| pH | 7.95 | 0.54 | 6.70 | 8.80 |
| Nitr | 0.08 | 0.03 | 0.03 | 0.19 |
| Phos | 0.07 | 0.04 | 0.00 | 0.18 |
| Turb. | 26.1 | 22.2 | 4.0 | 200 |

Area 1

Figure 6.2
Statistical Water Quality Parameters, Area 1, 1973

Table 6.1

Water Quality Parameters of Area 1
1973 - 1974

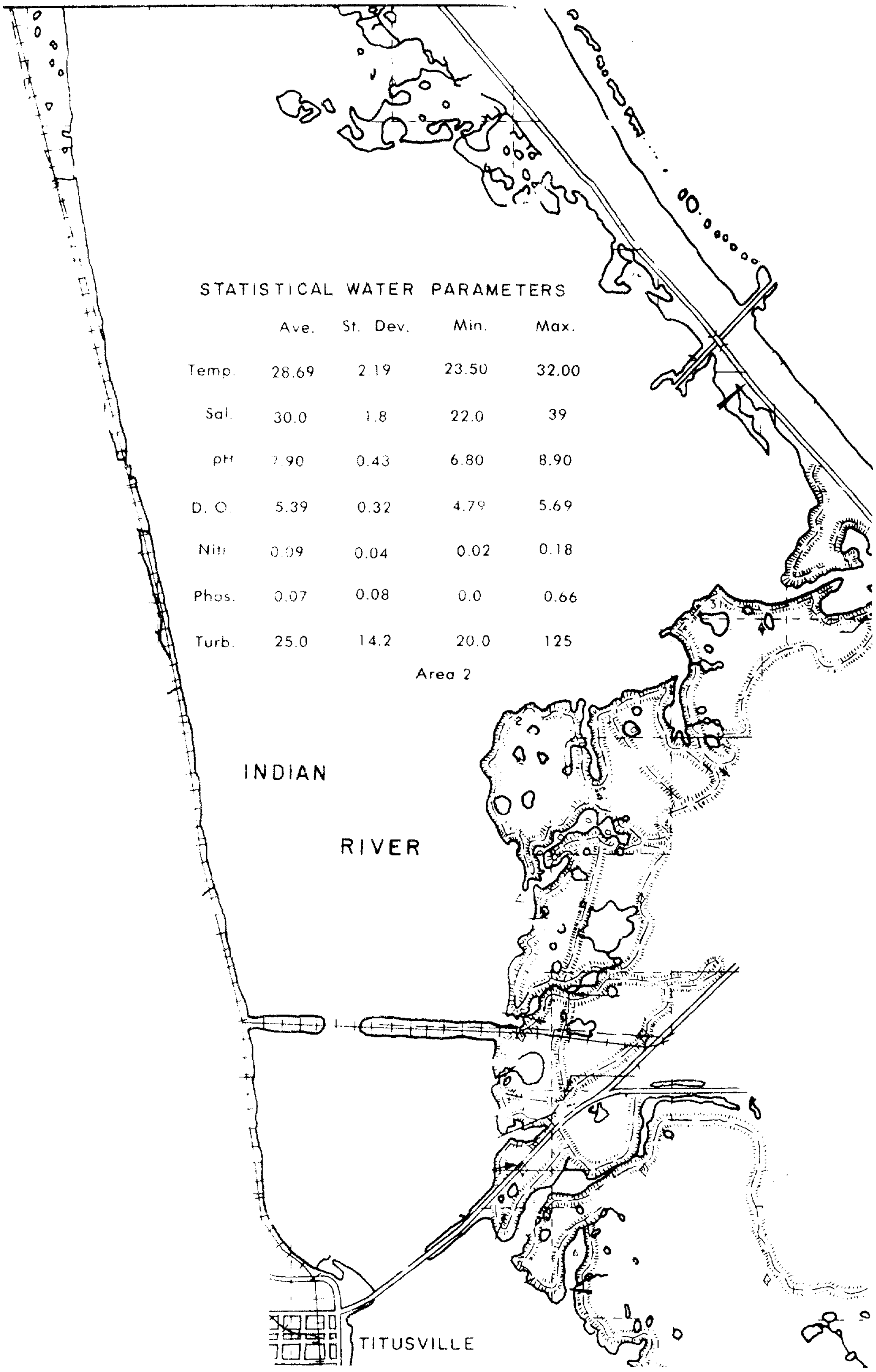
| | Average | Standard Deviation | Minimum | Maximum |
|---|---|---|---|---|
| Temperature, °C | 26.4 | 5.3 | 17.5 | 33.0 |
| Salinity, °/oo | 24.9 | 1.8 | 14.0 | 28.0 |
| pH | 8.3 | 0.3 | 6.3 | 8.8 |
| Dissolved Oxygen, ppm | 6.6 | 1.8 | 2.7 | 11.9 |
| Nitrate, ppm | 0.05 | 0.03 | 0.00 | 0.16 |
| Phosphate, ppm | 0.21 | 0.20 | 0.00 | 2.30 |
| Turbidity, J.U. | 33.0 | 11.2 | 8.0 | 71.0 |
| Sulfate, ppm | 3.20 | 1.98 | 1.27 | 10.92 |

Similarly, the portion of the Indian River lying north of the Titusville Causeway was designated as Area 2. The statistically determined values for the water quality parameters for 1972-73 in Area 2 are given in Figure 6.3 and the corresponding values for 1973-74 are given in Table 6.2.

Table 6.2

Water Quality Parameters for Area 2
1973 - 1974

| | Average | Standard Deviation | Minimum | Maximum |
|---|---|---|---|---|
| Temperature, °C | 26.5 | 4.9 | 18.5 | 33.0 |
| Salinity, °/oo | 27.4 | 1.4 | 24.0 | 32.0 |
| pH | 8.2 | 0.2 | 7.4 | 8.6 |
| Dissolved Oxygen, ppm | 5.72 | 1.5 | 2.3 | 9.4 |
| Nitrate, ppm | 0.07 | 0.08 | 0.00 | 0.80 |
| Phosphate, ppm | 0.18 | 0.23 | 0.00 | 2.10 |
| Turbidity, J.U. | 29.2 | 13.6 | 0.0 | 61.0 |
| Sulfate, ppm | 3.15 | 1.80 | 1.55 | 7.12 |




| | Ave. | St. Dev. | Min. | Max. |
|---|---|---|---|---|
| Temp. | 28.69 | 2.19 | 23.50 | 32.00 |
| Sal. | 30.0 | 1.8 | 22.0 | 39 |
| pH | 7.90 | 0.43 | 6.80 | 8.90 |
| D. O. | 5.39 | 0.32 | 4.79 | 5.69 |
| Nitr | 0.09 | 0.04 | 0.02 | 0.18 |
| Phos. | 0.07 | 0.08 | 0.0 | 0.66 |
| Turb. | 25.0 | 14.2 | 20.0 | 125 |

Figure 6.3
Statistical Water Quality Parameters, Area 2, 1973

The portion of Indian River Lagoon subjected to analysis was designated as Area 3. The statistically determined values of the water quality parameters for this area for 1972-73 are shown in Figure 6.4, and those for 1973-74 are listed in Table 6.3.

Table 6.3

Water Quality Parameters for Area 3: 1973-74

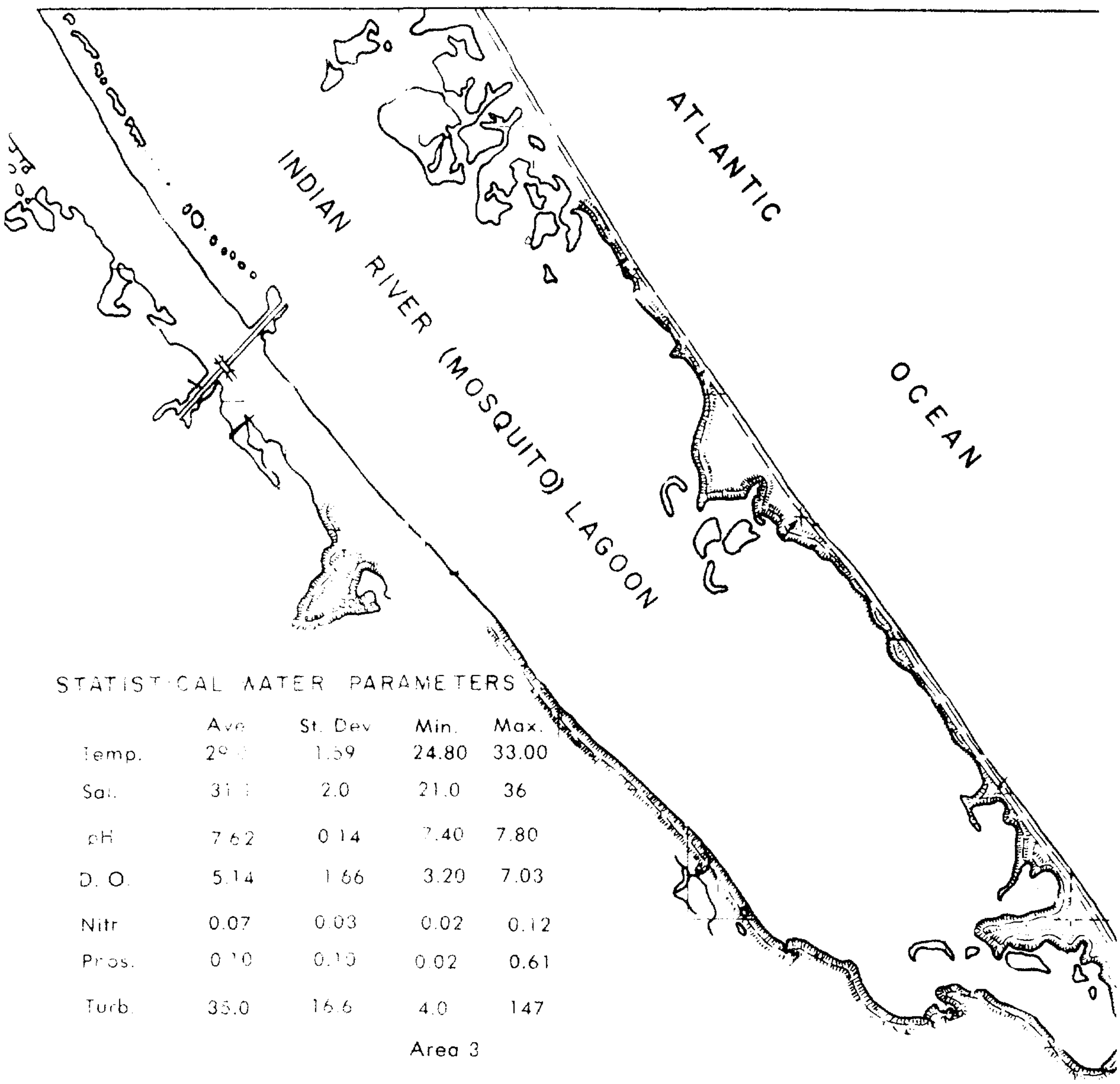
| | Average | Standard Deviation | Minimum | Maximum |
|---|---|---|---|---|
| Temperature, °C | 27.5 | 4.3 | 19.5 | 31.5 |
| Salinity °/oo | 30.8 | 2.2 | 26.0 | 37.0 |
| pH | 8.3 | 0.2 | 7.7 | 8.9 |
| Dissolved Oxygen, ppm | 6.2 | 1.4 | 3.4 | 10.0 |
| Nitrate, ppm | 0.05 | 0.03 | 0.00 | 0.12 |
| Phosphate, ppm | 0.18 | 0.15 | 0.02 | 0.90 |
| Turbidity, J.U. | 34.9 | 16.8 | 4.0 | 106. |
| Sulfate, ppm | 3.81 | 2.24 | 1.76 | 7.94 |

Area 4 was the designation given for that portion of the Banana River lying north of SR 528 (Bennett Causeway). The statistically determined values of the water quality parameters for Area 4 are shown in Figure 6.5 for 1972-73, and the corresponding values for 1973-74 are given in Table 6.4.

Table 6.4

Water Quality Parameters for Area 4: 1973-74

| | Average | Standard Deviation | Minimum | Maximum |
|---|---|---|---|---|
| Temperature, °C | 28.0 | 3.7 | 21.0 | 31.6 |
| Salinity, °/oo | 23.2 | 1.6 | 20.0 | 28.0 |
| pH | 8.4 | 0.2 | 8.0 | 8.9 |
| Dissolved Oxygen, ppm | 6.2 | 1.5 | 2.3 | 12.8 |
| Nitrate, ppm | 0.04 | 0.02 | 0.00 | 0.12 |
| Phosphate, ppm | 0.14 | 0.09 | 0.04 | 0.73 |
| Turbidity, J.U. | 26.6 | 13.4 | 4.0 | 61.0 |
| Sulfate, ppm | 2.49 | 1.05 | 1.40 | 4.75 |

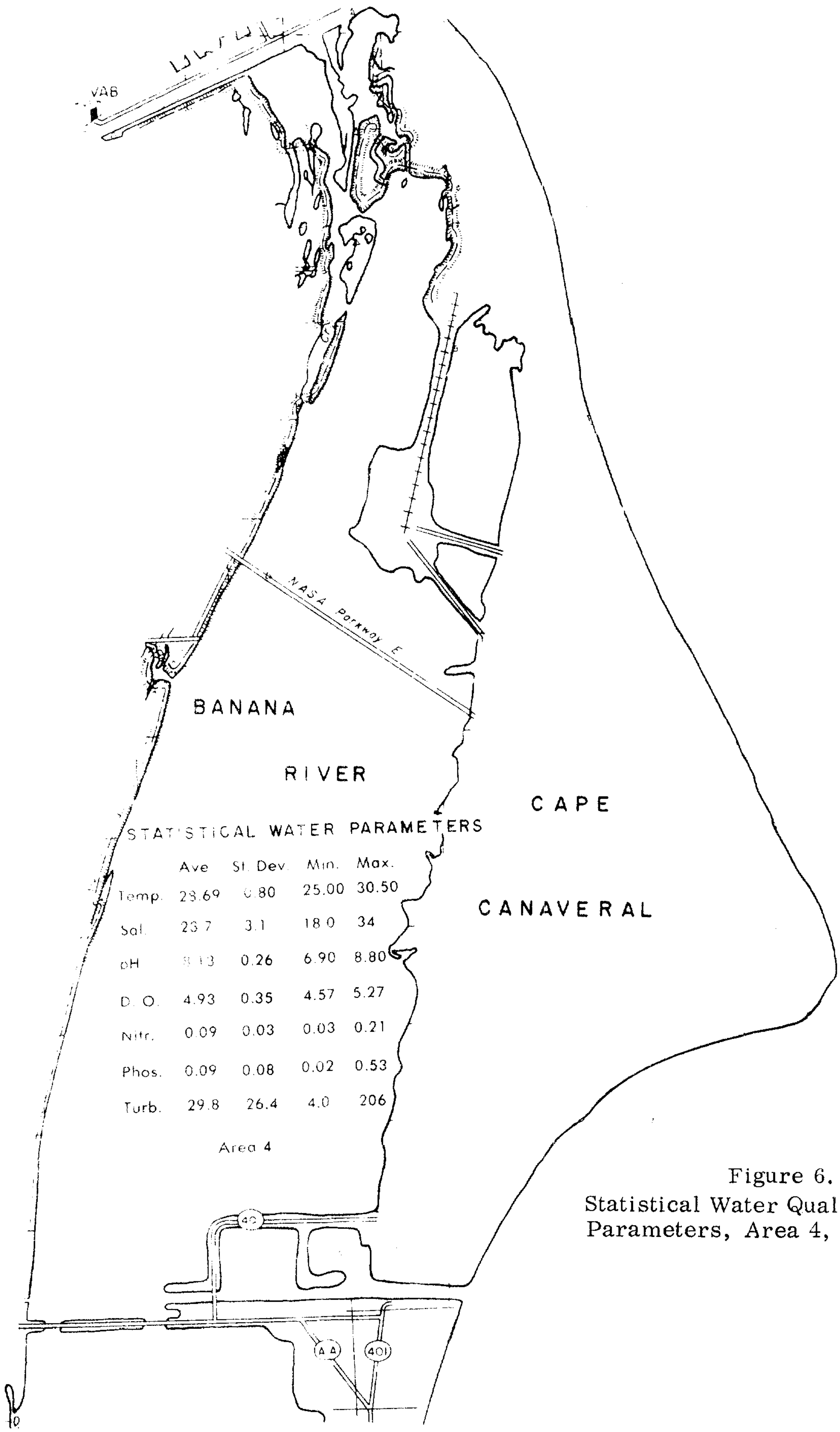



STATISTICAL WATER PARAMETERS

| | Ave. | St. Dev | Min. | Max. |
|---|---|---|---|---|
| Temp. | [illegible] | 1.59 | 24.80 | 33.00 |
| Sal. | [illegible] | 2.0 | 21.0 | 36 |
| pH | 7.62 | 0.14 | 7.40 | 7.80 |
| D. O. | 5.14 | 1.66 | 3.20 | 7.03 |
| Nitr | 0.07 | 0.03 | 0.02 | 0.12 |
| Phos. | [illegible] | [illegible] | 0.02 | 0.61 |
| Turb. | 35.0 | 16.6 | 4.0 | 147 |

Area 3

Figure 6.4
Statistical Water Quality Parameters, Area 3, 1973




STATISTICAL WATER PARAMETERS

| | Ave | St. Dev. | Min. | Max. |
|---|---|---|---|---|
| Temp. | 28.69 | 0.80 | 25.00 | 30.50 |
| Sal. | 23.7 | 3.1 | 18.0 | 34 |
| pH | 8.13 | 0.26 | 6.90 | 8.80 |
| D. O. | 4.93 | 0.35 | 4.57 | 5.27 |
| Nitr. | 0.09 | 0.03 | 0.03 | 0.21 |
| Phos. | 0.09 | 0.08 | 0.02 | 0.53 |
| Turb. | 29.8 | 26.4 | 4.0 | 206 |

Area 4

Figure 6.5
Statistical Water Quality Parameters, Area 4, 1973

Statistically determined water quality parameters for the total area for 1972-73 and 1973-74 are displayed in Table 6.5 It is apparent the yearly values determined by area give a more coherent representation of the individual basins; however, the values in Table 6.5 do provide a good overview of the nature and extent of variations that can be anticipated in these lagoonal waters. The probable cause of some of the larger variations will be examined in the following sections dealing with the individual parameters.

Table 6.5

Water Quality Parameters for Total Area

| | Average | Standard Deviation | Minimum | Maximum |
|---|---|---|---|---|
| Temperature, $^{o}C$ | | | | |
| 1972-3 | 28.6 | 1.8 | 23.5 | 33.0 |
| 1973-4 | 27.0 | 4.8 | 17.5 | 33.0 |
| Salinity $^{o}/oo$ | | | | |
| 1972-3 | 27.8 | 3.8 | 10.0 | 39.0 |
| 1973-4 | 26.2 | 3.2 | 14.0 | 37.0 |
| pH | | | | |
| 1972-3 | 8.0 | 0.4 | 6.7 | 8.9 |
| 1973-4 | 8.3 | 0.3 | 6.3 | 8.9 |
| Dissolved Oxygen, ppm | | | | |
| 1972-3 | 5.2 | 0.8 | 3.2 | 7.0 |
| 1973-4 | 6.2 | 1.6 | 2.3 | 12.8 |
| Nitrate, ppm | | | | |
| 1972-3 | 0.08 | 0.03 | 0.02 | 0.21 |
| 1973-4 | 0.05 | 0.05 | 0.00 | 0.80 |
| Phosphate, ppm | | | | |
| 1972-3 | 0.08 | 0.08 | 0.00 | 0.66 |
| 1973-4 | 0.18 | 0.18 | 0.00 | 2.30 |
| Turbidity, J.U. | | | | |
| 1972-3 | 28.0 | 21.0 | 0.0 | 206 |
| 1973-4 | 30.9 | 13.9 | 0.0 | 106 |
| Sulfate, ppm | | | | |
| 1972-3 | ND | | | |
| 1973-4 | 3.11 | 1.83 | 1.27 | 8.28 |

All of the data for each site in each basin collected during the two year interval (1972-74) was (computer) compared with the yearly average for the specific basin in question. Through this analysis, the sites which had parameter values most nearly the same as those of the basins, as well as those whose values were the most dissimilar were identified. Thus, five sites each in the four basins (total of 20 sites) were selected. Three of the five sites were for typical basin values while the remaining two were the atypical ones. The selected sites are tabulated in Table 6.6. It is believed that regular monotoring of these sites will provide an adequate check on the nature and status of the waters of each lagoonal basin.

Table 6.6
Recommended Monitoring Sites

| Station No. | Latitude | Longitude | Site Type |
|---|---|---|---|
| | Area 1 | | |
| 1-3 | 28°32'N | 80°46'W | typical |
| 1-6 | 28°33'N | 80°46'W | typical |
| 1-20 | 28°36'N | 80°47'W | typical |
| 1-18 | 28°36'N | 80°45'W | atypical |
| 1-27 | 28°35'18"N | 80°42'W | atypical |
| | Area 2 | | |
| 2-9 | 28°41'N | 80°48'W | typical |
| 2-10 | 28°42'N | 80°49'W | typical |
| 2-17 | 28°43'N | 80°47'W | typical |
| 2-7 | 28°40'N | 80°47'W | atypical |
| 2-24 | 28°44'N | 80°46'W | atypical |
| | Area 3 | | |
| 3-7 | 28°43'N | 80°43'W | typical |
| 3-9 | 28°44'N | 80°44'W | typical |
| 3-12 | 28°45'N | 80°45'W | typical |
| 3-8 | 28°43'N | 80°42'W | atypical |
| 3-11 | 28°44'N | 80°42'W | atypical |
| | Area 4 | | |
| 4-3 | 28°26'N | 80°38'W | typical |
| 4-11 | 28°28'N | 80°38'W | typical |
| 4-17 | 28°30'N | 80°37'W | typical |
| 4-8 | 28°27'N | 80°39'W | atypical |
| 4-18 | 28°30'N | 80°38'W | atypical |

### 6.3.1 Temperature

Water temperature at any given location in the lagoonal complex is largely a consequence of the prevailing meterological conditions. The relatively high solar influx combined with the generally dark bottom results in the bulk of the solar heat being absorbed and converted into heat. Since a large fraction of these waters are relatively shallow and the winds are comparatively light, the "shallows" frequently become significantly heated (i.e., above 30°C) in the summer time. Since the prevailing air is usually somewhat undersaturated in water vapor, evaporation readily occurs.

As a general statement, the water temperature is generally between 2° and 3° above the ambient air temperature. There are times, of course, when this generalization is upset; however, most of these discrepancies can be attributed to substantial, short-term weather shifts (e.g. passage of a frontal system, tropical storm activity, etc.)

### 6.3.2 Salinity

Salinity values, like temperature, are largely a consequence of the prevailing meterological condition. The fact that there are oceanic connections at Ponce de Leon Inlet and Sebastian Inlet can not altogether be neglected since conditions can (and have) persisted when saline water derived from the oceans reached the general area of the lagoons in the vicinity of KSC (Lasater, 1960). However, evaporation of lagoonal waters and land runoff are the more important facets.

It was established in these studies that the southern portion of the Indian River Lagoon represents an area where the evaporation - land runoff are more or less in balance over a yearly cycle. However, it must be recognized that a portion of the influx (as well as efflux) for Indian River Lagoon is accomplished via Haulover Canal. Thus, Indian River Lagoon acts as a "salt water" reservoir for both itself and the northern reaches of the Indian River. In contrast, the principal source of land runoff occurs in the Melbourne area and prevailing winds slowly ($\approx$1 cm/sec or 0.5 mile/day) cause the diluted water to drift into the KSC area (Carter and Okubo, 1966). The upper reaches of the Banana River appear to act in a manner analogous to the Indian River Lagoon in that it provides a source of more saline water to the central portion of the Banana River. However, there is a distinct difference in the case of the Banana River in that there is a much larger portion of land from which direct land drainage reaches this basin. Thus, the increased salinity is rapidly pushed southward with the advent of the rainy season. Never-the-less, the upper reaches of the Banana River are an important facet in the saline levels of the Banana River.

Examples of the saline levels observed in these waters are shown in Figure 6-6 through 6.9. It should be noted that a "saline tongue" can be traced from the Indian River Lagoon through Area 2 and into Area 1.

### 6.3.3 Nutrients

Although marine plants are capable of utilizing nitrite ($NO_2^-$) and ammonia ($NH_3^+$) as well as nitrate ($NO_3^-$), and many factors suggest that these lower oxidation state forms of nitrogen are continually produced by lagoonal processes, most tests for nitrite and ammonia in the water column were negative and only an occasional trace amount of these materials were recorded. There are two probable reasons why these chemical species were generally absent. The more probable one is that these chemical species were trapped in the sediments since Peffer (1975) has shown the sediments are nutrient traps. However, it is also possible that the rate of production of nitrite/ammonia was such that endemic species consumed these materials as rapidly as they were released. Certainly, the generally good dissolved oxygen values would preclude any significant build up of these species.

Orthophosphate ($PO_4^{\equiv}$) values seldom reached the typical oceanic values, but, except in extreme drought periods, there was usually some orthophosphate present. Since the adjacent land is both porous and permeable, it is probable that a significant amount of the orthophosphate is derived from ground water percolating into the lagoons (Woodsum, 1974). Other important sources are internal regeneration and land run off.

In typical oceanic conditions the per-atom ratio of nitrogen to phosphorus (N/P) is 15:1, but this type of ratio was never encountered in the lagoons and the observed values generally were less than 6:1. Accordingly, nutrient conditions favored the growth of blue-green algae. One of the causes of the discrepencies in the N/P ratio is that the denitrifying bacteria are the most "efficient" at temperatures between $35^o$ and $40^o$ (Spotte, 1970). On the other hand several bacteria which are capable of "fixing" atmospheric nitrogen ($N_2$) have been shown to be present in the lagoons (Larson, 1975).

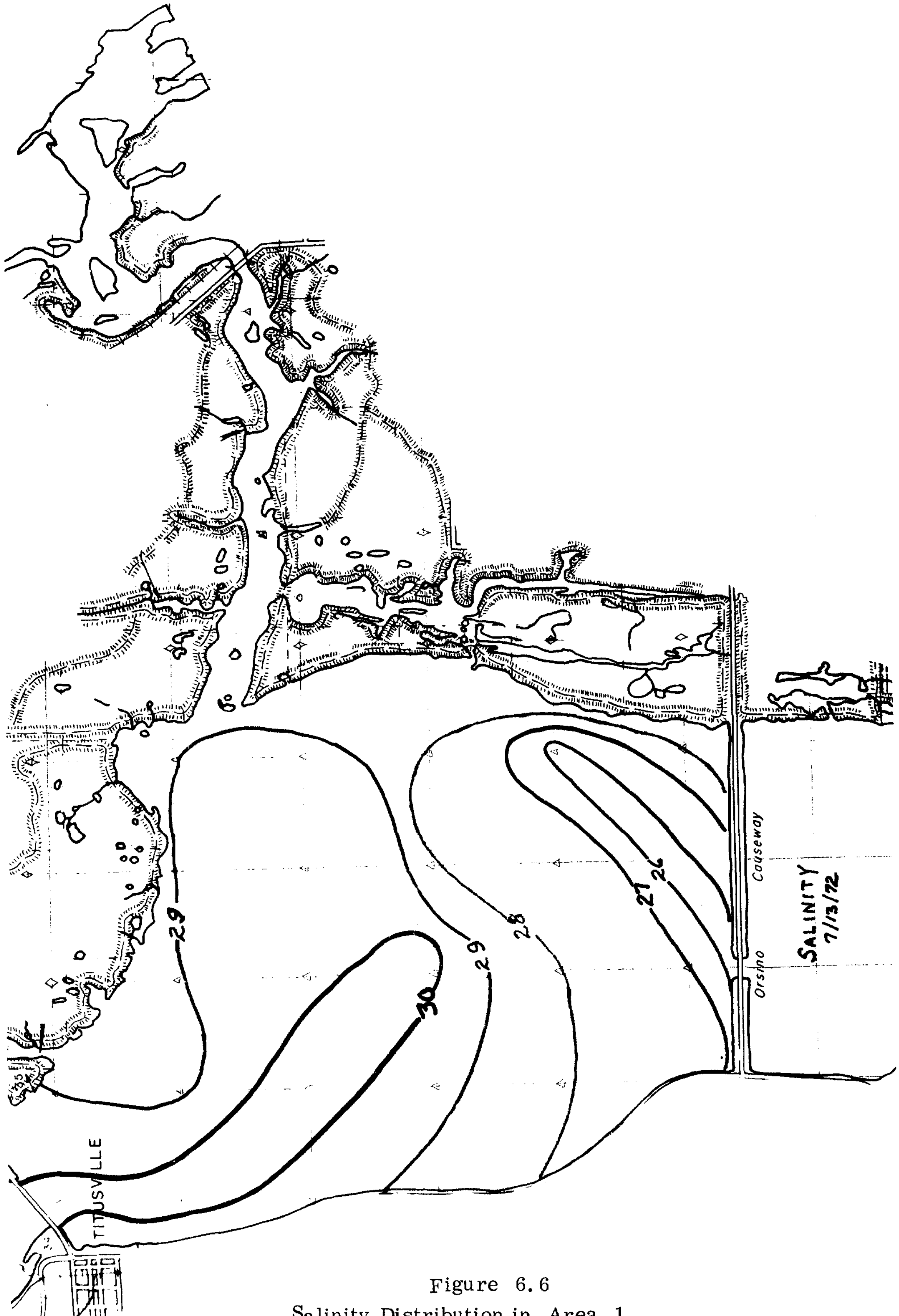



Figure 6.6
Salinity Distribution in Area 1

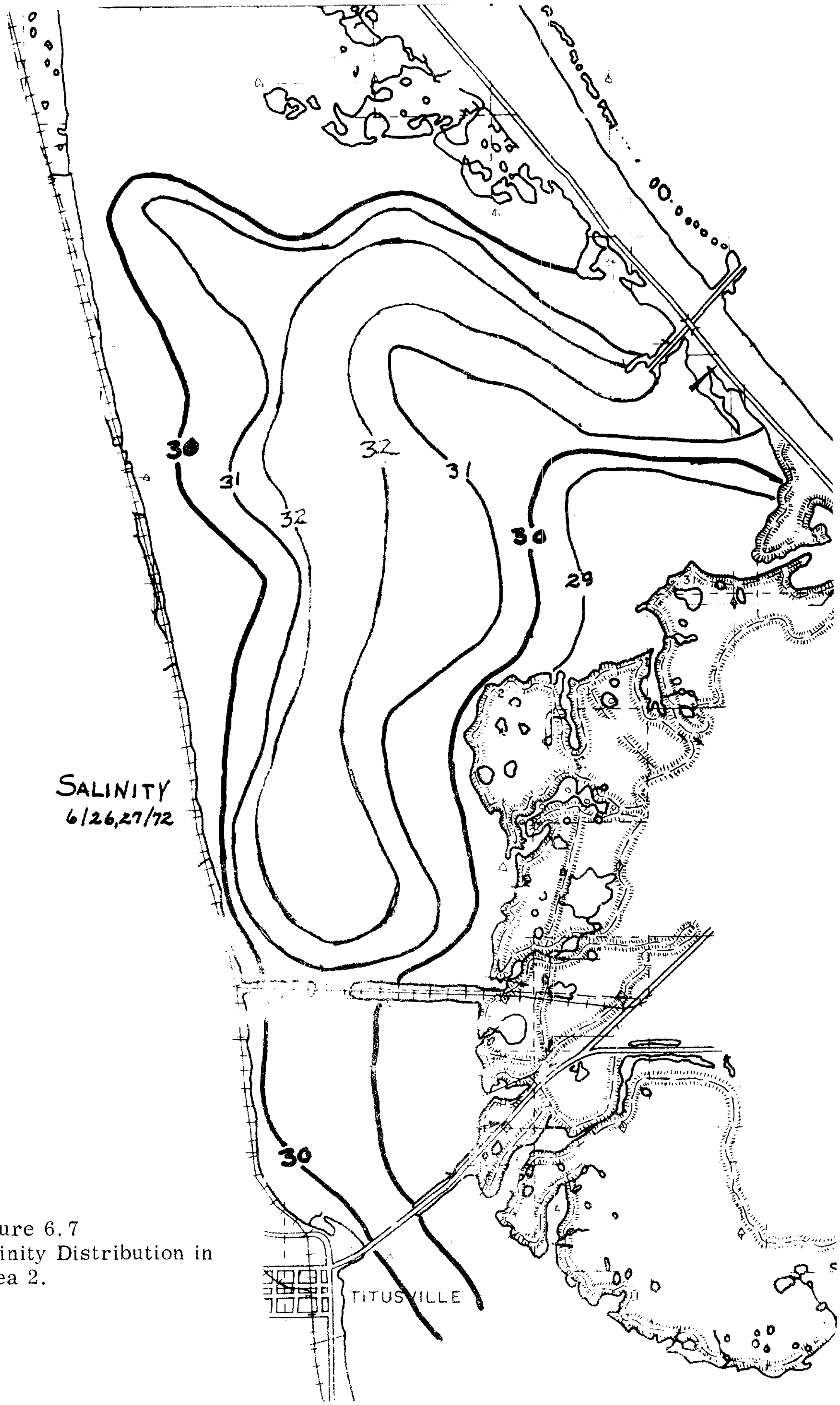



Figure 6.7
Salinity Distribution in
Area 2.

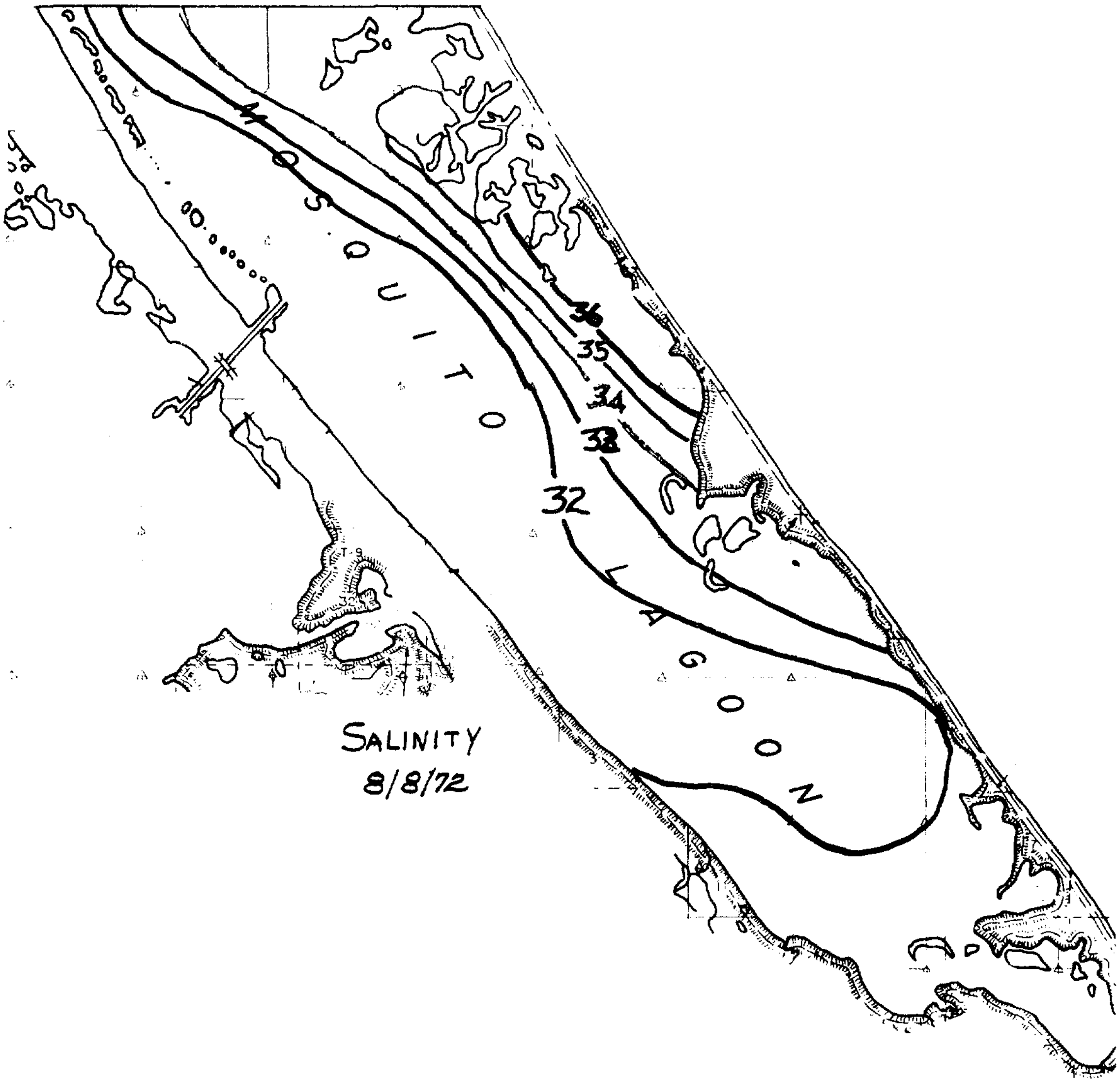



Figure 6.8
Salinity Distribution in Area 3.

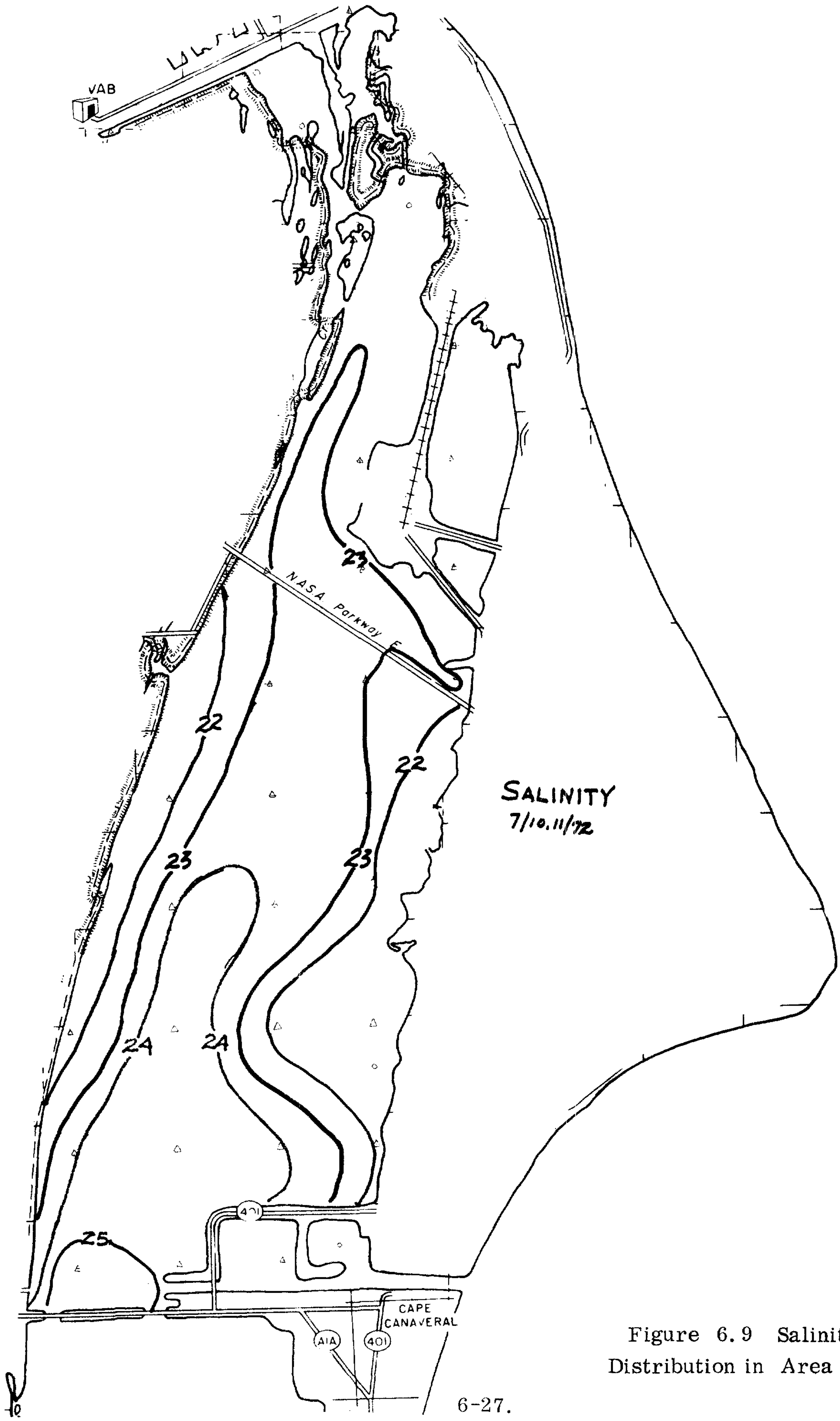



Figure 6.9 Salinity Distribution in Area 4.

### 6.3.4 pH

Although the salinities of the lagoonal waters are generally below oceanic levels, there is sufficient dissolved materials in the water so that the system is buffered. In addition, there are large amounts of calcareous shell fragments in the upper layers of the sediments and infiltrating ground water is mineralized. Accordingly, the pH range is usually oceanic (i. e. about 8). On rare occasions the pH has been observed to be substantially above and below the typical value of 8. The causes of these fluctuations in the water column have not been identified.

It became evident in the review of the water quality parameters taken in conjunction with the sediment characterization that some discrepencies were present, especially in the pH values. Examination of the procedures employed in the sediment studies lead to the conclusion that the observed values were real and that some discontinuity was present. A detailed search was made using an in situ "combined probe" consisting of a pH electrode and a dissolved oxygen probe. It was established that there was a thin layer of water adjacent to the sediments which had water quality parameters substantially different from the general water column. In particular the pH was lower (c. 6. 5) and the oxygen was either depleted or nearly so. Measurements indicate this layer is less than 10 cm in thickness and may be no more than one cm. This aspect deserves further examination.

### 6.3.5 Dissolved Oxygen

Dissolved oxygen values throughout the water column were generally good (5-6 ppm) with supersaturation values often being encountered over heavy grass beds. The depletion of the dissolved oxygen in the water adjacent to the sediments was noted above and this observation is consistent with the widespread negative redox (Eh) potentials observed for the surface layer of the sediments.

Most of the oxygen present appears to be a consequence of photosynthetic activity: however, a 15 knot wind will stir the sediments in the bottom of the ICWW.

### 6.3.6. Turbidity

Turbidity values vary widely due to both meterological effects and biological activity. During those portions of the year when there is a substantial influx of nutrient laden run-off water, the biological activity causes the turbidity to rise. Similarly, those portions of the year when the wind speeds are sufficiently high to cause the bottom sediments to be disturbed, the turbidity will also be high. The turbidity is frequently high where the water is in intimate contact with the roots of the black and white mangroves since both of these plant types are known for their high tannin and lignin contents. It is for this reason as well as for other plant materials present that the waters of Banana Creek often have exceptionally high turbidity values.

During the summer months before the rains begin, the waters of the lagoon often become remarkably clear. This clarity is concurrent with the bloom of the red algae (Hypnea cervicornis) which occurs when the water temperature exceeds 29°C. This sharp decline in the turbidity is a consequence of the red algae consumption of the nutrients so that the other species of algae/ phytoplankton are reduced to minimal values. In addition, the gelatinous character of the algae aids the entrapment of suspended inorganic materials. Thus, turbidity values fall to yearly lows under these conditions The start of the rainy season usually leads to the demise of the algae, brings an influx of nutrients and increased wind speeds, and the turbidity values rise again.

### 6.3.7 Chloride and Sulfate

A number of checks were made of the chloride ($Cl^-$) levels in the lagoonal complex and in all instances the values could be correlated directly with those which could be computed from the measured salinity values. Since this observation was consistent with others made elsewhere in Florida, no further chloride determinations were made.

Sulfate values, almost consistently, were below these which might be expected based on the salinity. This observation was unexpected since significant amounts of hydrogen sulfide laden aquifer waters are known to enter the lagoons, as well as a number of other sulfur sources. The low sulfate values appear to be a consequence of the somewhat higher values of calcium ion present in the water (Hutchison, 1973). Although the sulfate values are somewhat low, there is no shortage of sulfur in the system.

### 6.3.8 Trace Metals

Trace metal studies were carried out on the sediments (Tower, 1975) and in a dominant aquatic plant - white mangrove (Fettes, 1975). The specific metals examined were cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), lead (Pb), and zinc (Zn). The levels found in the sediments were low compared to similar studies (e.g., Segar and Pellenbarz, 1973) and the highest levels were found in areas where there were fine grained organic containing sediments. However, even the highest values were not at a level of significance. In general, the distribution of the metals could be correlated with probable source(s). For example, lead values increased in the vicinity of roadways, and zinc values were generally a maximum where boat traffic (sacrificial anodes) was prevalent and minimal where boat traffic was rare. Cadmium levels were more or less uniform throughout the area while iron, chromium, and copper appeared to relate directly to the utilization of the metal in the particular area.

Trace metal levels in the mangroves did not show significant concentration of the six metals in question (Fettes, 1975). There was some concentration of iron and lead by the mangroves but not excessively.

### 6.3.9 Organics

A number of studies have been performed on the various organic components usually present in saline water. Principal effort was directed at the extractable oils and greases and the amino acids. The extractable oils and greases are cited in Chapter 17-3 of the Florida Administrative Code and an acceptable level of 15 mg/l established. Chen (1974) showed that significant amounts of proteins were present in the decaying manatee grass.

All of the studies on the extractable oils and greases have yielded unusually low values (e.g., 1 to 3 mg/1). These low values are in sharp contrast to values observed in the estuarine waters of the Peace River (Punta Gorda, Fla.) where values as high as 227 mg/1 were encountered (Nevin and Lasater, 1973).

Amino acid studies were frustrating in that no detectable amino acids were found. Based on the test sensitivity, it has been concluded that the levels of dissolved free amino acids were less than 0.25 ug/1 of alpha-amino nitrogen (Artus, 1975). In other studies, up to 7 ug/1 of alpha amino acid nitrogen were found (Hobbie et al, 1968).

The absence of amino acids and the low levels of extractable oils and greases suggest that these substances are being consumed about as rapidly as they are being released into the water column. It is highly probable that microbiological activity plays an important role in the utilization of these compounds. Cohenour, 1975 found oil-degrading bacteria are present throughout the lagoonal waters in the vicinity of KSC.

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